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# Improved Exchange Rate Farmers through Rice Falied Crop Intensification in Tolitoli, Indonesia

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**Abstract**

Farmer Trade Rate (NTP) is a price comparison received by farmers at the price paid by farmers, which is one indicator measure the welfare of farmers. The analysis of NTP research, has been conducted (Budi, 2015; BPS, 2013; Simatupang, 2007; Mokuwa, 2013; Jhung Ahn, 2016) note that low NTP is affected by production, household consumption, Selling of rice and the use of superior seeds. Despite efforts to improve NTP has not been done, so too In Tolitoli. The result is difficult to know the level of farmers' welfare in terms of the size of NTP obtained by farmers. So to increase the NTP used agricultural intensification by using organic fertilizer, which can increase NTP. The purpose to know the factors that affect (NTP), the magnitude of the increase in NTP improve the welfare of farmers, and comparisons of NTP users of organic and inorganic fertilizers. This study uses primary data obtained from farmers through direct interviews using a prepared list of questions. Farmer of respondents was taken by using slovin method so that determined big sample of rice farmer farmer as many as 117 people apply intensification by using organic fertilizer. The data were analyzed using multiple linear regression analysis. The result of the research showed that the influence of NTP, the Food Consumption Exchange Rate (NTKP) and the Production Factor Exchange Rate (NTFP) contributed 86.7% and significantly to the increase of NTP. Increased NTP of Organic Fertilizer has implication to farmer's prosperity. Organic fertilizer users obtain higher NTP than inorganic fertilizer users. Can be concluded intensification system by using organic fertilizer can increase NTP.

**Keywords:** farmers exchange rate, organic fertilizer

## 1. Introduction

The agricultural sector is one of the sectors or business fields supporting the Indonesian economy. Based on the results of the agriculture census (ST) 2013 by the Central Bureau of Statistics (BPS, 2013) noted that the contribution of the agricultural sector over the past ten years declined and ranked third after the manufacturing and trade, hotel and restaurant sector. In the national development, the role of the agricultural sector is, among other things, the provision of basic food needs, the formation of foreign exchange (through exports), and the reservoir of labor, especially in rural areas.

Central / national agricultural development targets: achieving self-sufficiency in food and sustainable self-sufficiency, increasing food diversification, increasing value added, competitiveness, exporting, and improving farmer's welfare. The wetland rice sector is a sector that determines the economy in Indonesia as well as in Tolitoli District, since most have livelihoods by farming (regional profile of Tolitoli District, 2014). Government policy in improving the welfare of farmers has a very strategic meaning. One measure of farmers 'purchasing power that reflects farmers' welfare level, published by the Central Bureau of Statistics (BPS) and formulated in the Farmers Exchange Rate (NTP), the NTP index is one of the indicators used to measure the exchange rate of products sold by farmers Products needed by farmers in production and consume goods and services for household purposes. NTP has double impact (Supriyati, Saptana, & Sumedi, 2001) not only in increasing the participation of farmers and production in stimulating the rural economy, creating rural employment and growing demand for non-agricultural products; But also expected to reduce the difference (create balance) of development between regions (rural-urban), as well as between regions and the optimization of national resources. Efforts to increase the NTP has been done by the central government and local governments through fertilizer subsidies, counseling, and also the provision of capital. But all that can not increase the NTP as expected.

The orientation of agricultural development towards improving the welfare of farmers, it is very relevant to assess the exchange rate of farmers (NTP) as one indicator of farmers' welfare level and state of the rural economy and improvement efforts NTP. (Setiani, et al, 2007). Farmers Exchange Rate (NTP) is interpreted as a marker (indicator) of farmers' welfare. The concept of NTP measurement is very simple, measured as the ratio of the received price index and the price index paid by farmers, making it easy for the general public to understand. NTP is equal to the comparison of the price index received by the farmer with the price index paid by the farmer means the index received by the farmer with the price index paid by the farmer in the rural area (ib). The NTP relationship with the farmer's welfare level as a producer is clearly visible in the position (it) which is on the numerator of the NTP number. If the price of agricultural products rises, assuming the production volume is not reduced, the income or income of farmers from the harvest will also increase. Price developments indicated that it is an indicator of the level of welfare of producer farmers from the income side.

Therefore, to see the level of welfare of farmers as a whole also need to see the other side of the development of the amount of expenditure / expenditure, both for consumption and production needs, farmers as producers and also as consumers faced with the choice of allocating income, the first to meet basic needs (Consumption) for the survival of farmers and their families. Both expenditures for agricultural production are the livelihood fields that include the operational costs of production and investment and capital market formation. For this it is possible only if the basic needs of farmers have been met, thus investment and capital goods formation are the determining factors for farmers' welfare levels in terms of NTP.

NTP can be used as: (1) farmers 'welfare equipment, (2) farmers' purchasing power, (3) price determinants received and price determinants paid by farmers. A measure of the purchasing power of farmers at a glance can indicate that their welfare level is formulated in the form of Farmer Trade Value (NTP) formed by the complex interrelationship of a price-forming system, both the price received and the price paid by the farmer.

Farmers' welfare levels published by the Central Bureau of Statistics (BPS) are formulated in the Farmers Exchange (NTP). The term exchange rate actually has a broad meaning. In general, the exchange rate can be classified into four groups (Ruauw E 2010), namely: (a) Barter Terms of Trade, (b) Factorial Term of Trade, (c) (IncomeTerms of Trade) and (d) Farmers Term of Trade. (Setiani, et al, 2007)

Based on data from the Food and Horticulture Service Office of Tolitoli District.2015) NTP May 2015 was a decline for food crops, horticulture, and smallholder plantations. NTP food crops fell by 3.44 percent, a sharp drop in food crop NTP from 100.80 to 97.33 was due to a fall in the index received by the wetland rice farmer group. Furthermore, it is written that the time period between harvest and honey season (drought) becomes a transition period for farmers

Furthermore, in particular NTP food crops in Tolitoli District in November 2014 reached 98.71. This figure is still classified as having not reached the level of farmers' welfare (BPS, 2014), this is in line with the results of agricultural census (2013) that the contribution of the agricultural sector has decreased.

The study of NTP has been done in other regions even abroad, the increase of NTP is a marker of the welfare of farmers, but the increase of NTP by using organic fertilizer has never been done. So that the intensification of agriculture by using organic fertilizer made an option to improve the NTP, because most people in Tolitoli district is an agrarian society based on the agricultural sector. So need to study in depth about the factors that affect NTP, the increase of NTP with the incentives using organic fertilizers, and know the difference NTP users of organic and inorganic fertilizers in Tolitoli District.

## 2. Method

The research was conducted in Tolitoli District consisting of 3 subdistricts, Galang Subdistrict, Tolitoli Utara Subdistrict and Dampal Selatan District. The three districts are chosen because it is the center of rice field production in Tolitoli district, the geographical location of the three districts respectively, South Dampal is adjacent to Donggala Regency, North Tolitoli is adjacent to Buol Regency, and Galang District is located in the center of Tolitoli district. This research is planned to be carried out in the planting season of 2015 - 2016 for 3 times the harvest season

The population of 4600 rice farmers either using organic or non-organic fertilizer. Respondents who will be sampled as many as 117 people for rice farmers (given treatment by using organic fertilizer) and 117 rice farmers who use an-organic fertilizer, sampling using the formula Slovin (Asnawi, 2014), as follows:

$$n = \frac{N}{1 + Ne^2} \quad (1)$$

where:

n: number of samples

N: number of population

e: limit tolerance of error (error tolerance)

In this sampling set the limit tolerance of error (error tolerance) of 0.15 (e = 15%) for each district area. This study uses primary data obtained from direct interviews of respondents and secondary data obtained from other supporting literature. Data in this research is obtained through questionnaires, interviews, observation / observation and documentation and secondary data available in farmer groups. Observation on the production process is used to match the truth of data that has been given or obtained previously. Documentation is performed to obtain an overview of the general conditions during the production process in accordance with the provisions of the farm sapta selected as the sample.

The analysis used in this research is panel data regression method. By using cross section dummy variable (dummy region) which become research sample to know factor influencing to NTP. If NTP < 100 decreases, NTP = 100 breaks, NTP > 100 surplus.

Estimate the relationship of one dependent variable with two independent variables with the general formula:

$$Y = a + bD_i + e \quad (2)$$

Reprinted with twelve independent variables as follows:

$$Y = a_0 + b_1X_1 + b_2X_2D \quad (3)$$

where:

Y: Farmers Exchange Rate

$X_1$: Food Consumption Exchange Rate (NTKP)

$X_2$: Production Factor Exchange Rate (NTFP)

Farmers exchange value is obtained by the formula:

$$NTP = (HT / HB) X 100$$

where:

HT = Price index received by farmers

HB = price index paid by farmers

## 3. Results and Discussion

Based on the results of secondary data, farmers in Tolitoli district are grouped based on the ability of the farmer group, the division of farmers group ability class at 1 January 2016 data from the Office of Food Crops and Horticulture from 10 districts. The division, namely, beginners as many as 948 groups, further 232 groups, 25 groups of madya, and the main does not exist in Tolitoli district. The number of farmers in Tolitoli district is 26.283 with 91 gapoktan groups. Based on the results obtained through interviews, observation, documentation and spreading of questionnaires to the research subjects in North Tolitoli sub-district as many as 34 people, Galang 43 people, and South Dampal 40 peasants with the number of subjects 234 people, 117 people using organic fertilizer and 117 User of an-organic fertilizer. The results of interviews and data analysis obtained information factors that affect the NTP which has implications on the welfare of farmers. The influential factors are: (1) The exchange rate of the factors of production (NTFP), (2) The consumption exchange rate (NTKP) which consists of food consumption, and non-food consumption, together affects the increase of NTP. This is in line with the results of Rudi's research, 2011 in West Kalimantan which concluded that one of the facto which affects NTP is non-food consumption consisting of board, clothing, health and education costs. In contrast to Ginting, Ginting R., & Lubis (2013) write that the factors that affect the NTP in Deli serdang is the low price received by farmers.

The result of the analysis shows that by applying the system of intensification of organic fertilizer use can increase Farmers Exchange Rate (NTP). With the increase of NTP has implications for the welfare of farmers. This is in line with opinion of Elizabeth & Darwis (2000) that the increase in NTP can improve the welfare of farmers in East Java. This is confirmed by Ikin Sadikin, 2008 which states that, one indicator of farmers' welfare is the high NTP. The result of analysis shows that the NTP value of organic fertilizer users in each sub-district varies, the average of NTP in North Tolitoli subdistrict is 117.6, Galang 118.3 and South Dampal 115,9. The average acquisition of NTP users of organic fertilizer in Tolitoli district is 117.3. While NTP users of anorganic fertilizers dikecamatan Tolitoli Utara 114.3, Galang 112.1, and South Dampal 113.8. The average yield of NTP inorganic fertilizer users was 113.4. As seen in the following table (table 1) and diagram (Figure 1).

Table 1. Farmers Exchange Rate

| sub-district | An-organic | Organic |
|---|---|---|
| Tolitoli Utara | 114,2 | 117,6 |
| Galang | 112,1 | 118,3 |
| Dampal Selatan | 113,8 | 115,9 |
| Mean | 113,4 | 117,3 |

Based on the result of regression test, the amount of organic fertilizer contribution in the increase of NTP in Tolitoli district has a positive effect with the contribution of 86.7% dependent variable (NTP) influenced by independent variable (Production Factor Exchange Rate (NTFP) and Food Consumption Exchange Rate (NTKP ), Meaning that production factors, food consumption and non-food consumption are closely related to the increase of NTP, compared to previous studies conducted by Prabawati that contribute to the increase of NTP in West Sumatra due to high wage during one harvest season and low production.

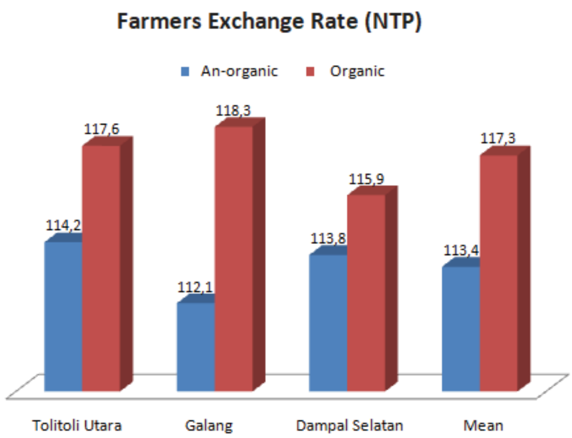


Figure 1. Different Value of NTP (An-organic and Organic)

The results of the analysis also show that there is a significant difference between organic and inorganic fertilizer users in Tolitoli district. What is seen from the average NTP users of organic fertilizer is 117.3 and the average of anorganic fertilizer users is 113.4. The difference between organic and inorganic fertilizer users in Tolitoli district is 3.90 percent, the use of organic fertilizer can increase the exchange rate of farmers (NTP) in Tolitoli district, the high NTP can affect the welfare of rice farmers in Tolitoli district. This is in line with the results of previous research conducted by Ginting et al (2013), Ruauw (2010), Unnevehr, Juliano, & Perez, C. M. (2001), Budi et al. (2015), inferred that farming activities have a goal to increase productivity in order to gain higher profits. Production and productivity can not be separated from the factors of production owned by farmers to increase production of their crops (Asnawi, 2014).

Based on the results of interviews with farmers, the selling price of organic fertilizer products is higher when compared to the selling price of an-organic rice, for rice price. During April 2015, the price of low quality grain at the farmers' level is Rp 3.59224 per kilogram. This decreased by 7.39 percent compared to the previous month. While in grain milling valued only Rp 3,670.00 per kilogram or down 7.17 percent over the previous period. (Budi, 2015).

The exchange rate of Central Sulawesi farmers in the last three years still stands below 100 percent. BPS (2015) Central Sulawesi Farmer's Trade Values (NTP) during August 2015 amounted to 97.71 percent, down 0.51 percent compared to the previous month's NTP. This is due to the decrease of NTP food crop sub-sector by 1.06 percent. The farmer's price index fell 0.55 percent, while the price index paid by farmers (ib) fell 0.05 percent.

In general, food expenditure is still greater than non-food in Tolitoli district. This is different from the results of research Rahmad (2001) factors that affect the non-food consumption factor NTP. However, with the increase of NTP, it can be interpreted to improve the prosperity of farmers using organic fertilizer in Tolitoli district.

## 4. Conclusion

Factors influencing the increase of farmer's exchange rate (NTP) are produced production, food consumption factor, and non-consumption factor, and the use of fertilizer The amount of significant influence of organic fertilizer use is 86,7% with significant value 0.00 <0.05. Factors affecting the welfare of farmers is the price paid by farmers and high production costs are not directly proportional to the price received by farmers, through farmers sapta intesifikasi in this case using organic fertilizer can increase the exchange rate of farmers that have implications for improving the welfare of farmers. From this result, we suggestion that the need for counseling and socialization to farmers to utilize organic fertilizer as an alternative to increase rice paddy NTP as well as to improve the welfare of farmers in Tolitoli district.

## References


Asnawi, R. (2017). Peningkatan produktivitas dan pendapatan petani melalui penerapan model pengelolaan tanaman terpadu padi sawah di Kabupaten Pesawaran, Lampung. *Jurnal Penelitian Pertanian Terapan*, *14*(1).

Aulia. (2016). Analisis NTP dan angka harapan Hidup di Sumatera Utara. *Journal Agroekonomi, 16*(1).

Badan Pusat Statistik. (2013). Indikator pembangunan Ekonomi daerah kabupaten Tolitoli. Palu

Badan Pusat Statistik. (2014). Indikator pembangunan Ekonomi daerah kabupaten Tolitoli. Palu

Badan Pusat Statistik. (2015). Provinsi Sulawesi Tengah dalam Angka. Palu.

Badan Pusat Statistik Nasional. (2017).

Budi, (2015). Nilai Tukar Petani, SPI minta Impor Beras Dihentikan. Berita Bisnis. Bandung.

Direktorat Pangan Dan Pertanian, (2013). Studi Pendahuluan Rencana Pembangunan jangka Menengah Nasional (RPJMN) Bidang pangan Dan Pertanian 2015-2019. Kementerian Perencanaan Pembangunan Nasional/Badan Perencanaan Pembangunan nasional.

Dinas Tanaman Pangan dan Holtikultur Kab. Tolitoli, (2016). Laporan Akhir Analisis Nilai Tukar Petani Padi sawah di Kabupaten Tolitoli.: Palu. Dinas Tanaman Pangan Dan Hortikultura Kab. Tolitoli. Prov Sulawesi Tengah

Dwidjono H. Darwanto. (2005). Ketahanan Pangan Berbasis Produksi dan Kesejahteraan Petani. *Ilmu Pertanian 12*(2), 152-164, Fakultas Pertanian UGM dan MMA-UGM. Yogyakarta

Elizabeth, R., & Darwis, V. (2000). Peran Nilai Tukar Petani dan Nilai Tukar Komoditas Dalam Upaya Peningkatan Kesejahteraan Petani Kedelai (Studi Kasus: Propinsi Jawa Timur). *SOCA (Socio-Economic of Agriculturre and Agribusiness)*, *6*(1).

Ginting, M. S., Ginting, R., & Lubis, S. N. (2014). Faktor-Faktor yang Mempengaruhi Nilai Tukar Petani Ubi Kayu (Studi Kasus: Desa Tadukan Raga, Kecamatan STM Hilir, Kabupaten Deli Serdang, Provinsi Sumatera Utara). *Journal on Social Economic of Agriculture and Agribusiness*, *3*(3).

Ikin Sadikin dkk, (2008) Kinerja beberapa indikator kesejahteraan petani padi dipedesaan Kabupaten Kerawang. BPTP Jawa Barat. *Jurnal Iptek Tanaman Pangan, 6*(2).

Jhun Ahn Chun, et al., (2016). Assessing rice productivity and adaptation strategies for Southeast Asia under climate change through multi-scale crop modeling. *Journal Agricultural Systems, 143*, 14-21. https://doi.org/10.1016/j.agsy.2015.12.001

Rachmad (2001). Analisis Nilai Tukar Petani Indonesia. Journal Litbang Pertanian Manado.

Ruauw, E. (2010). Nilai Tukar Petani Sebagai Indikator Kesejahteraan, *Petani jurnal ase, 6*(2), 1-8.

Rudi. (2011). Nilai tukar petani dan faktor-faktor yang mempengaruhi di sentra produksi jagung Kalimantan Barat. *Journal Litbang Kalimantan Barat, 2*(3).

Setiani, et al., (2007). Kontribusi Teknologi Usaha tani dan Aprestasi Pasar Terhadap Nilai Tukar Petani Di Wilayah Miskin.

Supriyati, Saptana, & Sumedi. (2001). Dinamika ketenagakerjaan dan penyerapan tenaga kerja di pedesaan jawa (kasus di propinsi Jawa Barat, Jawa Tengah dan jawa timur). Pusat Penelitian dan Pengembangan Sosial

Ekonomi Pertanian, Bogor Badan Penelitian dan Pengembangan Pertanian, Departemen Pertanian RI.

Syam, M. (2008). Padi Organik dan Tuntutan Peningkatan Produksi Beras. *Jurnal Imtek Tanaman pangan, 3*(1).

Talpur Mokuwa, et al., (2013) A review on the enhancement of rice production in paddy field with minimum input of water. *Journal African Journal of Agricultural Research, 6*(3).

Unnevehr, L. J., Juliano, B. O. dan Perez, C. M. (2001). Consumers demand for rice grain quality in Southheast Asia. In Rice Grain Quality and Marketing. Papers presented at the International Rice Research Conference. *International Rice Research Institute. Philippines*. 15-23.

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# The Role of Soil Amendments on Population Dynamics of Insect Pests, Growth Parameters and Yield of Eggplant, *Solanum melongena* (L.) Moench

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**Abstract**

Loss of soil fertility as a result of continuous cropping on the same piece of land has necessitated the need to improve soil fertility for better crop yields. Inorganic and organic fertilizers have been used to improve soil fertility, however, excessive use of soil amendments improve vegetative growth of plants thereby attracting large numbers of insect pests. Cow dung and poultry droppings were used as soil amendments in a field experiment using eggplant *Solanum melongena*. The effects of these organic manures were compared with inorganic fertilizer (NPK) and a control where there was no application of soil amendment in a randomized complete block design with 3 replicates. Parameters studied were pests' and their numbers, plant height, number of leaves per plant, leaf area, stem girth and yield. The major insect pests identified on the plant were *Bemisia tabaci*, *Aphis gossypii*, *Leucinodes orbonalis* and *Eublemma olivacea*. *Bemisia tabaci* and *Aphis gossypii* scores were significantly larger on cow dung and poultry manure plots. *Leucinodes orbonalis* and *Eublemma olivacea* numbers were not significantly different on the treated and control plots. Mean plant height, number of leaves and yield differed significantly among the soil amended plots. Even though soil amendments improve the nutrient content of the soil and the yield of crops it could lead to increase in pests numbers and damage caused to plants.

**Keywords**: *Aphis gossypii*, *Bemisia tabaci*, insecticide, manure, stem girth, transplanting

## 1. Introduction

Eggplant (*Solanum melongena* L.) also known as garden egg is one of the important vegetable crops widely cultivated and consumed in many countries. It is cultivated together with other vegetables such as pepper, tomato and okra (Ibekwe *et al*., 2014) but may also be cultivated in a monocropping system. The fruits of eggplants are essential sources of carbohydrates, vitamins, proteins and mineral salts (Shirley, 2000). Its consumption has increased in developing countries like Ghana due to population growth. Raw eggplant is composed of 92% water, 6% carbohydrates, 1% protein and negligible fat (San Jose *et al.,* 2014) and small quantities of thiamine, niacin, riboflavin and iron (Siemonsma and Piluek, 1994).

Cultivation of vegetable crops is hampered by a number of constraints such as low soil fertility, insufficient rainfall and the incidence of diseases and pests. Insect pests are the most important limiting factor to increased production of eggplant and other vegetable crops. One hundred and forty six insect species have been documented to be pests of eggplant (Critchley, 1995).

The use of organic and inorganic fertilizers has impacted positively on the yield of eggplant; however, dependence on chemical fertilizers for increased crop production may not always be feasible (Insaidoo and Quarshie-Sam, 2007). The fact that chemical fertilizers are expensive and may not be readily available to the small scale farmer is a drawback to increased crop production. The importance of eggplant in terms of its nutritional value and as an export crop is negatively affected by a number of insect pests which attack the plant at various stages of growth. These include piercing and sucking insects such as whiteflies, aphids and thrips and plant defoliators such as the grasshopper, *Zonocerus vareigatus* and *Acraea peneleos* (Owusu–Ansah *et al.,* 2001*)*. The most destructive pest of eggplant is the fruit and shoot borer *Leucinodes orbonalis* which can cause yield reduction up to 70% (Van Steenwyk and Barnett, 1985).The larvae of eggplant fruit and shoot borer make holes in the tender shoots resulting in withering of the plant. Larvae feed inside the fruit causing severe economic damage. Other major pests of eggplant include aphid, *Aphis gossypii* (Goggin, 2007), the spotted beetle, *Epilachn*a *dodecastigana* (Wiedemann), (Alagarmalai *et al*., 2014) and the leafhopper, *Amarasca devastans* (Van Steenwyk and Barnett, 1985).

In order to increase food production for the ever-increasing human population, there is the need to reduce the effects of insect pests on cultivated crops and improve the nutrient content of the soil. Chemical fertilizers, when applied to the soil increase agricultural productivity. The commonly deficient nutrient in the soil is nitrogen and its application in the form of nitrates leads to increased yield. High photosynthetic activity, dark green leaves and healthy vegetative growth are associated with adequate nitrogen supply (Jahn *et al*., 2004). The continuous use of chemical fertilizer as soil amendment may not be the most environmentally preferred option to improve soil fertility in Ghana and other developing countries. This is due to its cost, the fact that it may not be readily available and on time and the problem of run-off of excess fertilizer into water bodies.

The alternative to the use of chemical fertilizer is the application of organic fertilizer. Poultry manure and waste from other farm animals is the alternative to increasing the nutrient content of the soil (Dauda, 2008) for plant growth and increased food production. Poultry manure has been used over the years as a source of plant nutrients to increase soil productivity, soil organic carbon, microorganisms and yield of crops (Beckmann, 1973). Organic manures are less expensive, but they provide the plant with good sources of nitrates and phosphates which are the main constituents of poultry manure (Rahman, 2000). Other important elements such as calcium, magnesium and sodium are present in poultry manure (Dauda *et al*., 2005). According to Aliyu *et al*. (1992), the extensive use of inorganic fertilizer has a depressing effect on yield, reducing the number of fruits, delaying and depressing fruit setting leading to heavy vegetative growth.

Application of inorganic fertilizer imposes a huge financial burden on farmers, with its attendant negative effects. The current study evaluated poultry manure and cow dung as soil amendments in the management of pests of eggplant and how these affected growth parameters and yield of the plant.

## 2. Materials Methods

### *2.1 Study Area*

The experiment was conducted on an experimental farm of the Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology, Kumasi from December 2016 to March 2017. The area lies within latitude 06$^{o}$ 41 N and longitude 01$^{o}$33W and in the forest region of Ghana. The soil type is intermediate between sand and loam and is well drained. Average annual precipitation is 166 cm; relative humidity during the study was 69.3% to 76.1 %. Average daily minimum and maximum air temperatures range from 21-23 $^{o}$C and 31-34 $^{o}$C respectively (Mochiah *et al*., 2011).

### *2.2 Land Preparation*

The entire field was cleared of weeds and the soil was turned over using a hoe, a local farming implement. Twelve plots each measuring 5 m x 1.5 m were laid out, with 0.5 m alley between 2 plots for easy movement.

### *2.3 Preparation of Organic Manure*

Poultry droppings and cow dung were obtained from the Animal Farm of the Animal Science Department. Each was heaped in the open separately and allowed to decompose for 4 weeks before they were used.

### *2.4 Nursing, Transplanting and Application of Soil Amendments*

Eggplant, *S. melongena* seeds (var. Nsuroawia), a local variety obtained from the Horticultural Division, CSIR-Crops Research Institute of Council for Scientific and Industrial Research (CSIR) were sown on seed bed and covered with palm fronds, which were removed after germination. Seedlings were watered daily in the evening until ready for transplanting, after 4 weeks of germination. The experiment was conducted in a randomized complete block design, with 4 treatments and 3 replications. The treatments were: poultry manure, cow dung, NPK (15-15-15) compound fertilizer and a control in which there was no application. Transplanting of eggplant seedlings was done 4 weeks after seed germination. On each plot there were 3 columns with 10 plants in each column. Within each column planting interval was 50 cm. The interval between 2 columns was 50 cm. Two weeks after transplanting, application of soil amendments was done. Chemical fertilizer was applied at a rate of 10 g/plant and this was done by putting it into small hole about 10 cm from the base of the plant. In the case of organic manure, 50 g each of poultry droppings and cow dung was applied around the stem of the plant in their respective plots. The control plots remained untreated.

*2.5 Data Collection*

2.5.1 Insect Pest Enumeration

This commenced 1 week after application of soil amendments and continued weekly till harvest. Sampling and data collection were carried out between 6 am and 8 am when the insects were least active. At each sampling and on each plot, plants were carefully examined for signs of pest infestation. Aphids and whiteflies were assessed using a visual scoring scale with regard to colony size: 0-No aphids or whiteflies; 1-Few individuals; 2-Few isolated small colonies; 3- large isolated colonies; 4-large isolated colonies; 5-Large continuous colonies (Salifu, 1982).Other insect pests were collected into specimen bottles and taken to the laboratory for identification and counting.This was done weekly until harvest.

2.5.2 Growth Parameters

2.5.2.1 Leaf Area

Ten weeks after transplanting; 3 leaves from each sampled plant were plucked and used to determine leaf area. Digital image protocol by O'Neal *et al*. (2002) was used to measure leaf area by using a desk-top scanner and public domain software for measuring existing leaf area.

2.5.2.2 Plant Height

Plant height was measured using a meter rule; this was taken from the base of the stem to the uppermost canopy of the leaves. The heights of 5 plants were measured and the means were calculated and recorded.

2.5.2.3 Total Number of Leaves

Total number of leaves of the 5 sampled plants was counted and the mean for each treatment was calculated and recorded.

2.5.2.4 Stem Girth

The diameter of each of the sampled plant was measured using a micrometer screw gauge at weekly intervals for 5 weeks and the means were calculated.

2.5.2.5 Yield Assessment

Matured fruits were harvested twice a week, placed in labelled envelopes and weighed. This was done for 3 weeks and the mean weight per week for each treatment was calculated.

*2.6 Data Analysis*

Data obtained were analyzed using the Graph pad prism (version 6.0). Analysis of variance was performed on the parameters studied. Where the differences were significant, the means were separated using Turkeys' multiple comparison test at 95% confidence level.

**3.Results**

*3.1 Insect Pests of Eggplant*

The major insect pests identified on eggplant during the study period were: the whitefly, *Bemisia tabaci* Genn., aphid, *Aphis gossypii* Glover, spotted beetle, *Epilachna dodecastigina*, (Wied.) the shoot and fruit borer, *Leucinodes orbonalis* Guinee, Brinjal leafroller *Eublemma olivacea* (Walker) and the leaf hopper, *Amrasca devastans* (Dist.).

3.1.1 Bemisia tabaci

Eggplants grown on soil amended with poultry manure recorded the largest mean score, while the control plots recorded the least score. Significant differences in *B. tabaci* scores were recorded on eggplants grown on the nutrient–amended soil and the control (P=0.03), however, no significant differences in *B. tabaci* scores were observed on eggplants grown on the nutrient-amended plots (Table 1).

3.1.2 Aphis gossypii

*Aphis gossypii* scores ranged from 0.33 on the control plots to 1.71 on the cow dung-amended soil. Significant differences in *A.gossypii* score existed between the treated plots and the control; however, there were no significant differences between poultry manure and cow dung-amended soils (Table 1).

Table1. Effects of soil amendments on mean population of insect pests of egg plant (*Solanum melongena*)

| Treatment | *Bemisia tabaci* | *Aphis gossypii* | *Eublemma olivacea* | *Leucinodes orbonalis* | *Amrasca devastans* |
|---|---|---|---|---|---|
| Control | 1.03 ±0.80[a] | 0.33±0.02 [a] | 0.00 | 0.00 | 1.28 ±0.80[a] |
| Cow dung | 1.73 ±0.80[b] | 1.71±0.23 [b] | 1.42 ±0.06 [a] | 0.28 ±0.01[a] | 3.85 ±0.96[b] |
| Poultry manure | 1.73 ±0.14[b] | 1.13±0.08 [b] | 8.85 ±3.10 [a] | 0.42 ±0.02[a] | 7.01 ±1.27[b] |
| NPK | 1.63 ±0.10[b] | 0.47±0.03[a] | 0.00 | 0.00 | 4.28 ±1.40[b] |
| P value | 0.003 | 0.002 | 0.067 | 0.196 | 0.007 |

Within columns means with the same letter are not significantly different (P>0.05).

3.1.3 Eublemma olivacea

This insect was totally absent on the control plots as well as the NPK-treated plots, and present only on poultry manure (8.85) and cow dung amended soil (1.42).

3.1.4 Leucinodes orbonalis

Very small numbers of this pest was encountered on eggplants grown on plots amended with poultry as well as cow dung plots.

3.1.5 Amrasca devastans

The population of *A. devastans* was low on eggplant. It ranged from a mean of 1.28 on the control plots to 7.01 on poultry manure-amended soil. The differences were highly significant. There were no significant differences in *A. devastans* numbers on eggplants grown with the different soil amendments.

*3.2 Influence of Soil Amendments on Growth Parameters of Eggplant*

3.2.1 Plant Height

Plant height ranged from 50.81 cm on the control plots to 63. 14 cm on the cow dung-amended soil (Table 2). The observed differences were significant. Mean plant height on NPK-treated plots and poultry manure-treated plots did not differ significantly, but were significantly shorter than plants grown on the cow dung amended soil.

Table 2. Effects of soil amendments on growth parameters and yield of egg plant (*Solanum melongena*)

| Treatment | Plant height (cm) | Number of leaves | Stem girth (mm) | Leaf Area ($cm^2$) | Yield (kg) |
|---|---|---|---|---|---|
| Control | 50.81 ±4.40[a] | 27.1±8.35[a] | 12.9 ±1.2[a] | 129.4 ±25.1[a] | 0.99 ±0.06[a] |
| Cow dung | 63.14 ±5.80[b] | 38.3±11.1[b] | 15.5 ±1.6[b] | 203.4 ±70.9[a] | 7.09 ±2.50[b] |
| Poultry manure | 60.31 ±7.60[c] | 35.6±11.8[a] | 16.1 ±1.7[b] | 184.4 ±57.8[a] | 3.51 ±1.20[c] |
| NPK | 59.17 ±7.55[c] | 30.8±10.3[a] | 16.2 ±1.8[b] | 190.7 ±66.1[a] | 4.24 ±0.76[c] |
| P value | 0.009 | 0.012 | 0.005 | 0.358 | 0.012 |

3.2.2 Number of Leaves and Leaf Area

Eggplants grown on cow dung-amended soil recorded the largest number of leaves, whilst the control plants recorded the least number of leaves; the differences were significant. Plants grown on poultry manure soil recorded significantly larger number of leaves than those grown on cow dung-amended soil. Mean leaf area of plants grown on amended soils and control did not differ significantly (P=0.358).

3.2.3 Stem Girth

Plants grown on nutrient-amended soils recorded significantly larger stem girth than the control. It ranged from 12.9 mm on the control plots to 16.2 mm on plots amended with chemical fertilizer. Among the treated plots, stem girth did not differ significantly, but all differed from the control (P=0.005).

*3.4 Yield of Eggplant*

Application of soil amendments resulted in significant increase in yield, ranging from 0.99 kg on the control plots to 7.09 kg on cow dung treated plots. Yield of eggplants on NPK and cow dung- treated plots differed significantly; however, yield on NPK and poultry manure-treated plots did not differ significantly (Table 2).

**4.Discussion**

The various soil amendments had significant effect on *B.tabaci* and *A. gossypii* scores. The significantly larger scores of these pests was due to better growth of eggplants on those plots which then supported large numbers of these pests. Organic manure is known to contain many minerals such as nitrates, phosphates (Rahman, 2000), magnesium and calcium (Dauda *et al*., 2005) and other minerals needed for healthy growth of plants. On the other hand, the chemical fertilizer used for the study contained only nitrogen, phosphorus and potassium. The high nitrogen content of organic manure and the fact that it contained other minerals enhanced better growth and therefore supported larger numbers of *B. tabaci* and *A. gossypii*. Studies by Zaini *et al*. (2013) and Jauset *et al*. (2000) reported that plants with high nitrogencontent increased egg survival and therefore supported large numbers of whiteflies. Contrary to this result, a study by Mochiah *et al*. (2011) on the effect of NPK and poultry manure on the pests of cabbage found no significant differences in the numbers of *Plutella xylostella* and *Brevicoryne brassicae* on plots treated with the two soil amendments.

Initially pests' numbers were small on all treated plots and the control, however, subsequent addition of the soil amendments resulted in increased pests' numbers, except on the control plots. Better vegetative growth of plants made them more attractive to feed on. Nutrient application and availability enhance vegetative growth, with large succulent leaves which are then able to support large numbers of phytophagous insects, including sap feeders. When soil is amended with organic and inorganic fertilizers, nitrogen contained in them is taken up by the plants in the form of nitrates and ammonium ions which plants use to form amino acids and other nitrogenous compounds such as chlorophyll (Jahn *et al*., 2004). This enhances vegetative growth, hence attracting larger numbers of insect pests.

The major pest recorded at fruit formation stage was the fruit and shoot borer *Leucinodes orbonalis*; however, they were totally absent from the control and NPK-treated plots. They were present only on the organic manure treated plots, in very small numbers. Ndereyimanal *et al*. (2013) recorded very small numbers of Brunjal shoot and fruit borer on plots treated with chemical fertilizer. A related study by Hosain (2009) reported that higher doses of NPK fertilizer increased the incidence of the pod borer *Helicoverpa armigera* compared to the control. This is an indication that increasing the nutrient content of the soil probably has the effect of increasing pests' numbers on crops.

Application of soil amendments had a significant effects on eggplants grown on cow dung amended soil since mean plant height was significantly taller than that of other treatments and the control. Similar results were recorded for number of leaves. It appears that organic fertilizer provided better medium of growth than chemical fertilizer. Poultry manure and cow dung amended soils produced taller plants than NPK-treated plots. Increased plant height on plots treated with organic manure was due to the presence of high phosphorus on the manure-treated plots ((Adilakshmi, 2008). According to Mochiah *et al*. (2011) 30- 50% of phosphorus in animal manure is in organic form and must undergo mineralization into inorganic form to be available to plants. Results from our study, corroborates that of Aliyu (2000) that poultry manure positively affects vegetative development of garden eggs, thus improving the health and promoting growth of the plant. Organic manure is able to hold significant amounts of water compared to chemical fertilizer (Rakshit, 2009), thus making more water available to plants. This was even more significant due to the fact that the study was conducted during the period of low rainfall where soil moisture was low. Therefore the ability of organic manure to hold enough water made it readily available for nutrient uptake for growth.

Poultry and cow dung manure recorded larger numbers of leaves as a result of better availability of nutrients, an observation that was also asserted by Jahn *et al*. (2004) and Ulikan (2008). High nitrogen content in the soil enables plants to undergo vigorous growth. Soil amendments had significant effects on leaf area, with cow dung-amended plots recording larger leaf area than plants grown on NPK-amended soil, however, Mochiah *et al*. (2011) recorded larger leaf area on NPK-treated plots compared to poultry manure-treated plots. Increasing the nutrient content of the soil mainly increases leaf are index and light absorption, resulting in increased photosynthetic activity. This has been reported on crops such as lucerne (*Medicago sativa*) by Lemaire *et al*. (2005). Availability of soil nutrients and increased photosynthesis led to increased growth and yield. Cow dung, which recorded significant increase in plant height and leaf area also recorded the best yield. This shows that when fertility of the soil is improved it leads to increase in yield. Work done by Deshmukh and Takte (2007) on tomato revealed that application of NPK increased yield by 16%. A related study by Mochiah *et al*. (2011) on the use of poultry manure as soil amendment recorded the best yield on the control plots. This was attributed to low pest infestation and percent leaf damage. Application of soil amendments to improve soil fertility has the effect of increasing crop production, however, excessive use of inorganic fertilizers can lead to improved vegetative growth making it more attractive to insect pest attack and increased pest damage resulting in reduction in yield.

## 5. Conclusion

Application of cow dung and poultry droppings to the soil significantly increased *Bemisia tabaci* and *Aphis* *gossypii* scores but had no significant effect on shoot and fruit borer *Leucinodes orbonalis* infestation. Application of soil amendments leads to improve crop yields, however, excessive use of inorganic fertilizer and organic manure increase vegetative growth and makes the plant more attractive to insect pests to cause damage to the plant. Our quest to increase crop production through nutrient application to the soil must be done together with pest management strategies in order to obtain the full benefits of soil amendments.

**References**

Adilakshmi, A. Korat, D. M., &Vaishnav, P. R. (2008)Effect of organic manures and inorganic fertilizers on insect pests infesting okra. *Karmataka Journal of Agricultural Science, 21*(2), 287-289.

Alagarmalai, J., Selvaraj, P., & Kuppusany, E. (2014).Antifeedant and insecticidal properties of selected plant extracts against *Epilachna dodecastigma* and *Henosepilachna vigintioctopunctata* (Coleoptera: Coccinellidae). http://file.scirp.org/Html/3-127001941792

Aliyu, L., Karikari, S. K., & Ahmed, M. K. (1992). Yield and yield components of eggplant (*Solanumgilo* L.) as affected by date of transplanting, intra-row spacing and nitrogen fertilization. *Journal of Agricultural Science and Technology, 2*(1), 7-12.

Beckman, E. O. (1973). Organic vegetable farming.Luxury or necessity. *Technical Communication of ISHA.29*, 247.

Critchley, B. R. (1995). Manual for the integrated pest Management of diseases, insects, nematodes, and weeds of garden egg, okra, onion, peppers and tomato in BrongAhafo, Ghana. Natural Resources Institute (NRI), UK.

Dauda, S. N., Ajayi, F, A., &Ndor, E. (2008) Growth and yield of water melon, (*Citrullus lanatus*) as affected by poultry manure application. *Journal of Agricultural and Social Sciences, 4*, 121-124.

Dauda, S. N., Aliju,L., & Chiezey, U.F. (2005) Effect of variety, seedling age and poultry manure on growth and yield of garden egg (*Solanum gilo* L.). *The Nigerian Academic Forum,*9, 88-95.

Deshmukh, M. R., &Takte, R. L. (2007) Effects of fertigation on growth and yield of tomato. *Indian Journal of Entomology, 32*(2), 181-183.

Goggin, F. L. (2007). Plant-aphid interaction: molecular and ecological perspectives: *Current Opinion in Plant Biology, 10*(4), 399-408. https://doi.org/10.1016/j.pbi.2007.06.004

Hossain, M. A., Prodham, M. Z. H., &Haque, M. A. (2009). Response of NPK fertilizer on the incidence of pod borer, *Helicoverpa armigera* (Hubner) and grain yield of chicken pea. *Bangladesh Journal of Scientific and Industrial Research, 44*(1), 117-124. https://doi.org/10.3329/bjsir.v44i1.2720

Ibekwe, H. N., Ogbu, J. U., Uwalaka, O. A., Ngbede, S. O., & Onyegbule, U. N. (2014). Efficacy of plant-derived insecticides for the control of insect pests of garden eggs (*Solanum* sp.) in Southeastern Nigeria.*International Journal of Scientific and Technology Research, 3*(8), 1-6.

Insaidoo,T.F.G., &Quarshie-sam, S, J. (2007).Evaluation of the effects of hedgerow intercropping using *Leucaena leucocephala* and fertilizer application on growth and yield of garden eggs (*Solanum melongena*). *Journal of Science and Technology, 27*(2), 62-70. https://doi.org/10.4314/just.v27i2.33041

Jahn, G. C. (2004). Effects of soil nutrients in the growth, survival and fecundity of insect pests of rice.An overview and a theory of pests' outbreaks with consideration of approaches. *Multitrophic interactions in soil and integrated Control' International Organization for Biological Control (IOBC) wprs Bulletin, 27*(1), 115-122.

Jauset, A. M., Sarasua, M. J., Avilla, J., & Albajes, R. (2000). Effect of nitrogen fertilization level applied on the greenhouse whitefly. *Journal of Economic Entomology, 19*(4), 255-261. https://doi.org/10.1016/S0261-2194(00)00016-8

Lemaire, G., Avice, J. C., Kim. T. H., &Ourry, A. (2005). Development changes in sahoot N dynamics of lucerne (*Medicago sativa* L.) in relation to leaf growth dynamics as a function of plant density and hierarchical position within the canopy. *Journal of Experimental Botany, 56*, 935-943. https://doi.org/10.1093/jxb/eri084

Mochiah, M. B., Baidoo, P. K., & Owusu-Akyaw, M. (2011). Influence of nutrient applications on insect population and damage to cabbage. *Journal of Applied Biosciences, 38*, 2564-2572.

Ndereyimanal, A., Praneethal, S., Pugalendhil, L., & Hategekimana, A. (2013).Effect of spacing and fertigationon incidence of shoot and fruit borer (*Leucinodes orbonalis* Guenee) in eggplant (*Solanum melongena* L.) grafts. *Indian Journal of Agricultural Science, 1*(5), 102-105.

O'Neal, M. E., Landis, D. A., & Isaacs, R. (2002).An inexpensive accurate method for measuring leaf area and defoliation through Digital Image Analysis.*Journal of EconomicEntomology, 95*(6), 1190-1194. https://doi.org/10.1603/0022-0493-95.6.1190

Owusu-Ansah, F. Afreh-Nuamah, K., Obeng-Ofori, D., &Ofosu-Badu, K. G. (2001). Growth-promoting properties and yield effects of aqueous neem seed extract, biotic and karate on local garden eggs (*Solanum integrifolium* L.) in the field. *Journal of Ghana Science Association, 3*(3), 136-144. https://doi.org/10.4314/jgsa.v3i3.17776

Rahman, S. A. (2000). The place of organic manure in sustaining agricultural development tin Nigeria. Paper presented at Science Technology and Society National Workshop in Lafia, Nasarawa State, 11$^{th}$ July 2000.

Rakshit, A., Sarkar, N. C., &Sen, D. (2009). Influence of organic manures on productivity of two varieties of rice. *Journal of Central European Agriculture, 9*(4), 629-633.

Salifu, A. B. (1982). Biology of cowpea flower thrips and host plant resistance.MSc. Thesis.University of Ghana, Legon.

San Jose, R., Sanchez Mata, M. C., Camara, M., & Prohens, J. (2014). Eggplant fruit composition as affected by the cultivation environment and genetic constitution. *J. Sci*. *Food Agric., 94*(13), 2774-2784. https://doi.org/10.1002/jsfa.6623

Shirley, S. (2000). Simple eggplant Kosher recipes from around the world. 9$^{th}$ Edition, GefenPublishing House, Jerusalem, 91360, Israel, pp. 15.

Ulikan, H. (2008). Agronomic adaptation of some field crops. A general approach. *Journal of Agronomy and Crop Science,* 194, 169-179. https://doi.org/10.1111/j.1439-037X.2008.00306.x

Van Lenteren, J. C., &Noldus, L. (1990). Whitefly-Plant relationship: Behavioral and ecological aspects. Whiteflies: their Bionomics, *Pest Status and Management (July)*, 47-89.

Van Steenwyk, R. A., & Barnett, W. W. (1985). Improvement of navel orangeworm (Lepidoptera; Pyralidae) egg traps. *Journal of Economic Entomology, 78*, 282-286. https://doi.org/10.1093/jee/78.1.282

Zaini, M. R., Rawi, C. S. M., & Abu, H. (2013).Effect of nutrient and pre-infested Brunjal, *Solanum melongena* by whitefly and aphid population dynamics of whitefly, *Bemisia tabaci. Journal of Agriculture, Forestry and Fishery, 2*(1), 1-10. https://doi.org/10.11648/j.aff.20130201.11

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# Characterization of the Production and Dissemination Systems of Nile Tilapia in Some Coastal Communities in Ghana

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**Abstract**

Aquaculture development has been identified as a key process to meeting the demand for cheap and readily available source of protein. The resultant has been the springing up of cages along the Volta Lake with most farmers producing Nile tilapia. However, the sector faces an array of challenges which needs urgent attention. A study was undertaken to ascertain the production systems and dissemination channel of Nile tilapia among farmers along selected coastal regions in Ghana. A survey of 190 farmers representing the fish farming community in the area was used -these comprised 187 males and 3 females. Pond culture and cage culture were the most common holding facilities used constituting 58.8% and 28.9% respectively. The production of all-male tilapia was popular among farmers and constituted 66.8% of production, while the production of mixed sex tilapia formed 25.8 %. The study revealed that the high prices of fish feed and lack of access to finance were the top ranking financial challenge facing fish farmers in the area corresponding to 73.2% and 51.1% of the response respectively. Other factors such as distance to hatchery and price of fingerling was a significant factor affecting the choice of source of fingerling for stocking ($P<0.05$) for farmers who used dugout ponds. There was no clearly laid down protocol for dissemination the tilapia. Farmers (16%) who undertook dissemination directly supplied fingerlings and broodstock to other farmers. Investment of capital into tilapia production can improve productivity and profitability.

**Keywords:** *Oreochromis niloticus*, Akosombo strain, socio-economics, culture systems

## 1. Introduction

Aquaculture and fisheries plays an important role in contributing to the protein nutrition in Ghana. The annual demand of fish exceeds 1,000,000mt, whiles production is about 440,000, leaving a deficit of 600,000mt (GNA, 2017). The role of aquaculture in meeting this deficit has become more pressing than ever. With a current annual aquaculture production of more than 50,000mt, the production is predicted to increase to over 100,000 metric tonnes by the end of 2017 (GNA, 2017). The sector employs 5,000 directly and 150,000 indirectly through the aquaculture market value chain (FAO, 2016). In 2012, the country ranked as the fourth food fish aquaculture producer in Africa, after Egypt, Nigeria and Uganda (FAO, 2014). However, with an ever-increasing human population, improved economic situation in some sectors, and greater awareness of the health aspects of fish, the demand of fish is predicted to increase (Ponzoni, 2006).

There are approximately 5000 fish farmers operating some 19 000 fish ponds and cages in Ghana (FAO, 2016). Few farmers undertake pen culture and atidja/acadja culture; whilst mariculture is virtually non-existent in Ghana. Nunoo, Asamoah and Osei-Asare (2014) noted that both pond and pen aquaculture are profitable venture which needs to be explored. The latter also noted that that large-scale operations were more profitable and viable than small scale operations. The eastern corridor is the most productive sector contributing more than 80% of the total production. This area of the country is characterized by presence of the Volta Lake and Volta River which provide a conducive opportunity for cages culture. These cages are generally stocked to capacity and produce more fish per unit area compared to pond culture. Although Wijkstrom and MacPherson (1990) noted that aquaculture had the potential to alleviate poverty among the rural poor, a survey conducted in 2007 indicated that the rate of abandonment of pond was increasing (Asmah, 2008). The reasons attributed to this finding were lack of readily available tilapia fingerlings and the lack of readily available, standardized and affordable pelleted fish feed. However, with the growing demand for fish, there is a good and readily available market for tilapia produced, making the species the most preferred species in aquaculture (Nunoo, Asamoah & Osei-Asare, 2014; Aseidu, Failler & Beyens, 2016).

Nile tilapia (*Oreochromis niloticus*) is the mainstay of the aquaculture industry contributing more than 90 % of the total production. Their ease of propagation, tolerance to handling, fast growth, as well as tolerance to a wide range of environmental conditions have been an important factor which has led to their increased culture. *Oreochromis niloticus* is a microscopic herbivorous feeder, subsisting mainly on phytoplankton, periphyton as well as fresh and decaying plant material (Moriera, 2002; Oteino, Kitaka & Njiru, 2014). The species thrive in freshwater, and can be cultured with little or no supplementary feeding. Where feed is provided, small-scale rural pond farmers use wheat bran, maize bran, rice bran and brans of other cereals, which are readily available on the local market. In addition, other supplementary feeds which are used in aquaculture include agricultural wastes such as cocoyam leaves, agricultural-industrial byproducts such as local brewery waste, and household food waste (FAO, 2016). Tilapias perform well under different culture systems and have been produced under varying management strategies. This has made the culture of Nile tilapia one of the easiest and profitable ventures to exploit. However, the slow growth rate and their ability to stunt has been a major challenge to the industry. Given the importance of the Nile tilapia to aquaculture, the development of an improved strain has been carried out.

The most popular and well documented strain of tilapia in Ghana is the Akosombo strain. This strain was developed by the CSIR-Water Research Institute by a 4×4 diallel cross of three populations of *O. niloticus*, collected from three different agro-ecological zones within the Volta system in Ghana and a farmed strain from a local producer (Attipoe & Abban, 2004; Attipoe, 2006). Although the strain grows about 30% faster than wild unimproved strains and has the potential to boost aquaculture in the country, the impact of this strain is yet to be felt due to the use of wild populations which have not undergone any genetic improvement programme. However, there is the need to identify and document other strains of Nile tilapia used by farmers and the factors that influence their choice of strain.

The intervention of government to support the aquaculture sector through the provision of fingerlings/Tilapia Breeding Programme, shrimp production, Nucleus-Outgrower Fish Farmers Scheme, Fish Feed Production and an Inland Fisheries Resource Management (GoG, 2017) can be achieved if the challenges facing the sector is addressed. The important role aquaculture plays in protein nutrition and enhancement of livelihood has brought to the fore the need to identify some of the important parameters which characterize aquaculture production in the country. However, given that there are limited hatcheries in the country, there is the need to identify the pathways for dissemination of fish. The research was set at identifying socio-economic factors that influences the breeding and the dissemination pathways used in Nile tilapia culture with special emphasis on the southern sector of the country. This will provide information necessary to advice management and bring to the fore some challenges that mitigate against the growth of the aquaculture industry.

## 2. Materials and Methods

Ghana has a coastline of 550km which spans four different regions. The regions selected for the survey were Central, Greater Accra, Eastern and Volta regions. These regions contribute more than 80% of the total aquaculture production in the country (MOFAD, 2013, 2014). The Central and Greater Accra Regions are predominantly characterized by pond culture whereas the Eastern and Volta regions have more cages due to the presence of the Volta Lake / River. There are about 300 000 individuals who directly depend on Lake Volta for their livelihood, of which 80 000 are fishers and the rest are fish processors and traders (IDAF-Yeji Terminal Report, 1993; Bene & Rusell, 2007; BoG, 2008).

A cross-sectional survey designed was employed to target individual fish farmers as well as officials of aquaculture departments. Sample size was determined using the formula derived by Kothari (2004). Within the regions, a stratified random sampling technique was used in the selection of respondents. Socio-economic data was collected through a structured questionnaire for the survey. All questionnaires were administered through face-to-face interviews by the researcher and research assistants. Data from questionnaires were coded and recorded into the spreadsheets of the Statistical Package for Social Sciences (SPSS vr 20) for statistical analysis. Socio-economic data analysis involved the use of descriptive statistics (means, modes, standard deviations, variance, percentages, and frequencies) whereas inferential statistics involved the use of correlation and chi square. A multinomial logistic regression model was developed to ascertain the relationship between predictor variables and the type of aquaculture facility used and source of fingerling/broodstock whereas a binomial logistic regression model was used to test the relationship between predictor variables and the possibility of disseminating tilapia. All statistics were tested at the probability level of $p \leq 0.05$.

## 3. Results

A total of 190 respondents which included 3 females and 187 males were obtained from the survey. The age of the farmers ranged between 20 and 79 years, with a mean age within the 40-49 year range (Table 1). The level of education of the respondents indicated that 30.5% had JHS education, 45.3% had senior secondary education, whilst 17.9 % had tertiary education. More than 90% were Christians, whilst the rest belong to either traditional, Islam and other religions. Married persons represented 83% whilst 11% were never married. There were 50.6% of the respondents who had been in aquaculture within the last three years whilst the remaining had been in aquaculture for more than 4years. In terms of persons been employed on the farm, 77% employed 1-3 person whiles the remaining employed more than 4 persons; however, a few (3) farms employed more than 50 individuals.

Table 1. Descriptive statistics of demographic characteristics of the respondents

| Parameter | Frequency | Percentage |
|---|---|---|
| *Sex* | | |
| Male | 187 | 98.4 |
| Female | 3 | 1.6 |
| *Age* | | |
| 20-29 | 18 | 9.5 |
| 30-39 | 35 | 18.4 |
| 40-49 | 69 | 36.3 |
| 50-59 | 53 | 27.9 |
| >=60 | 15 | 7.9 |
| *Level of Education* | | |
| No education | 2 | 1.1 |
| Primary | 10 | 5.3 |
| Junior High School | 58 | 30.5 |
| Senior High School | 86 | 45.3 |
| Tertiary | 34 | 17.9 |
| *Religion* | | |
| Christian | 178 | 93.6 |
| Traditional | 6 | 3.2 |
| Other | 6 | 3.2 |
| *Ethnicity* | | |
| Akan | 89 | 46.8 |
| Ewe | 46 | 24.2 |
| Dangme | 46 | 24.2 |
| Others | 9 | 4.8 |
| *Occupation* | | |
| Aquaculture | 49 | 25.8 |
| Fisherman | 10 | 5.3 |
| Farmers | 56 | 29.5 |
| Teachers | 12 | 6.3 |
| Formal Business | 24 | 12.6 |
| Informal Business | 39 | 20.5 |
| *Marital Status* | | |
| Single | 31 | 16.3 |
| Married | 159 | 83.7 |
| *Number of children* | | |
| No child | 19 | 10.0 |
| 1-3 | 76 | 40.0 |
| 4-6 | 86 | 45.3 |
| >7 | 9 | 4.7 |
| *Number of Employees* | | |
| 1-3 | 145 | 76.3 |
| 4-6 | 27 | 14.2 |
| >7 | 18 | 9.5 |
| *Source of funding* | | |
| Self | 112 | 58.9 |
| Family Support | 50 | 26.3 |
| Bank Loan | 17 | 8.9 |
| Joint partnership | 9 | 4.7 |
| Government | 2 | 1.1 |

Source and choice of fingerlings for Fish Farming

The respondents got their fingerlings from private hatcheries (40.5%), governmental outlets (35.8%), other farmers (12.6%), self-propagation on their farm (9.5%) and through collection from rivers (1.9%) (Table 2).

Famers obtained their fingerlings and broodstocks from farms in different parts of the country including Prestea (in the Western Region), MoFAD-Kumasi (in the Ashanti Region), Okyereko, Ekumfi-Esuohyia, Mankessim, Adjumako, Kasoa (in the Central Region), MoFAD-Ashiaman (in the Great Accra region), Akosombo, Akuse, Asutsare, Senchi, Sedorn, Dodi (in the Eastern region) and Fante – Akura (in the Volta Region). A reasonable proportion of the farmers (36.9 %) used the Akosombo strain whilst the remaining farmers used other strains of Nile tilapia. The Akosombo strain was obtained from ARDEC -Akosombo, Ashiaman, and Okyereko. The predominant culture system that was practiced was all male-tilapia (66.7%)

Price of 2g fingerlings ranged between 0.14 Cedis and 0.22 Cedis (1USD = 4.31GHC), with a mean price of 0.146 Cedis; however, farmers who got their fingerlings from other farmers had it for free or paid not more than 0.10 Cedis (Fig.1). There was a significantly high probability of a farmer undertaking self-propagation of broodstock and fingerling on farm to use multiple holding facilities (pond, tank and cage) as compared to the others ($P<0.05$). The respondents who used dugout ponds also noted that means of delivery of the fingerling as well the distance to the hatchery also influenced choice of fingerling; however same could not be said for respondents who used other facilities. Social status including level of education, age, type of occupation as well as source of income, did not affect the choice of fingerling for production ($P>0.05$).

Approximately 60% were self-funding their enterprise, 26.7% had some family support whilst 9% used bank loans. Partnership comprising two to five persons constituted 4.7%, and government supported ventures were the least prevalent (1.1 %). Dugout ponds was the most dominant (58.8%) holding facility used for aquaculture. This was followed by cages (28.9%) whilst concrete tanks only were the least common facility used. All-male tilapia production was the most dominant culture method been used (66.8%) whilst fewer farmers ventured into the production of broodstock (25.8%). The remaining farmers undertook polyculture of tilapia with African catfish (*Clarias gariepinus*). Among the farmers who produced fingerlings, most of them (73.9%) generally raised their fingerlings with the aim of stocking their own cages and sold a relatively smaller portion to other customers. Stocking density for pond culture ranged between 5-20 fish per square meter, whilst farmers who were into cages was between 200- 300 fish per square meter. Broodstock were kept in hapas of varying dimensions and used for production of fingerlings.

Table 2. Culture system and source of fingerlings of respondents

| Parameter | Number | Percentage |
|---|---|---|
| *Source of fingerling* | | |
| Wild | 3 | 1.6 |
| Other farmers (friends) | 24 | 12.6 |
| Self-propagation | 18 | 9.5 |
| Private Hatcheries | 77 | 40.5 |
| Governmental departments | 68 | 35.8 |
| *Type of Culture System* | | |
| All-male | 127 | 66.8 |
| Mixed Sex | 49 | 25.8 |
| Polyculture | 12 | 6.3 |
| Mixed culture | 2 | 1.1 |
| *Type of holding facilities* | | |
| Earthen/Dugout Ponds | 108 | 56.8 |
| Concrete tank | 1 | 0.5 |
| Cages | 55 | 28.9 |
| Ponds and concrete tanks | 6 | 3.2 |
| Ponds and Cages | 14 | 7.4 |
| Ponds, concrete tanks and cages | 6 | 3.2 |

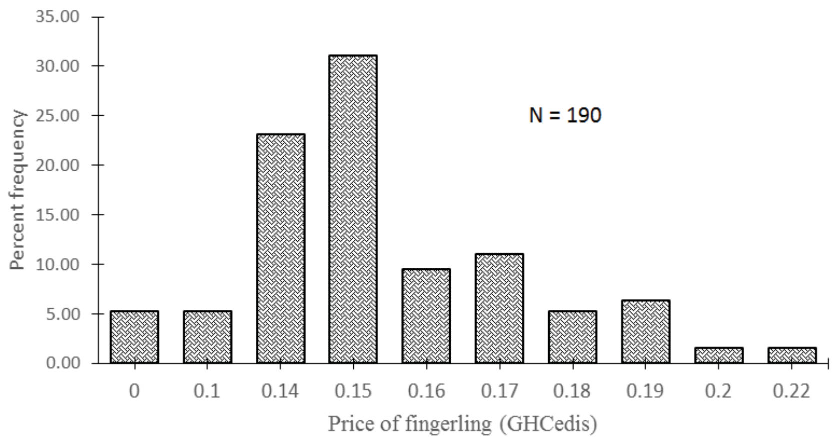


Figure 1. Price of 2g fingerling sold at various farms along the southern sector of Ghana (1USD = 4.3GHC)

Generally, respondents who were between the ages of 20-29 undertook more cage culture than the other age groups ($P<0.05$). However, respondent who were older than 30 years tended to undertake more pond culture only than the other types (Table 3). Persons who self-financed or had family support used more dugout ponds whilst those who took loans from banks undertook more cage culture ($P<0.01$). Furthermore, respondents who were in partnership as well as those who had spent more than 10 years in aquaculture had a significantly higher chance of using more than one production facility ($P<0.01$).

Table 3. Relationships between some parameters (age, family size and source of finance) on the type of culture facility used for aquaculture

| | N | Concrete tanks | Dugout | Cage | Ponds &Cages | Ponds & Tanks | Ponds, Tanks & Cages | $\chi^2$ (*p-value)* |
|---|---|---|---|---|---|---|---|---|
| *Age* | | | | | | | | |
| 20-29 | 18 | 0.0 | 16.7 | 77.8 | 5.6 | 0.0 | 0.0 | 46.79(0.00*) |
| 30-39 | 35 | 2.9 | 48.8 | 40.0 | 8.6 | 0.0 | 0.0 | |
| 40-49 | 69 | 0.0 | 66.7 | 23.2 | 4.3 | 2.9 | 2.9 | |
| 50-59 | 53 | 0.0 | 68.6 | 17.6 | 5.9 | 3.9 | 3.9 | |
| ≥60 | 15 | 0.0 | 46.7 | 13.3 | 26.7 | 6.7 | 6.7 | |
| *Family size* | | | | | | | | |
| No child | 19 | 5.3 | 31.6 | 52.6 | 10.5 | 0.0 | 0.0 | |
| 1-3 | 76 | 0.0 | 69.7 | 19.7 | 2.6 | 2.6 | 5.3 | 33.25(0.00*) |
| 4-6 | 86 | 0.0 | 54.7 | 27.9 | 10.5 | 4.7 | 2.3 | |
| ≥7 | 9 | 0.0 | 22.2 | 66.7 | 11.1 | 0.0 | 0.0 | |
| *Source of Finance* | | | | | | | | |
| Self | 112 | 0.00 | 56.25 | 33.93 | 6.25 | 1.79 | 1.79 | |
| Family support | 50 | 2.00 | 80.00 | 10.00 | 2.00 | 6.00 | 0.00 | 99.49(0.00*) |
| Loan from bank | 17 | 0.00 | 29.41 | 52.94 | 17.65 | 0.00 | 0.00 | |
| Government | 2 | 0.00 | 0.00 | 0.00 | 0.00 | 50.00 | 50.00 | |
| Partnership | 9 | 0.00 | 0.00 | 33.33 | 33.33 | 0.00 | 33.33 | |
| *Number of years in aquaculture* | | | | | | | | |
| 1-3 | 96 | 1.0 | 61.5 | 28.1 | 6.2 | 3.1 | 0.0 | 37.46(0.00*) |
| 4-6 | 70 | 0.0 | 58.6 | 31.4 | 2.9 | 1.4 | 5.7 | |
| 7-9 | 16 | 0.0 | 37.5 | 31.2 | 25.0 | 6.2 | 0.0 | |
| ≥10 | 8 | 0.0 | 25.0 | 12.5 | 25.0 | 12.5 | 25.0 | |

The target market for majority of the farmers (93.2%) were urban and peri-urban centres, however, point of sale of the products was at farm gate (85.3%) in their fresh forms. The use of cold store facilities and market centres for sales of fish made up the remaining component (14.7%). The respondents also noted that the customers preferred bigger fish (250g and above) over smaller fish (below 200g). High cost of feed and lack of financial assistance was noted by 73.2% and 51.9% of the respondents respectively to be a major challenge facing the industry.

*3.1 Perception of Farmers about Akosombo Strain*

There were 89 farmers who knew about the strain, of which fifty-two (52) used the strain for propagation. Farmers got information on the strain through friends (70%) whilst the remaining gained information through workshops. Incidentally, majority (55.8%) who used the strain responded that the price of a 2g fingerling was moderate, whilst 40.4% thought the cost was either expensive or very expensive; and the remaining (3.8%) felt the price was low. This notwithstanding majority of the farmers (63.5%) attributed their choice for the fish to the proven performance (fast growth) whilst customer preference (25.5%) was the next important factor. Consequently, most of the farmers gave a high score on the performance of the strain; ranking it as satisfactory (48.1%) and highly satisfactory (46.2%). Although there were other strains of tilapia been produced and sold to fish farmers, most of them were not well documented with respect to the parent material used to produce the strain. In some cases, hatcheries had purchased the Akosombo strain and had crossed them with broodstock from other farms or wild populations.

*3.2 Dissemination of Strains of Tilapia*

Dissemination of strains of Nile tilapia was undertaken by 32 (16.8%) of the farmers; out of which 24 (75%) farmers supplied fingerlings directly to other farmers, whereas the remaining 8 (25%) sold both fingerlings and broodstock to other famers. A logistic regression analysis conducted to predict dissemination of tilapia by the farmers using age, level of education, family size, marital status, year in aquaculture, number of employees, source of fingerling, price of fingerling and type of holding facilities as predictors yielded a Nagelkerke's $R^2$ of 0.389 indicating a moderately strong relationship (Table 4). A test of the full model against a constant only model was statistically significant, indicating that the predictors as a set reliably distinguished between disseminators and non-disseminators of tilapia (chi square = 45.715, p < 0 .000 with df = 9). Prediction success overall was 90.5% (97.6% for non-dissemination and 46.2% for dissemination). The Wald criterion indicated that only price of 2g fingerling made a significant contribution to prediction (p = 0.001). The standardized beta coefficient, Exp(β), value indicates that when educational level is raised by one unit the odds ratio is 1.5 times as large and therefore farmers with higher education are 1.5 more times likely to disseminate tilapia.

Table 4. Some parameters and their effect on dissemination of tilapia

| Predictors | B | S.E | Wald | Df | Sig. | Exp(β) |
|---|---|---|---|---|---|---|
| Age | -0.123 | 0.270 | 0.209 | 1 | 0.647 | 0.884 |
| Marital Status | 0.208 | 0.934 | 0.049 | 1 | 0.824 | 1.231 |
| Level of education | 0.376 | 0.355 | 1.120 | 1 | 0.290 | 1.457 |
| Family size | -0.100 | 0.430 | 0.054 | 1 | 0.816 | 0.905 |
| Years in Aquaculture | -0.029 | 0.390 | 0.005 | 1 | 0.941 | 0.972 |
| Number of employees | 0.246 | 0.518 | 0.226 | 1 | 0.634 | 1.279 |
| Source of fingerling | 0.328 | 0.326 | 1.014 | 1 | 0.314 | 1.388 |
| Production facility | 0.234 | 0.226 | 1.067 | 1 | 0.302 | 1.263 |
| Price of fingerling | 0.036 | 0.010 | 11.781 | 1 | 0.001 | 1.036 |
| Constant | -5.526 | 2.296 | 5.795 | 1 | 0.016 | 0.004 |

Reference = No dissemination

## 4. Discussion

Culture of tilapia continues to be the major contributor to total aquaculture production in Ghana. The importance of this sector to food security, income generation and indirect benefits of employment cannot be over emphasized. The study revealed that men, who happen to the head of households, owned most (98.4%) of the fish farms with majority of them being between the ages of 40-59. This may be due to the fact that most of the farms were run through self-financing (58.9%) and family support (26.3%). Although women are involved in the various aspects of aquaculture ranging from feed production to production of fish for market, ownership of aquaculture facilities have been dominated by males in most parts of the country. This situation is not peculiar to Ghana but cuts across most West-African countries (Trottier, 1987). Women usually get involved in the value chain by purchasing and processing fish for consumers. Raising farmers' income is a necessary precursor to high capital investment in agriculture. This can be achieved through reducing the sizes of families and hence dependency ratio. Increased involvement of women in decision-making framework will stimulate their participation in farming activities. Generally, few farms were run by full-time fish farmers (25.8%) whilst 50% were run by farmers and persons involved in the informal business sector. This indicates that aquaculture is still seen as a part-time hobby, with minimal capital investment (Hiheglo, 2008; DoF, 2009). This further explains the low number of people that were employed on the farms (1-3); indicating that the farmers were mostly undertaking aquaculture on the subsistence level. However, farms who employed more than ten (10) people were mainly financed by partnership or the government. Although aquaculture is a profitable venture, low investment from the private sector as well as lack of information concerning economic profitability continue to mitigate against the growth of the sector. This is evidenced by the low numbers (4.7%) of farmers who were funded through partnerships. However, with the rising cost of feed, fingerlings and the other inputs required for aquaculture, it may be necessary to consider other forms of financial assistance in enhancing productivity.

The dominating type of aquaculture undertaken is small scale with extensive production of all-male tilapia in earthen ponds. This situation is similar in other West African countries as well as East African countries (IFOAM, 2013). The type of breeding system employed reflected a range of different intended outcomes; either subsistence or commercial. Hiheglo (2008) noted that although aquaculture has great potential, the industry is dominated by small scale operators. These farmers purchase sex-reversed fingerlings and stock them in the facilities, however, most of the dug-out ponds operators were not feeding their fish on regular basis. Although the initial cost of setting up a dug pond may be lower than that of a cage, the high stocking density employed in the latter ensures that profits margins offset the initial cost. Antwi, Kuwornu, Onumah and Bhujel (in press) noted that the average production in cages was 74 kg, however, productivity could be improved and increased to 1 ton per cage per cycle if the farms are managed properly. Cage culture is also threatened by theft and lack of well-designed market structure. Farmers also complained that their products are been purchased by customers at lower prices, reducing their profit margins. In addition, due to the high levels of productivity of cage, there is the need for access to preservation facilities. Thus choosing an aquaculture system is about managing a trade-off between available capital, skills and the quality of fish demanded by a farmer’s potential market.

Culture practices undertaken by the farmers include purchase of all-males, mixed sex, polyculture and mixed farming. The moderate correlation between the levels of education and the culture practices undertaken on the farms ($r = 0.22$) indicates that most farmers (irrespective of the level of education) was more interested in purchasing sex-reversed fingerlings and growing them for the market than engaging in other complex practices. This also reflects the low level of technical knowledge of the farmers. Although mixed sex culture could be undertaken by farmers, they still preferred the use of sex-reversed males. However, a few farmers who practiced mixed sexed culture in the cages, generally use the facility for broodstock production. These were later transferred to dugout ponds from which egg and fry production were undertaken.

Although the sector has experienced a significant increase in production within the last decade, there are socio-economic factors which mitigate against its growth. Socio-economic factors such as level of education, income, occupation, farm size, land tenure, place of residence, culture and ethnicity, religion have been proposed to be major determinants of thought patterns, decisions and attitudes (Kodiwo, 2012). The distance to the hatchery was a factor which affected 39.5% of the respondents. This group indicated that distance to the hatchery increased mortality of fingerlings as well as added to the cost of production due to transportation. Stress and high mortality due to transportation of fish from one facility to another continues to be a challenge to fish farmers. The high rate of mortality (up to 50%) that some farmers reported indicated the need for improvement in transportation of fish. This challenge as well as the high cost of fingerling and feed has been the paramount challenge for most farmers. Although most farmers obtained their supply of fingerlings from privately owned hatcheries and farms, those supplied by government agencies and departments were significantly cheaper ($p>0.05$). However, farmers considered other factors such as personal relationship with the hatchery operator, proven performance of strain and advice from friends in deciding the choice of source of seed for production. Private hatchery operators most often provided means of transportation of fingerlings and broodstock. This may be an important factor in encouraging farmers to purchase fingerlings and broodstock from these hatcheries.

One challenge that most farmers faced was their inability to afford readily available feed. Most commercial fish feeds are either too expensive or unavailable to some farmers – especially, those in the Central Region. The resultant has been the frequent mixing of local feeds with kitchen wastes, whilst others feed sparsely. Fish feed is expensive in Ghana and is responsible for the high aquaculture production costs. They make up about 70 percent of the total production cost, with the imported feeds being 30 percent more expensive than the locally-produced ones (FAO, 2009, 2016). Whereas availability of fish seed (fingerlings) is not a major challenge in the industry, issues of the quality of the fingerlings has been a major concern to the farmers. As the seed is one of the most important components of the aquaculture development, availability of good quality seed whenever needed accelerates the industry growth. Therefore, in order to support the maximum potential growth of tilapia industry, policy makers, researchers and other involved should emphasize the seed production technology and its dissemination.

The dissemination of improved strains did not go through any properly laid down procedure. Farmers could purchase improved strains of broodstock and fingerlings directly from the nucleus i.e. ARDEC and other governmental agencies. Hatcheries crossed the Akosombo strain with any strain of their choice – either from the wild of from other farms. Hence the possibility of losing the genetic gains of the Akosombo strain cannot be overemphasized. Although Rosendal, Olesen and Tvedt (2012) raised concerns about possible challenges due to ownership of the Akosombo strain as well as potential conflicts over access and benefit sharing (ABS) and legal protection over tilapia genetic material, the survey revealed that some hatcheries developed their own strain after the purchase of the improved strain. This puts pressure on the research institution to produce enough to meet the demands of the market. Access to improved strains in the industry is very open with farmers been able to buy fingerlings and broodstock from most of the farms. A few well-established farms, however, were reluctant in selling fingerlings and broodstock to other farmers. In Ghana, accessing genetic resources is relatively uninhibited and thus faces several challenges (UNEP, 2008). Further to that, in Ghana, there is no specific legislation on ABS corresponding to the CBD provisions, the Bonn Guidelines or other international instruments. Country reports presented at the 2002 INGA Expert Consultation held in Thailand revealed that, in general, the capacity of the member country institutions (both public and private) to maintain and manage the improved strains is weak and overall strategies for the dissemination of these strains are lacking. This may be one of the reasons why some well-established farms were unwilling to share their improved strains to other farmers. Proper dissemination of improved strain will open key areas of collaboration that such as seed production, seed distribution, extension, financing for farm operations, and setting directions for the tilapia sector (ADB, 2005). Investment of capital into aquaculture has been a major concern for fish farmers in the country. Hence there is the need for education and sensitization of players/investors on the viability of aquaculture and the possible gains which can be made (Mbugua, 2007).

## 5. Conclusion

The study has brought some socio-economic factors which affects the choice of fish for aquaculture along the coastal districts of Ghana. The major challenges faced by fish farmers included: means of transportation of fingerlings, cost of feed and access to financial assistant; whiles indigenous knowledge of culture of tilapia, community patronage, theft and low price of farm products were minor factors. Few women own farms and this call for the sensitization and provision of support for women to venture into aquaculture. Most farmers use strains of tilapia other than the Akosombo strain and purchase their fingerlings from private hatcheries. Farmers who produced their own fingerlings used a combination of pond culture and either concrete tank or cage culture. However, pond culture remains the dominant holding facility used by farmers. The Akosombo strain of tilapia was used by 36.9 % of the farmers, with a vast majority of the farmers (70%) getting information on the strain through other farmers.

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## References

Abban, E. K., Asmah, R., Awity, L., & Ofori, J. K. (2009). Review on National policies and Programmes on Aquaculture in Ghana. *SARNISSA*.

Ansah, Y. B., Frimpong, E. A., & Hallerman, E. M. (2014). Genetically-Improved Tilapia Strains in Africa: Potential Benefits and Negative Impacts. *Sustainability*, *6*, 3697-3721. https://doi.org/10.3390/su6063697

Antwi, D. E., Kuwornu, J. K. M., Onumah, E. E., & Bhujel, R. C. (in Press). Productivity and constraints analysis of commercial tilapia farms in Ghana. *Kasetsart Journal of Social Sciences*. https://doi.org/10.1016/j.kjss.2016.12.001

Aseidu, B., Failler, P., & Beyens, Y. (2016). Enhancing aquaculture development: mapping the tilapia aquaculture value chain in Ghana. *Reviews in Aquaculture*, *8*, 394-402. https://doi.org/10.1111/raq.12103

Asmah, R. (2013). Aquaculture site selection and carrying capacity estimates for inland and coastal aquaculture in West Africa. *In* L.G. Ross, T.C. Telfer, L. Falconer, D. Soto & J. Aguilar-Manjarrez, eds. *Site selection and carrying capacities for inland and coastal aquaculture,* pp. 197–205. FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6-8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland. FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO. 282 pp.

Attipoe, F. Y. K. & Abban, E. K. (2004). Evaluation of culture performance of ecotype collections of Nile tilapia (*Oreochromis niloticus*) from the Volta system as the basis for fish breeding and selection program in Ghana. In: Abban, E. K., Casal, C. M. V., Dugan, P., Falk, T. M.(Eds.), Biodiversity, Management and Utilization of West African Fishes. WorldFish Center Conference Proceedings, pp.16–17.

Attipoe, F. Y. K. (2006). Breeding and Selection for Faster Growth Strains of the Nile Tilapia, *Oreochromis niloticus*, in Ghana. (Doctoral Thesis, University of Cape Coast, Ghana),

Béné, C., & Russell, A. J. M. (2007). *Diagnostic study of the Volta Basin fisheries. Part 1 - Livelihoods and poverty analysis, current trends and projections*. Volta Basin Focal Project Report No 7. WorldFish Center Regional Offices for Africa and West Asia, Cairo Egypt, and CPWF, Colombo, Sri Lanka, 67 p.

Bhujel, R. C. (undated). How to Produce Billions of High Quality Tilapia Fry. 8pp

Directorate of Fisheries (DOF). (2009). Annual Report for Fisheries Commission of the Ministry of Food and Agriculture. Ministry of Food and Agriculture, Ghana.

Eknath, A. E., & Acosta, B. O. (1998). Genetic improvement of farmed tilapias (GIFT) project: Final report, March 1988 to December 1997. International Center for Living Aquatic Resources Management, Makati City, Philippines.

FAO (2009). Impact of rising feed ingredient prices on aquafeeds and aquaculture production. *In*: Rana, K.J.; Siriwardena, S.; Hasan, M.R. (ed). Fisheries and Aquaculture Technical Paper. No. 541. FAO, Rome, 63p.

FAO (2014). FAO Global Aquaculture Production Volume and Value Statistics Database Updated to 2012.

FAO (2016). Fishery and Aquaculture Country Profiles: The Republic of Ghana

Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of Agricultural Innovations in Developing Countries: A Survey. *Economic Development and Cultural Change, 33*(*2*): 255-298. https://doi.org/10.1086/451461

Ghana News Agency, GNA (2017). Ghana's annual fish production deficit over 600,000 metric tonnes. https://www.ghanabusinessnews.com/2017/02/11/ghanas-annual-fish-production-deficit-over-600000-metric-tonnes/ view February 13, 2107.

GIFT (1998). Genetic Improvement of Farmed Tilapia (GIFT) Project. Final Report. March 1988 to December 1997) Part 1. ICLARM. Makati, Metro Manila.

Gjoen, H. GIFT Program Continues: Distribution of Fast-Growing Tilapia to Expand. Available online: http://pdf.gaalliance.org/pdf/GAA-Gj%F8en-Dec01.pdf (accessed on 11th November 2016).

Government of Ghana (2017). Ministry Of Fisheries And Aquaculture Development. http://www.ghana.gov.gh/index.php/media-center/news/2234-ministry-of-fisheries-and-aquaculture-development. viewed February 12, 2017

Hiheglo, P. K. (2008). Aquaculture In Ghana; Prospects, Challenges, Antidotes And Future Perspectives. (Master Thesis, University of Tromsø, Norway).

IDAF (1993). Terminal report, IDAF project, Yeji, Ghana, 196.

IFOAM (2013). Scoping Study on Organic Aquaculture in 5 East African Countries. Censkowsky, U. & Altena, A. (eds). International Federation of Organic Agriculture Movement, 64pp.

Jenkins, A., Velandia, M., Lambert, D. M., Roberts, R. K., Larson, J. A., English, B. C., & Martin, S. W. (2011). Factors Influencing the Selection of Precision Farming Information Sources by Cotton Producers. *Agricultural and Resource Economics Review, 40*(2), 307-320. https://doi.org/10.1017/S106828050000808X

Kodiwo, M. P. (2012). Social-economic factors influencing agricultural land use intensity in Siaya district – Kenya. (Master's thesis. Kenyatta University, Kenya)

Lind, C. E., Safari, A., Agyakwah, S. K., Attipoe, F. Y. K., El-Naggar, G. O., Hamzahd, A., … Ponzoni, R.W. (2015). Differences in sexual size dimorphism among farmed tilapia species and strains undergoing genetic improvement for body weight. *Aquaculture Reports 1*, 20-27. https://doi.org/10.1016/j.aqrep.2015.03.003

Little, D. C., Murray, F. J., Leschen, W., & Waley, D. (2013). Socio-economic factors affecting aquaculture site selection and carrying capacity. *In* L.G. Ross, T.C. Telfer, L. Falconer, D. Soto & J. Aguilar-Manjarrez, eds.

*Site selection and carrying capacities for inland and coastal aquaculture,* pp. 103–115. FAO/Institute of Aquaculture, University of Stirling, Expert Workshop, 6-8 December 2010. Stirling, the United Kingdom of Great Britain and Northern Ireland. FAO Fisheries and Aquaculture Proceedings No. 21. Rome, FAO. 282 pp.

Mittal, S. (2012). Modern ICT for Agricultural Development and Risk Management in Smallholder Agriculture in India. CIMMYT. *Socio-Economics Working Paper 3*. Mexico: CIMMYT

Mittal, S., & Mehar, M. (2016). Socio-economic Factors Affecting Adoption of Modern Information and Communication Technology by Farmers in India: Analysis Using Multivariate Probit Model, *The Journal of Agricultural Education and Extension, 22*(2), 199-212. https://doi.org/10.1080/1389224X.2014.997255

MOFAD (2013). 2012 Annual report. Accra, Ghana: Ministry of Fisheries and Aquaculture Development.

MOFAD (2014). 2013 Annual report. Ministry of Fisheries and Aquaculture Development

Moreira, R. (2002). Contribution of omnivorous tilapia to eutrophication of a shallow tropical reservoir: Evidence from a fish kill. *Freshwater Biology*, *47*, 2443-2452. https://doi.org/10.1046/j.1365-2427.2002.01013.x

Nunoo, F. K. E., Asamoah, E. K., & Osei-Asare, Y. B. (2014). Economics of aquaculture production: a case study of pond and pen culture in southern Ghana. *Aquaculture Research*, *45*(4), 675-688. https://doi.org/10.1111/are.12003

Ofuoku, A. U., Emah, G. N., & Itedjere, B. E. (2008). Information Utilization among Rural Fish Farmers in Central Agricultural Zone of Delta State, Nigeria. *World Journal of Agricultural Sciences, 4*(5), 558-564.

Otieno, O. N., Kitaka, N., & Njiru, J. M. (2014). Some aspects of the feeding ecology of Nile tilapia, *Oreochromis niloticus* in Lake Naivasha, Kenya. *International Journal of Fisheries and Aquatic Studies*, *2*2, 01-08.

Ponzoni, R. W. (2006). Genetic improvement and effective dissemination: Keys to prosperous and sustainable aquaculture industries. In: R. W. Ponzoni, B. O. Acosta and A. G. Ponniah (eds), "Development of Aquatic Animal genetic Improvement and Dissemination Programs: Current status and action plans". WorldFish Center Conference Proceedings 73, 120p.

Ponzoni, R. W., Nguyen, N. H., Khaw, H. L., & Rodriguez Jr. B. M. (2012). Considerations about effective dissemination of improved fish strains. *WorldFish*, Penang, Malaysia. Working Paper: 2012-47.

Rosendal, G. K., Olesen, I., & Tvedt, M. W. (2012). Access to, equity and protection of genetic resources in Ghana: The case of tilapia (*O. niloticus*). FNI Report 15/2012, 28pp.

Simpson, G. (2012). Opportunities for Small Scale Suppliers within the Tilapia Value Chain in Ghana: a case study of fish farming in Achavanya. (Master's thesis.,The Hague, The Netherlands)

Thompson, N. M. (2012). Two Studies Evaluating Input Use in Soybean and Cotton Production. (Master's Thesis, University of Tennessee). Available at http://trace.tennessee.edu/utk_gradthes/1215

Trottier B, (1987) Women in Aquaculture Production in West Africa. In: FAO Corporate Document Repository. Women in Aquaculture. Originated by Fisheries Aquaculture Department. Rome, Itali. [Online] Available at: www.fao.org/docrep/s4863e05.htm- (Accessed: 2/18/2017).

UNEP (2008). Access to Genetic Resources in Africa: Analysing ABS Policy Development in Four African Countries, pp 25-34.

Wijkstrom, U. N., & MacPherson, N. J. (1990). A cost benefit analysis of culture based fisheries development in small dams and dugouts. Field work paper 1: the economics of culture based fisheries. Field Document F1:TCP/GHA0051. FAO, Rome, Italy.

Woynarovich, E. (1979). The feasibility of combining animal husbandry with fish farming, with special reference to duck and pig production. Pp 203-208. In: T. V. R. Pillay and Wm. A. Dill (eds), *Advances in Aquaculture*. 653pp.

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# The Perfect Match: Simultaneous Strawberry Pollination and Bio-Sampling of the Plant Pathogenic Bacterium *Erwinia pyrifoliae* by Honey Bees *Apis mellifera*

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**Abstract**

In this study we show that honey bee colonies placed in a greenhouse for pollination of strawberry can simultaneously be used to indicate the presence of the plant pathogenic bacterium *Erwinia pyrifoliae*. This was demonstrated by using two methods of qualitative sacrificial and non-sacrificial bio sampling of the honey bee colony. A novel method for non-sacrificial subsampling, named the Beehold device, was applied. Applying the Beehold device did not disturb or affect negatively the honey bee colony. The study demonstrated that the integration of pollination service and bio-sampling functioned. In the sacrificially derived honey bee subsamples, *E. pyrifoliae* was detected prior to any visible infection in the plant; however, *E. pyrifoliae* was detected via non-sacrificial sampling at the same time as plant infection was first observed. The Beehold device is a practical tool for monitoring plant pathogens via forager bees during flowering until fruit onset, but is not as sensitive as directly sampling honey bees.

**Keywords**: Beehold tube, bio sampling, *Erwinia pyrifoliae,* honey bee, non-sacrificial subsampling, sacrificial subsampling

## 1. Introduction

Honey bees (*Apis mellifera*) are widely employed for pollination of horticultural crops. Pollination by the honey bee occurs when workers inadvertently transfer pollen from male flower anthers to receptive female flower stigmas during nectar and pollen foraging. Foraging behaviour is affected by the colony and brood nest – pollen and nectar foragers of colonies with relatively large brood nests collect larger pollen loads and perform longer forager trips than those from smaller colonies (Eckert et al., 1994). Although pollen foragers are insensitive for the quality of the pollen they collect, decrease in quantity and quality of pollen results in an increase of the proportion of pollen foragers without increasing the overall foraging rate and pollen load weight (Pernal & Currie, 2001). During foraging, pollen and non-floral particles such as plant pathogenic bacteria and atmospheric deposited particles can adhere to the branched hairs of honey bees (Wadl et al., 2009). Honey bees groom themselves during foraging, and are further groomed by their in-hive sisters (Hodges, 1974; Bozic & Valentincic, 1995). Despite grooming, both pollen and non-floral particles passively remain on the bee's exterior (Lukoschus, 1957). Free & Williams (1972) estimated an average number of 4000 – 13000 pollen grains remain as a passive load on the honey bee. Paalhaar et al. (2008) demonstrated that honey bees that never left the colony have pollen in their hair, and that relatively small grains are dominant. Therefore, through in-hive pollen exchange, both in-hive and forager bees can carry a passive load (Degrandi-Hoffman et al., 1984, 1986). This makes the honey bee an active bio sampler of the environment, as well as a disseminator of plant pathogenic and non-pathogenic micro-organisms. For the latter, honeybee colonies are used as vectors to disseminate antagonistic micro-organisms directly into the flowers to prevent or inhibit pathogenic organisms growth. (Kovach et al., 2000; Kevan et al., 2008). Dissemination of plant pathogenic bacteria does not always result in disease.

Wounding is essential for entry by many plant pathogens. Infested or infected seed or other plant parts can be sources of bacterial inoculum. Once infection occurs, bacteria exudates are released through cracks or wounds in the infected area, or through natural openings such as stomata. Such bacteria are then likely to stick to the legs and bodies of insects, such as honey bees, flies, aphids and ants that land on the plant and come in contact with the bacterial exudates. Many of these insects are actually attracted by the sugars contained in the bacterial exudate and feed on it, thereby further smearing their body and mouthparts with the bacteria-containing exudate. When such bacteria-smeared insects move to other parts of the plant or to other susceptible host plants, they carry numerous bacteria on their body. As a result, the honey bee's feature of unintentional collection of non-floral particles makes each foraging honey bee an in-flower bio sampling honey bee. Subsampling of the honey bee colony for particles, including micro-organisms, can be done sacrificially or non-sacrificially. Sacrificial subsampling implies killing bees for analysis. Considering the honey bee's performance, sacrificial subsampling has its practical limits regarding frequency and sample size. In contrast, non-sacrificial subsampling does not occur at the expense of the honey bee colony. The trick of non-sacrificial honey bee colony subsampling is to remove particles from the bee's exterior without taking bees. The number of bees for non-sacrificial sampling is unlimited, with one single bee potentially sampled multiple times. Combining pollination service and bio sampling of plant pathogenic bacteria by the honey bee colony is therefore a logical match. This has been demonstrated during *Erwinia amylovora* studies. *E. amylovora* is the causative agent of fire blight, a disease of rosaceous plants that occurs in many countries around the world (Bonn & Zwet, 2000). In Italy, Austria and Switzerland, bees have been successfully used to detect *Erwinia amylovora* in flowering apple- and pear orchards. (Porrini et al., 2002; Halbwirth et al., 2014). Very few bacterial diseases are known from strawberry. In 1962, *Xanthomonas fragariae*, the causal agent of bacterial angular leaf spot of strawberry in Minnesota, USA, was reported (Kennedy & King, 1962). Atanasova et al., 2005 described finding *E. amylovora* on infected plants of *Fragaria ananassa* and *Fragaria moshata*. Recently, *Erwinia pyrifoliae* was described as the causative agent of a bacterial disease affecting production of strawberry under greenhouse cultivation conditions. Symptoms included brown petals, green young fruits turning brown, malformed fruits and bacterium slime on the surface of the young fruits (Wenneker & Bergsma–Vlami, 2015).

The aim of this study was to investigate if *E. pyrifoliae* in flowering strawberry greenhouse cultivation can be detected via qualitative sacrificial and non-sacrificial subsampling of honey bees.

## 2. Materials & Methods

### *2.1 Study Site, Honey Bee Colonies and Study Period*

The study was conducted between March – April 2015 in a four hectare greenhouse in Made (Province Noord-Brabant, The Netherlands) that was planted with strawberry (*Fragaria* x ananassa, cultivar Elsanta). Honey bee colonies were obtained from the beekeeping operation Ecopol Geffen (Province Noord-Brabant, The Netherlands). The colonies were relatively small and covered 5 to 6 simplex frames (3.5 x 2 dm), which is approximately 6000 – 8000 worker bees. Each colony had two to three frames with brood in all stages of development (Delaplane et al., 2013). To ensure sufficient pollination in the greenhouse, six honey bee colonies were replaced on April 3 with six new colonies from the Ecopol operation.

### *2.2 Non-Sacrificial Subsampling with the Beehold Device*

For non-sacrificial subsampling, a novel method using the Beehold device was applied. The Beehold device, schematically presented in Figure 1, is a novel non-sacrificial subsampler of honey bees entering the hive. The method takes advantage of honey bee landing behaviour wherein hive-entering bees approach the hive entrance by landing on the flight board or outer front board to walk toward the entrance. This tube via which the bees enter the hive is the Beehold tube. Hive-leaving bees exit the hive via a walk on the bottom board or via the inside front wall to find their way out via an opening in the front board of the hive. The Beehold tube protrudes from the inner front wall into the hive to prevent hive-leaving bees to exit the hive via the Beehold tube. To prevent hive-entering bees to enter via the out-tube, the out-tube protrudes the flight board. The Beehold device consists of a foam strip that seals off the hive, therefore leaving two openings - one for the in-tube (Beehold tube) and one for the out-tube. The Beehold tube, the sampling part of the Beehold device, 11 cm long and with an inner diameter of 1.9 cm, is internally covered by a thin transparent PVC foliar holding a sticky polyethylene (PEG) layer, covered with plastic gauze to stabilize the PEG's position on the PVC layer. The moderate sticky PEG layer allows particles attached to the hive-entering bee's hair and feet to adhere to it. The stickiness of the PEG depends on the ambient temperature. For this study, a mixture of one part PEG1000 and one part PEG1500 (v/v) was applied. PEG is non-toxic to bees and can be applied safely for study objectives (Crailsheim, 1985). Preliminary studies showed that 2 – 4% of particles on the bee's body adhere to the PEG layer in the Beehold tube. Figure 2 shows the Beehold tube with its translocation cover, the 50 ml Blue cap tube; Figure 3 shows the Beehold device the flight entrance, Figure 4 shows a detail of the out-tube and Beehold tube (in-tube) and Figure 5 shows hive-entering bees via the Beehold tube.

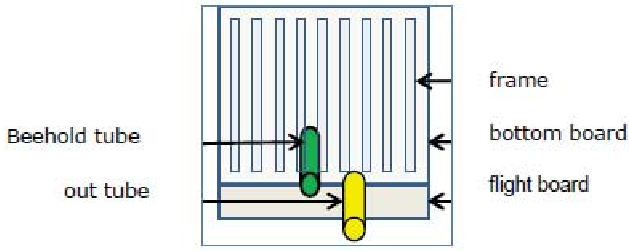


Figure 1. Top-down schematic drawing of the Beehold device and the position of the Beehold tube. Incoming bees enter the hive via the Beehold tube and are non-sacrificially subsampled by passing this tube. Bees leave the hive via the out tube

Figure 2. Beehold tube with 50 ml Blue cap

Figure 3. Beehold device in flight entrance


Figure 4. detail in- out tube (Beehold tube)

Figure 5. detail hive-entering bees via Beehold

*2.3 Pre-sampling of the Honey bee Colony at the Apiary*

On March 10, prior to the translocation of the colonies from the apiary to the greenhouse, 30 hive-entering bees were taken from one honey bee colony and tested for the presence of *E. pyrifoliae*. Beebread was not checked for *E. pyrifoliae* as this stored pollen is consumed by young nurse bees and therefore unlikely to circulate in the bee hive. Similarly, replacement colonies were not sampled and checked for *E. pyrifoliae* prior to translocation into the greenhouse.

*2.4 Subsampling of the Colonies in the Greenhouse*

On March 14, at the start of the strawberry bloom, six honey bee colonies were placed in the greenhouse for pollination. After translocation, the first and last colony in the line of the hives in the greenhouse were allocated for both sacrificial and non-sacrificial subsampling. The same was done with the second cohort of honey bee colonies. The two indicated colonies of the first cohort of colonies were subsampled from March 18 until April 1. Subsamples taken on April 8 and 15 were from the second cohort of colonies.

*2.5 Non-sacrificial Subsampling of the Honey bee Colony with the Beehold Tube*

On March 16, the Beehold device was placed in the entrance of the two colonies. From March 18, the start of the blooming, until April 15, the end of blooming the Beehold tubes were replaced weekly by new ones in the morning prior or at the start of the colony's activity. The exposure period of the hive-entering bees to the Beehold tube is the period hive-entering bees pass the Beehold tube. Because of the replacement prior to the colony's activity, the exposure period of each Beehold tube ends the day prior to the sampling day. After removal, the Beehold tubes were directly placed in a sterile 50 ml Greiner blue cap tube, transported to the laboratory within two hours of collection. The "Protocol Beehold tube", which describes the step-by-step Beehold tube method, from preparation to analysis, can be obtained from the corresponding author.

*2.6 Sacrificial Subsampling of the Honey bee Colony*

Sacrificial subsampling was performed weekly by taking 30 bees randomly via an opening in the cover board from the top of the frames. Immediately after sampling, the bees were placed in a 50 ml Greiner blue cap tube filled with 20 ml phosphate saline buffer (PBS 10 mM, pH 7.2) and transported to the laboratory within two hours. Bees were collected from the top of the colony because it was assumed that pollen and particles, including micro-organisms, can be found on all bees within a hive due to physical in-hive exchange among bees; sampling above the brood nest is less invasive.

*2.6 Preparation of the Samples for Functionality Checks of the Beehold Tube and Detection of E. pyrifoliae*

In the bee laboratory, two – three droplets of Tween 80 were added to the sacrificial subsample to facilitate removal of particles from the bee hairs. Subsequently, the samples were mechanically shaken with a Vortex device for at least two minutes to suspend particles from the bee's exterior into the buffer. Next, an aliquot of 500 µl buffer was pipetted in a 1.5 ml Eppendorfer tube for pollen determination. An aliquot of 12 ml was also pipetted into a sterile 12 ml sealable tube and transported immediately to the microbiology laboratory. From the non-sacrificially derived Beehold tubes, the PVC layer with the PEG and gauze was removed from the Beehold tube and inserted in the Greiner 50 ml blue cap tube in which the Beehold tube was transported. In this tube, 1.5 ml phosphate saline buffer was pipetted, along with one droplet of Tween 80. To dissolve the PEG into the buffer, the blue cap tubes were horizontally placed in a rotator and agitated for at least 15 minutes at room temperature. An aliquot of 500 µl of the PEG/phosphate buffer mixture was taken for pollen identification. The remainder of the PEG/phosphate buffer mixture was then pipetted into 12 ml sterile tubes and transported immediately to the microbiology laboratory.

### *2.7 Pollen Determination & Functionality of the Beehold Tube*

Presence of pollen demonstrated on the Beehold tube's PEG layer demonstrated its functionality. The botanic origin of the pollen reveals where foragers visit. The 1.5 ml Eppendorfer tubes with 500 µl rinsing fluid of sacrificially-sampled honey bees and the 1.5 ml Eppendorfer tubes with the 500 µl mixture of PEG/phosphate buffer, were centrifuged for 10 minutes at 14000 rpm to concentrate pollen. After centrifuging, the aliquot was poured off and the remaining pellet was re-suspended in the remaining approximately 40 µl supernatant. Next, 10 µl of the supernatant was pipetted on a microscope slide, dried at 70$^{o}$C on a temperature controlled heater, covered with fuchsine stained gelatin/glycerine (Kaiser), sealed with a microscope cover glass and stored at room temperature until microscopic determination.

### *2.8 Detection of Erwinia Pyrifoliae*

Recovery and population size of *E. pyrifoliae* on the honey bee body were determined by diluting a 20 µl aliquot of extract on Yeast Peptone Glucose (YPG) agar medium plates.. Plates were incubated for 2 to 3 days at 28°C so that they could be inspected for bacterial colonies with morphology similar to *E. pyrifoliae* colonies at 96 h. Positive and negative controls were included. Pure cultures of presumptive *E. pyrifoliae* isolates were identified using molecular testing (Wensing et al. 2011). Limit of detection (LOD) of *E. pyrifoliae* was set at 100 cells per reaction.

## 3 Results

### *3.1 Foraging Activity*

Observations showed a normal foraging pattern in the crop, with fluctuations in the foraging population.

### *3.2 Beehold Tube Functionality and Pre Sampling*

The hive-entering bees, sampled sacrificially prior to translocation from the apiary to the greenhouse, did not carry strawberry pollen, demonstrating the bees did not forage on strawberry prior to placement in the greenhouse. The colonies arrived in the greenhouse on March 16 and were first sampled on March 18. The March 18 samples did not contain strawberry pollen, showing that bees had not yet started to forage on the strawberry flowers in the greenhouse. A week later, the in-hive bees taken from the top bars did not contain strawberry pollen; however, the Beehold tubes did. This demonstrated foraging activity on the strawberry flowers. From April 1 onwards, all samples contained only strawberry pollen, showing the bees foraged exclusively on strawberry. Both mature and dry state of *Fragaria x ananassa* pollen was present, which is not abnormal in strawberry pollen (Dafni et al., 2012). Strawberry pollen in the Beehold tubes demonstrated hive-entering bees passed the Beehold tube.

### *3.3 Erwinia Pyrifoliae on Sacrificial Subsampled In-Hive Honey Bees*

On March 25, eleven days after introduction, and on April 1, in-hive bees of one of the two sampled colonies carried *E. pyrifoliae*. Again in both the April 8 and April 15 samples, the sampled replacement honey bee colonies also contained *E. pyrifoliae*.

### *3.4 Erwinia Pyrifoliae in the Beehold Tube*

From April 1 until the end of subsampling on April 15, the Beehold tube placed in front of the colony in which *E. pyrifoliae* was identified by sacrificial subsampling on March 25 also contained *E. pyrifoliae*.

## 4. Discussion and Conclusion

### *4.1 Foraging Activity in the Greenhouse, Bio Sampling and Colony Subsampling*

The four hectares foraging greenhouse area is a limited foraging area for honey bees compared to the 2800 hectares potential foraging area of a honey bee colony in the field. Therefore, foraging activity was lower compared to the activity in the field with optimal weather conditions. To what extent the in-greenhouse foraging activity was lower compared to the in-field activity has not been recorded nor were reliable references available. Our study demonstrated that honey bees foraged on the flowering strawberry within a greenhouse environment, and brought back pollen and viable *E. pyrifoliae* bacteria to the hive. As the sacrificially derived subsamples were pooled samples of 30 bees, it is unknown whether all bees in the sample carried *E. pyrifoliae*. Non-sacrificial subsampling with the Beehold tube is per definition qualitative, and will at most give a mean quantitative indication in case all hive-entering bees are counted. This was taken into account in the study set-up, aiming for a qualitative detection of the bacterium and not a quantitative detection and precise moment of influx of the bacterium. For the latter, with the applied sampling frequency, it is not possible to estimate the exact timing of the first influx of *E. pyrifoliae*. The in-hive physical exchange of particles on the bee's exterior among the bees in a colony occurs within days (Nixon & Ribbands, 1952). Furthermore, it is unlikely that all *E. pyrifoliae* bacteria brought in by the bees will be evenly distributed among bees in the colony. This likely depends on the number of bacteria to be distributed and the size of the colony; low numbers of bacteria brought in by the foragers in a big colony will likely result in heterogeneous distribution of bacteria.

*4.2 Beehold Tube's Functionality and Pre Sampling*

The identification of strawberry pollen (Figure 6) and the detection *E. pyrifoliae* in the PEG confirmed the Beehold tube's functionality as non-sacrificial subsampling tool. Based on the pollen, the bees foraged exclusively on strawberry during the study period. The pollen data show that honey bee colonies had not foraged on strawberry prior to translocation in the greenhouse, and once in the greenhouse, forager bees visited solely strawberry flowers in the greenhouse. In the pre-sampled colony of the first cohort colonies and in the first subsampled colonies on March 18, no *E. pyrifoliae* bacteria were detected, showing that this bacterium was not present in the sampled colonies translocated from the apiary to the greenhouse. Furthermore, it is unlikely that the colonies carried *E. pyrifoliae* before translocation because known host plants (i.e. *Pyrus* spp.) were not blooming at the time. In the Netherlands, *Pyrus pyrifolia* starts blooming mid-April. We accounted for this by translocating the colonies prior to this period.

Figure 6. PEG layer with pollen

*4.3 Detection of E. pyrifoliae in the Samples of the honey bee colony and estimation of the Timing of the Influx of E. pyrifoliae into the Colony*

In the honey bee colony, *E. pyrifoliae* bacteria were detected from March 25 and solely on one sampling location in the greenhouse. This may be the result of separate or interacting features such as bees of this colony visited more infected flowers than the other sampled colony, foragers of the colonies in the greenhouse were not homogeneously dispersed over the flowers, little influx of *E. pyrifoliae* bacteria, which was diluted by in-hive exchange to a non-detectable level, and the presence of *E. pyrifoliae* started on single spots and not all flowers are diseased. The latter was certainly the case as flowers showing symptoms of the *E. pyrifoliae* infection were heterogeneously distributed among the greenhouse. The grower estimated a 10% infection rate of flowers on April 15. Based on the known short viability of the related bacterium *E. amylovora* in a honey bee colony of some days (Wael, 1988), the data suggest a constant influx of new *E. pyrifoliae* bacteria from March 25. The second cohort of honey bee colonies placed in the greenhouse on April 3 were first sampled 5 days later. This sampling revealed *E. pyrifoliae*, and demonstrates that 4 days is sufficient for *E. pyrifoliae* to enter the hive by distributed among its workers.

*4.4 Sacrificial and Non-sacrificial Sampling of the Honey bee Colony for Detection of E. pyrifoliae*

The results show that sacrificial subsampling of in-hive bees was more sensitive compared to the Beehold tube. *E. pyrifoliae* was detected on in-hive bees prior to any symptoms of an *E. pyrifoliae* infection. Apparently sufficient bacteria were collected by the foraging bees to be detectable on the in-hive bee cohort in the period prior to any visible symptoms in the strawberry. With the Beehold tube, *E. pyrifoliae* detection coincided with the first visible symptoms of plant infection. Adherence of the bacterium to the PEG appeared to be insufficient to accumulate enough *E. pyrifoliae* bacteria for detection at this early stage of the infection. To improve non-sacrificial subsampling for bio sampling of *E. pyrifoliae* prior to the appearance of the ooze droplets, adherence of bacteria to the PEG and the intensification of the contact between PEG and hive-entering bees should be improved. The longevity of *E. pyrifoliae* on the honey bee's exterior is not known. Assuming the same survival period of *E. pyrifoliae* in a honey bee colony, the detection of *E. pyrifoliae* on March 24 indicates that foragers collected the bacterium from March 22.

In conclusion, the integration of pollination and bio sampling of plant pathogens by a honey bee colony is possible. Both sacrificial- and non-sacrificial sampling of honey bee colonies can be applied for qualitative bio sampling of *E. pyrifoliae* in strawberry greenhouse cultivation during flowering. *E. pyrifoliae* was detected via sacrificial subsampling of in-hive bees prior to visible symptoms of the infection in the strawberry flowers. Detection of *E. pyrifoliae* by non-sacrificial sampling with the Beehold tube was less sensitive, and coincided with the first visible symptoms of the *E. pyrifoliae* infection in the flowers. Future studies with other pollinating insects like bumble bees and application of the Beehold device may extend this combination of pollination and bio sampling.

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**References**

Atanasova, I., Kabadjova, P., Bogatzevska, N., & Moncheva, P. (2005). New host plants of *Erwinia amylovora* in Bulgaria. *Zeitschrift für Naturforschung C*, *60*(11-12), 893-898. https://doi.org/10.1515/znc-2005-11-1212

Bonn, W. G., & van der Zwet, T. (2000). Fire Blight The Disease and its Causative Agent*, Erwinia amylovora* (JL Vanneste ed.). *CABI Pub. Wallingford*, 37-53. https://doi.org/10.1079/9780851992945.0037

Bozic, J., & Valentincic, T. (1995). Quantitative analysis of social grooming behavior of the honeybee *Apis mellifera* carnica. *Apidologie*, *26*, 141-141. https://doi.org/10.1051/apido:19950207

Crailsheim, K. (1985). Distribution of haemolymph in the honeybee (*Apis mellifera*) in relation to season, age and temperature. *Journal of Insect Physiology, 31*(9), 707-713. https://doi.org/10.1016/0022-1910(85)90051-4

Dafni, A., Hesse, M., & Pacini, E. (Eds.). (2012). *Pollen and pollination*. Springer Science & Business Media.

Degrandi-Hoffman. G., Hoopingarner, R., & Baker, K. (1984). Pollen transfer in pear orchards: tree-to tree or bee-to-bee? *Bee World, 65*, 126-133. https://doi.org/10.1080/0005772X.1984.11098791

Degrandi-Hoffman, G., Hoopingarner, R., & Klomparens. (1986). Influence of honeybee (Hymenoptera: Apidae)in-hive pollen transfer on cross pollination and fruit set in apple. *Environmental Entomology, 15*(3), 723-725. https://doi.org/10.1093/ee/15.3.723

Delaplane, K. S., Steen, J. J. M. van der & Guzman-Novoa, E. (2013). Standard methods for estimating strength parameters of *Apis mellifera* colonies. *Journal of Apicultural Research, 52*(1), 1-12. https://doi.org/10.3896/IBRA/1.52.1.03

Eckert, C. D., Winston, M. L., & Ydenberg, R. C. (1994). The relationship between population size, amount of brood, and individual foraging behaviour in the honeybee, *Apis mellifera* L. *Oecologia*, *97*(2), 248-255. https://doi.org/10.1007/BF00323157

Free, J. B., & Williams, I. H. (1972). The transport of pollen on the body hairs of honeybees (*Apis mellifera* L.) and bumblebees (*Bombus* spp. L.) *Journal of Applied Ecology*, 609-615. https://doi.org/10.2307/2402458

Halbwirth, H., Gosch, C., Stich, K., Persen, U., Marco-Noales, E., Lòpez, M. M., ... Petrutis, K. (2014). Endbericht Forschungsprojekt Nr. 100867 (Phytfire): ERA-NET EUPHRESCO II: Methoden zum Nachweis von *Erwinia amylovora* zur phytosanitären Diagnose, raschen vor ort-Analyse und epidemiologischen Erfassung, Work Package 4: Vektor Monitoring. www.dafne.at

Hodges, D. (1974). Pollen loads of the honeybee: a guide to their identification by colour and form. London, Bee Research Association.

Kennedy, B. W., & King, T. H. (1962). Studies on epidemiology of bacterial angular leafspot on strawberry. *Plant Disease Reporter*, *46*, 360-3.

Kevan, P. G., Kapongo, J., Al-mazra'awi, M., & Shipp, L. (2008). Honey bees, bumble bees and biocontrol.

*Bee pollination in agriculture ecosystems. Oxford University Press, New York*.

Kovach, J., Petzoldt, R., Gary, E., & Harman, G. E. (2000). Use of honey bees and bumble bees to disseminate *Trichoderma harzianum* 1295-22 to strawberries for Botrytis control. *Biological Control, 18*(3), 235-242. https://doi:10.1006/bcon.2000.0839

Lukoschus, F. S. (1957). Quantitative Untersuchungen über den Pollentransport im Haarkleid der Honigbiene. *Zeitschrift für Bienenforschung, 4*, 1-19.

Nixon, H. L., & Ribbands, C. R. (1952). Food transmission within the honeybee community. *Proceedings of the Royal Society of London. Series B-Biological Science, 140*(898), 43-50. https://doi.org/10.1098/rspb.1952.0042

Paalhaar, J., Boot, W. J., Steen, J. J. M. van der, & Calis, J. N. M. (2008). In –hive pollen transfer between bees enhances cross-pollination of plants. In Proc. *Neth. Entomol. Soc. Meeting, 19*, 53-58.

Pernal, S. F., & Currie, R. W. (2001). The influence of pollen quality on foraging behavior in honeybees (*Apis mellifera* L.). *Behavioral Ecology and Sociobiology*, *51*(1), 53-68. https://doi.org/10.1007/s002650100412

Porrini, C., Sabatini, A. G., Carpana, E., Alexandrova, M., Medrzycki, P., Bortolotti, L., ... Girotti, S. (2002). Studi sul ruole delle api nella disseminazione del batteria *Erwinia amylovora* e come bioindicatori della presenza de fitopatogene nell'ambiente. In *Proceedings of the XIX Italian national Congress of Entomology* (pp1309-1318).

Wadl, P. A., Skinner, J. A., Dunlap, J. R. Reed, S. M., Rinehart, T. A., Pantalone, V. R., & Trigiano, R. N. (2009) Honeybee-mediated controlled pollination in *Cornus florida* and *C. kousa* intra- and interspecific crosses. *Horticultural Science, 44*(6), 1527-1533

Wael, de L. (1988). De honingbij als mogelijke vector van *Erwinia amylovora* (Burr). Proefschrift Faculteit van de Landbouwwetenschappen Gent.

Wenneker, M., & Bergsma-Vlami, M. (2015). *Erwinia pyrifoliae*, a new pathogen on strawberry in the Netherlands. *Journal of Berry Research*, *5*(1), 17-22.

Wensing A., Gernold M., & Geider K. (2011). Detection of *Erwinia* species from the apple and pear flora by mass spectroscopy of whole cells and with novel PCR primers. *Journal of Applied Microbiology, 112*, 147-158. https://doi.org/10.1111/j.1365-2672.2011.05165

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# Exploring Opportunities for Enhancing Innovation in Agriculture: The Case of Cocoa (*Theobroma cacao L.*) Production in Ghana

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**Abstract**

An exploratory study was conducted to identify opportunities to enhance innovation in the cocoa sector in Ghana. The specific objectives were to identify the key stakeholders in the cocoa industry, and elicit farmers and other stakeholders' perceptions on cocoa production and marketing practices, as well as the inherent constraints and opportunities. The study involved literature review of published information and the use of Participatory Rural Appraisal (PRA) tools such as focus group discussion, problem tree analysis, seasonal calendar, and ranking techniques to elicit information from the respondents and purchasing clerks in the Eastern and Western Regions of Ghana. The problem tree analysis indicated that low cocoa incomes were due to low cocoa yields which were in turn caused by high incidence of pest and diseases such as capsids/black pod/cocoa swollen shoot virus disease (CSSVD), declining soil fertility and use of unapproved planting materials. The seasonal calendar analysis indicated that most cocoa farmers were financially constrained, experience high labour availability and cost from May to July during which farm activities are high. Based on the study, researchers recommend that the Ghana Cocoa Board (COCOBOD) intensifies its efforts in implementing the opportunities such as crop/livelihood diversification, provision of crop insurance against risk, etc. identified to enhance farmers' welfare and the development of the entire cocoa industry. Addressing these constraints requires collaboration among the various stakeholders in the sector, including the government, research and extension as well as smallholder farmers.

**Keywords:** agriculture, exploratory survey, constraints, opportunities, innovation, cocoa, production, marketing, Ghana

## 1. Introduction

### *1.1 Background*

Agricultural development and poverty reduction require agricultural growth in productivity and incomes in rural communities. To achieve this, technologies and research findings must be shared with farmers and other stakeholders in the rural economy (Asenso-Okyere *et al*., 2008; Birner *et al*., 2006). Cocoa production has been a rural agricultural activity in Ghana and cocoa is an important cash crop to the economy of the country (MASDAR, 1998). It has contributed immensely to the socio-economic development of the country through the use of the foreign exchange and tax revenues earned by the government, the incomes obtained by cocoa farmers and other workers in the cocoa industry. According to MASDAR report (1998), cocoa cultivation is influenced by many factors and power relationships. These include various types of labour contracts, intra-household relations and indigenous land tenure systems. They are also closely linked to traditional political systems.

After introduction in the country, cocoa production was rapid with the first cocoa export occurring in 1885, and reached its peak of 568 000 tonnes in 1965, after which it started to decline until 1982 with an output of 159 000 tonnes in 1983/84 (Fig. 1) when drought and bush fires were intense (MASDAR, 1998). The decline in cocoa output, which affected the exported volumes (Fig. 2) and revenues, was attributed to the fact that the cocoa sector faced many internal problems some of which impacted the entire economy. These problems included: increasing disease problems exacerbated by lack of chemicals and machinery to apply them; an aging tree stock;

successive droughts in the late 1970s and early 80s; a rapidly deteriorating transport infrastructure which added to the inefficiencies of overstaffed marketing organization; and low producer prices that increased attractiveness of essential food crops and other perennial crops. Until the end of the wartime years cocoa farmers received world market prices less deductions for handling, freight and margins for the merchants (Ofosu, 1995). The Cocoa Marketing Board, now Ghana Cocoa Board (COCOBOD), currently playing regulatory role in the cocoa industry, was established in 1947 to stabilize producer prices and provide marketing services to the farmers.

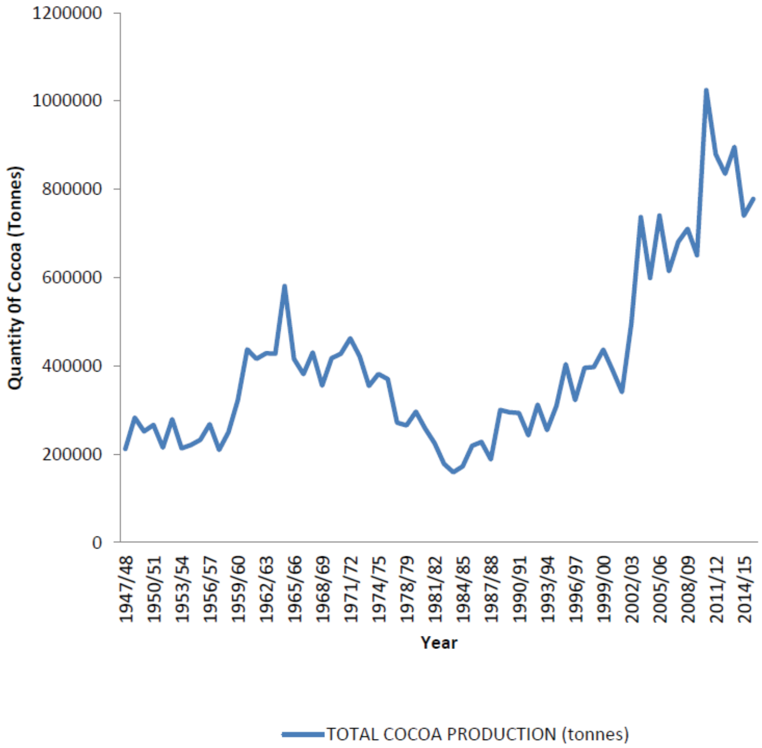


Figure 1. A Chart of Annual Cocoa Production Trend

Source: Ghana Cocoa Board (COCOBOD)

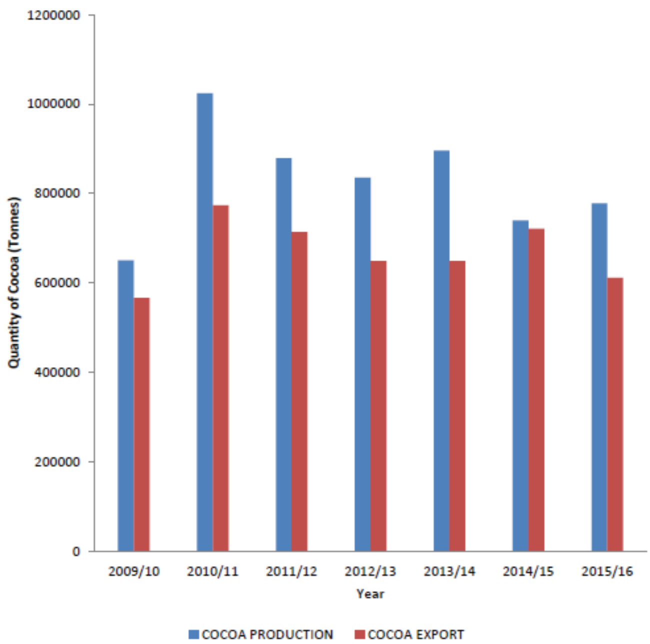


Figure 2. Annual Values of Cocoa Production and Export

Source: Ghana Cocoa Board (COCOBOD)

Overall cocoa production has recently been increasing, but output per unit area is still low (400 kg/ha) compared with that of other producing countries such as Cote d'Ivoire (1 000 kg/ha) and Malaysia (800 kg/ha). This increased yield was achieved through the implementation of Cocoa Disease and Pest Control (CODAPEC) and Cocoa High Technology (Hi-tech) programmes by Ghana Cocoa Board (COCOBOD) in response to the low adoption of CRIG technologies by the cocoa farmers (Henderson & Jones, 1990; Donkor et al*.,* 1991; MASDAR, 1998; Aneani et al*.*, 2007). The low adoption may be due to linear transfer of the technologies to the farmers; that is, the modified Training and Visit system of technology and knowledge transfer involving Research-Extension-farmer linkage. This system placed too much emphasis on technical innovations to increase cocoa production and productivity (Asenso-Okyere et al., 2008; Hounkonnou et al., 2012).

Akerlof (1970) believes that institutions are developed to counter the negative impacts of the dealings among the stakeholders or actors such as asymmetric information. According to Johnson (1992), institutions are sets of habits, routines, rules, norms, and laws, which regulate the relations between people and shape human interactions. By reducing uncertainty and, therefore, amount of information needed for individual and collective action, institutions are fundamental building blocks in all societies. Institutions give incentives to economic agents to act in certain ways which are beneficial to them (Klein, 1996). This is obtained by lowering the uncertainty around technology application, cost of transactions and protecting property rights.

Convergence of Science: Strengthening Innovation Systems (CoS-SIS) is a follow-up of a previous research programme (2001-2006), "Convergence of Science" (CoS), which emphasized the use of participatory technology development (PTD) to enhance smallholder livelihoods (Van Huis et al., 2007). Though the application of PTD approach improved farmers' livelihoods by enhancing the adoption of technologies to increase production and hence incomes, there were uncontainable institutional factors which hampered opportunities for smallholders to obtain the benefits of PTD (Hounkonnou et al., 2012). Therefore, CoS-SIS experimented on how institutional change might open opportunities for farmers to gain from PTD. In the quest for institutional factors and other constraints in the cocoa industry, this exploratory study was commissioned as a collaborative study between CRIG and CoS-SIS programme of University of Ghana.

Cocoa was selected for the following reasons: National priority crop because of its potential for reducing poverty; it has a wide geographical coverage as it can be cultivated in six out of the ten administrative regions of the country; and it is a cash crop.

### *1.2 Objectives of the Study*

The main objective of the study was to identify opportunities [an opportunity is defined here as a potential for a group of people to capture value, either through a change in their practices to exploit existing conditions or a change in institutional conditions that allow them to respond from their existing practices or both (Adjei-Nsiah et al., 2012)], challenges and factors that constrain the cocoa sector for solution. This will encourage investment in increased production, improved agricultural and environmental practices, reduce poverty, and enhance food security among smallholder farmers in Ghana.

The specific objectives were to:

Identify the key stakeholders in the cocoa industry.

Determine the nature of farmers and other stakeholders' perceptions on cocoa production and marketing practices.

Identify and assess the inherent constraints and opportunities.

## 2. Methodology

An exploratory study was conducted to test the CoS-SIS approach which adopts an interdisciplinary action research using an innovation system process in the study areas to identify technical, socio-economic, and institutional constraints in the cocoa industry for innovative solutions to provide cocoa farmers the opportunities for increased output and productivity. This design of the survey was adopted because of the exploratory nature and the fact that generally cocoa production is similar in all the cocoa growing regions.

### *2.1 Description of the Study Areas and Sampling Procedure*

The exploratory study was conducted in some cocoa districts of the Eastern and Western Regions from March to August, 2013. Those districts in the Eastern were Akim Oda and Suhum while that of Western were Dunkwa, Sefwi Essam and Boako (Table 1). The communities surveyed in the Eastern included Akim Oda, Akim Swedru, Anum Apapam and Brekumanso whilst that of the Western Region were Meretweso, Achiase, Kwamebikrom, Adabokrom and Punnikrom (Table 1). The Eastern Region was included in the study because it was in this region that cocoa was initially introduced and cultivated extensively in the country (MASDAR, 1998). Also, the reason for choosing the Western Region was that this region is currently the frontier of cocoa production after gradual shift from Eastern, Ashanti, Central, and Volta Regions of the country. The Western Region now produces about half of the total cocoa production in Ghana for export (MASDAR, 1998).

Table 1. Locations, number of focus group discussions and participating stakeholders (farmers & purchasing clerks)

| Region | District | Town/Village | Number of focus group discussions | Number of farmer participants | | Number of purchasing clerks participants | |
|---|---|---|---|---|---|---|---|
| | | | | Male | Female | Male | Female |
| Eastern | Suhum | Anum Apapam | 2 | 9 | 4 | - | - |
| | | Brekumanso | 2 | 12 | 1 | | |
| | Akim Oda | Akim Oda | 2 | 10 | - | - | - |
| | | Akim Sweduro | 2 | 10 | 4 | | |
| Western | Dunkwa | Meretweso | 1 | 16 | 1 | - | - |
| | | Achiase | 1 | 11 | 6 | - | - |
| | Sefwi Essam | Kwamebikrom | 1 | 14 | 1 | - | - |
| | | Adabokrom | 1 | 12 | 1 | - | - |
| | | Essam | 1 | | | 9 | - |
| | Boako | Punnikrom | 1 | | | 16 | - |
| Total | | | 14 | 94 | 18 | 25 | - |

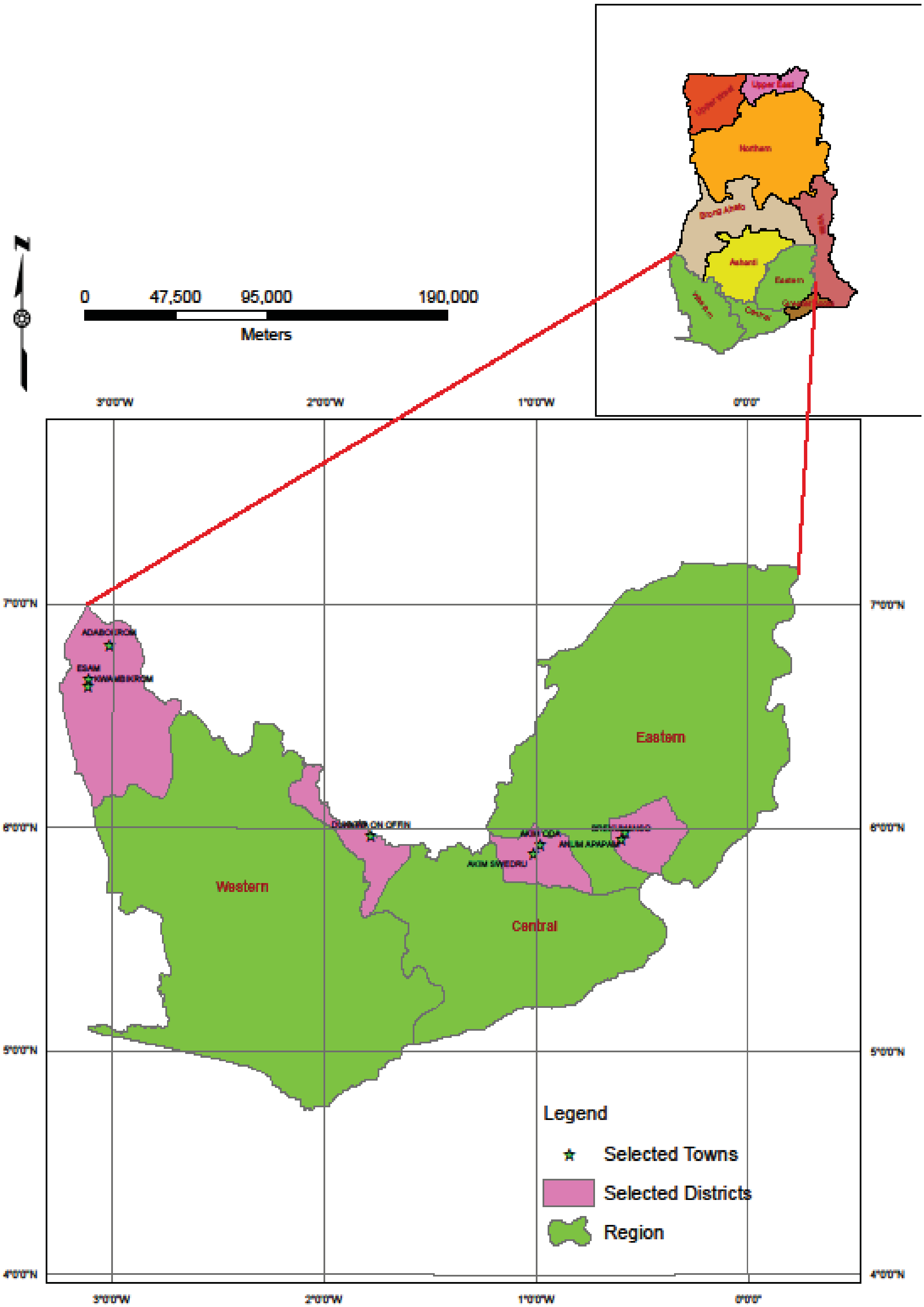


Figure 3. A map of Ghana indicating the regions, districts and communities surveyed

*2.2 Data Collection*

The study involved literature review and the use of Participatory Rural Appraisal (PRA) tools such as focus group discussion, problem tree, seasonal calendar, and ranking techniques to elicit information from the respondents and purchasing clerks in the study areas of Eastern and Western Regions of Ghana. Before the respondents were gathered into groups, the researchers contacted the chief farmer cocoa purchasing clerk in the community for briefing on the purpose of the survey, the types of information required, and the procedure for the discussion. Similarly, the groups were also briefed before the actual interview. Twelve focus groups of 10-17 farmers each were formed in four communities for the discussion using a checklist containing questions on input supply; technological, processing, marketing and institutional issues; and cocoa production constraints including illegal mining (*galamsey*). Another two focus groups of 6-10 purchasing clerks (PCs) of the various Licensed Buying Companies (LBCs) were formed in two communities for discussions on their operations and constraints, their relationship with the cocoa farmers, benefits/incentives farmers received from LBCs, and policy/institutional issues.

### *2.3 Data Analysis*

Data were analyzed employing stakeholder analysis, content analysis, scoring and ranking techniques. Seasonal analyses were also conducted on amount of rainfall, labour availability for farm activities and farmers' cocoa incomes and expenditures to determine patterns and constraints. The stakeholder analysis entailed identifying farmers, farmer associations and organizations affected by cocoa production issues that CoS-SIS project seeks to address. The stakeholders were categorized according to their interest or role in the cocoa industry. The content analysis was conducted to reveal the patterns and trends in the qualitative data collected during the focus group discussions. Constraints or problems face by farmers in cocoa industry were identified using problem tree analysis. This analysis involved the identification of the causes and effects of a specific problem which is assumed to be trunk of a tree, with the roots and leaves representing the causes and effects respectively. Then, the constraints were scored and ranked depending on degree of importance. In the scoring process, 20 stones were chosen to represent the number of identified constraints and the farmers scored each constraint by assigning a specific number of stones out of the total. The scores were averaged and ranked to determine the final position of a constraint among the others. Seasonal analyses were also conducted on amount of rainfall, labour for farm activities and farmers' cocoa incomes to determine patterns and constraints. The researchers did this by allowing the respondents to allocate a set of 15 stones among the months of the year, with number of stones given to each month representing the intensity.

## 3. Results

### *3.1 Stakeholder Analysis*

This study identified key stakeholders/actors in the cocoa industry with their specific roles, locations and relationships. They comprised Ghana Cocoa Board (COCOBOD) with the subsidiaries such as the Cocoa Marketing Company (Ghana) Limited (CMC), the Cocoa Processing Company Limited (CPC), the Cocoa Research Institute of Ghana (CRIG), the Cocoa Swollen Shoot Virus Control Unit (CSSVDCU), now renamed Cocoa Health and Extension Division (CHED), the Quality Control Company Ltd (QCCL); the Private Licensed Buying Companies (LBCs); cocoa farmers; and farmer association, with their specific roles, locations and relationships in the cocoa industry (Table 2). The relationship analysis demonstrated that there are dependency and cooperation among the stakeholders. These relations involve forward and backward linkages. Forward linkage represents the provision of inputs into the cocoa production process while backward linkage entails the utilization of the output through value addition to produce cocoa butter and liquor which are used in the confectionery and cosmetic industries.

Table 2. Stakeholders and their functions in the cocoa industry

| No. | Name Stakeholder | Function/Role played in the cocoa industry | Location of Head Office | Relationship with other institutions |
|---|---|---|---|---|
| 1 | Ghana Cocoa Board (COCOBOD) | COCOBOD is a statutory public board established by Ordinance in 1947. In line with the liberalization policy of the Government, COCOBOD now formulate policies, monitors and regulates the operations of the cocoa industry in Ghana. | Accra | 2; 3; 4; 5; 6; 7; 8; 9 |
| 2 | The Cocoa Marketing Company (Ghana) Limited (CMC) | CMC is responsible for the external marketing of cocoa beans as well as cocoa liquor, cocoa butter and cocoa cake, produced by the Cocoa Processing Company Limited. | Tema | 1; 3; 6 |
| 3 | The Cocoa Processing Company Limited (CPC) | CPC processes raw cocoa beans into semi-finished products such as cocoa butter, liquor, cake or powder. It also manufactures Golden Tree Brand Chocolate, Couverture "Pebbles" and Vitaco Instant Chocolate Drink. | Tema | 1; 2; 6; 8 |
| 4 | The Cocoa Research Institute of Ghana (CRIG) | CRIG investigates problems of diseases and pests of cocoa, kola, coffee, sheanut, cashew and the tallow tree (Pentadesmabutyracea), soil fertility, and good agricultural practices, develop planting materials for use by farmers e.g. cocoa seedlings/clones and coffee clones, with the view to increasing yield and farmers' income; and conducts research into the development of other products from cocoa waste and by-products. | New Tafo-Akim | 1; 5; 7; 9 |
| 5 | The Cocoa Swollen Shoot Virus Disease Control Unit (CSSVDCU), now renamed as Cocoa Health and Extension Division (CHED) | CSSVDCU/CHED is responsible for the control of cocoa swollen shoot virus disease and cocoa extension. | Accra | 1; 4; 7; 9 |
| 6 | The Quality Control Company Ltd (QCCL) | QCCL is responsible for inspection, grading, and sealing of cocoa, coffee and sheanut for export; and for fumigation and storage of cocoa. | Tema | 1; 2; 3; 8 |
| 7 | The Seed Production Unit (SPU) | The SPU is responsible for the multiplication and distribution of improved cocoa and coffee planting materials to farmers. | Accra | 1; 4; 5; 9 |
| 8 | The Private Licensed Buying Companies (LBCs) and Hauliers | The LBCs are responsible for domestic purchasing and hauling of cocoa beans to the port for export. | Accra and Kumasi | 1; 2; 3; 9 |
| 9 | The farmers represented by Ghana Cocoa, Coffee and Sheanut Farmers Association (GCCSFA) | The farmers actually produce the cocoa at the farm level. The GCCSFA is responsible for the procurement and distribution of agro-chemicals (insecticides, herbicides and fungicides) and spraying machines. It also acts as a representative body to articulate farmers' opinions at national level. | Accra | 1; 4; 5; 7; 8 |

### *3.2 Cocoa Production*

### *3.3 Identification of Constraints and Opportunities in Cocoa Production and Marketing*

#### 3.3.2 Problem Tree Analysis

The results of the problem tree analysis conducted with the respondents (Fig. 3) indicated that low incomes of farmers from their cocoa farms was the effect of low yields which were caused by high incidence of pests and diseases such as capsids, black pod and CSSVD; declining soil fertility; and use of unapproved planting materials. Also, high incidence of black pod disease resulted from limited disease and pest control practices which were in turn caused by poor access to credit, high cost of inputs, inadequate access to other inputs/agro-chemicals and labour dynamics. The inadequate access to inputs/agro-chemicals was attributed to poor implementation of the mass spraying policy, that is, CODAPEC programme and late supply of inputs. This was mainly due to the non-liberalized input supply.

Low cocoa yields were caused by illegal mining, *Galamsey*, which was attributable to labour dynamics. Declining soil fertility was attributed to limited soil management practices which were in turn ascribed to inadequate knowledge. The inadequate knowledge of the farmers was also caused by poor/insufficient extension service.

Planting of unapproved materials was caused by inadequate access to approved seeds and seedlings which was in turn caused by limited resources of the Seed Production Unit (SPU). In addition, the limited access to approved seeds and planting materials was attributed to the policy of allocation to CSSVDCU farmers which in turn was influenced by inequity in distribution of seed gardens.

3.3.1 Seasonal Calendar Analysis

The results of the seasonality analysis conducted with the respondents are presented in Figure 4. Some explanations were given at Adabokrom about the patterns revealed by the seasonal calendar. From January to March the hired labourers had money and therefore would not want to offer their labour for money while the farmers' labour demand was also low due to low farm activities. However, from May to July, the labourers and farmers needed money and there were also high farm activities. For October, November and December, there were low rainfall, low farm activity, both farmers and labourers had money, and *nnoboa* (exchange labour) was mostly used. The implication of these explanations is that most cocoa farmers are financially constrained in hiring labour which is available from May to July during which there are high farm activities.

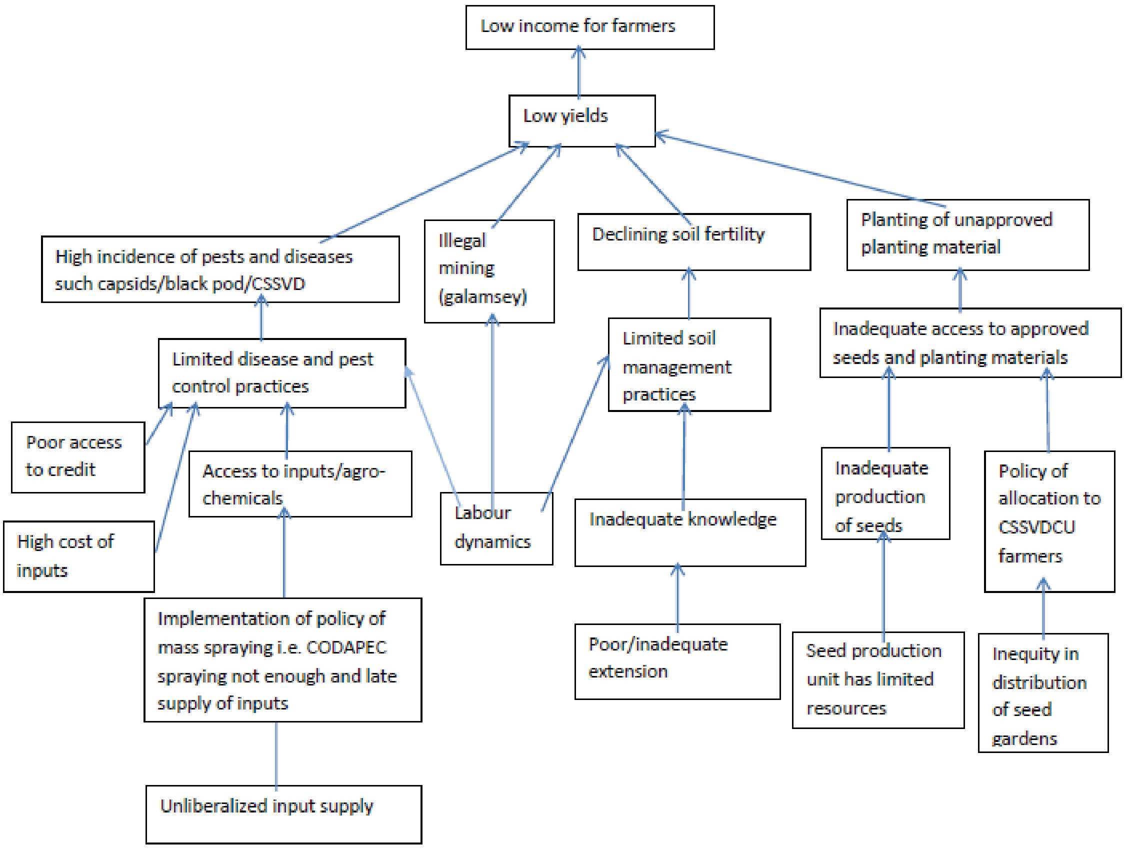


Figure 3. Problem tree diagram

Source: Exploratory survey (2013)

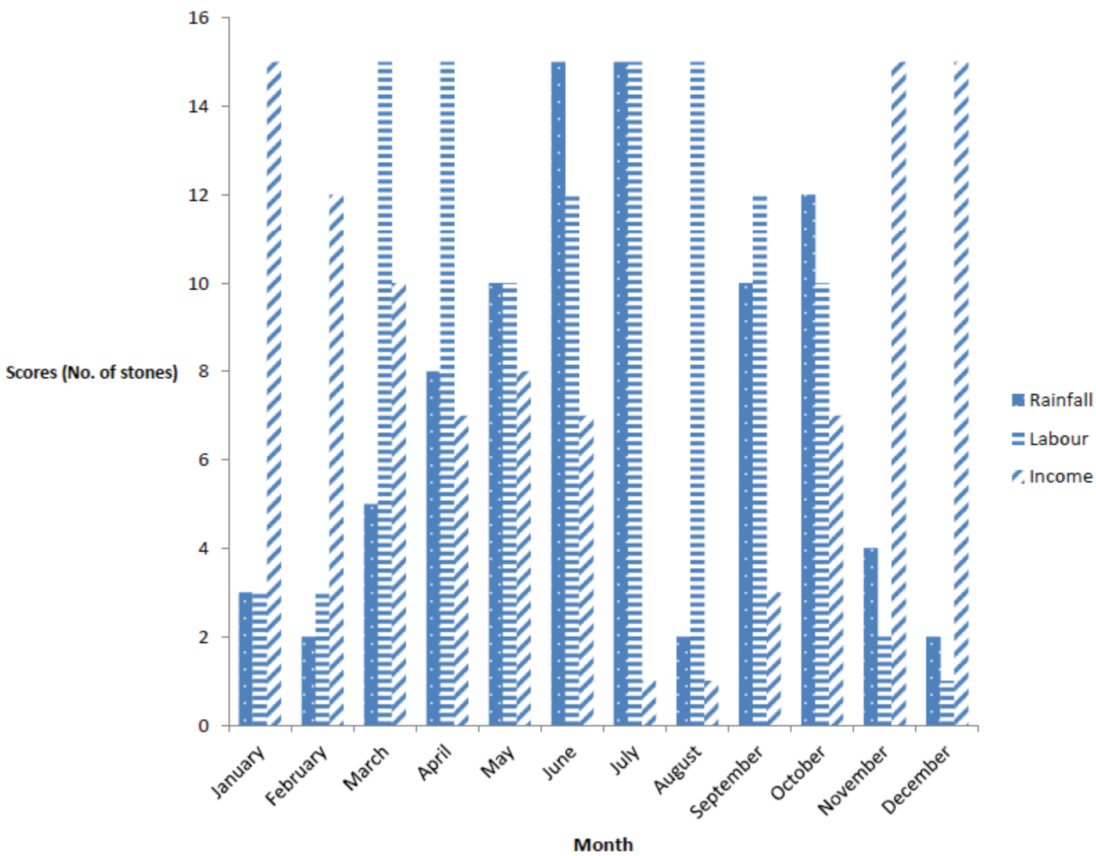


Figure 4. Seasonal calendar of rainfall, hired labour and income

Source: Exploratory survey (2013)

3.3.3 Perception of Participants on Cocoa Production Constraints/Opportunities

The respondents chose poor status of farming, low incomes, low employment opportunities and poor rural facilities as their most important constraints. However, poor health arising largely from poor standard of rural life and medical facilities was regarded as the least constraint (Appendix A, Table 1). The identified constraints of the participants were categorized into technical, socio-economic, social and institutional. The analysis of the scores and rankings of the constraints identified by the respondents indicated that they placed more emphasis on the socio-economic and social constraints than the technical and institutional ones (Table 3).

Table 3. Importance of technical, socio-economic, social and institutional constraints indicated by their average scores and rankings

| Category of constraints | Average score | Average ranking | Actual position/ranking |
|---|---|---|---|
| Technical | 189.9 | 21.1 | 3 |
| Socio-economic | 290.6 | 11.8 | 1 |
| Social | 225.2 | 16.9 | 2 |
| Institutional | 161.8 | 22.6 | 4 |

3.3.4 Policy/Institutional Issues

3.3.4.1 Perception of Farmer Respondents on Institutional Issues

According to the respondents in Brekumanso, there were several institutional factors such as taboos, values and norms which were laid down by their forefathers and they had been traditionally accepted by the communities. The taboos, values and norms sometimes caused delays in performing farm activities. For instance, certain days are prohibited for farming and this could delay timely application of chemicals to control pests and diseases.

The respondents also thought that government policies on inputs and pricing were major institutional constraints. Excessive bureaucracy within government sector caused delay in the supply of necessary inputs like fertilizers and seedlings and this impacted negatively on cocoa production. Lower producer price also negatively affected farmers' incomes and livelihoods.

3.3.4.2 Perception of Purchasing Clerk Respondents on Institutional Issues

The results of the focus group discussion with some cocoa purchasing clerks at Punnikrom and Essam in the Western Region are presented in Table 4. It can be deduced from the results evidence of operational and financial injustice the Purchasing Clerks (PC's) are subjected to by their licensed buying companies (LBC's). For instance, the PC's are made to pay the sealing and sieving costs instead of their LBC's when sub-standard cocoa was detected at the port by the quality control agents. Also, there was a concern of low amount of commission per bag of purchased cocoa paid to them. The PC's also responded to these injustices by malpractices such as adjustment of weighing scales to the detriment of the cocoa farmers. In addition, the results indicated inadequate incentives provided by the LBC's to their purchasing clerks and the farmers which negatively affected cocoa purchasing.

Table 4. Results of the focus group discussions with some cocoa purchasing clerks at Punikrom (Boako District) and Essam (Sefwi Essam District)

| Issue | Discussion |
|---|---|
| Operations of LBC's/PC's | From the discussion with the purchasing clerks in the Western Region, the respondents indicated that the Licensed Buying Companies (LBCs) and their Purchasing Clerks (PC's) were required by COCOBOD to purchase good quality cocoa beans for export. However, in the event of detecting a sub-standard cocoa at the port by the quality control agents after beans had been checked and sealed at the depot, only the PC's were made to bear the sealing and sieving costs instead of the LBCs. Also, the PC's had to attend meetings ("returns") every week at the district office for the collection of cocoa sacks and other obligations. All the transport expenses were borne by the PC's. Even some PC's pay for the cost of maintenance of the structure/warehouse use for cocoa purchases except for PBC. |
| Liberalization of internal cocoa marketing | The respondents stated that the liberalization of internal cocoa purchasing had led to competition among the PC's which had put farmers at the advantage and thus, refused to process their cocoa beans as expected, resulting in poor quality beans. It had also led some PC's to pre-finance the farmers who were expected to sell their cocoa beans to them, but unfortunately some of these farmers did not and even failed to repay the loans and therefore, put the PC's into debts. |
| Segregation of the cocoa beans | From the respondents, the segregation of the cocoa beans into flat, dark, black, and red beans posed some challenges to them. This was because the PCs sometimes could not get full bag of each of the above categories to be forwarded to the depot. Meanwhile the District Officers (DO's) after giving the money to the PC's expected in return the same number of bags per the amount given. Also, they could not send the 'add mixture' (a mixture of flat, black, red and dark beans) to the port since it would be rejected and the PC was surcharged with the resultant cost. Consequently, the PC's money for cocoa purchases became unavailable which affected cocoa buying. |
| Commission of the PCs on the purchased cocoa | The respondents expressed concern about the low commission paid to the purchasing clerks. Purchasing clerks received one kilogramme of cocoa beans or GH₵ 3.30 as a commission per every 64 kg (1 bag) of cocoa beans purchased.<br>The non-payment of salaries to the PCs had brought about a lot of cheating in the cocoa marketing system because PCs bore the cost of paying security persons and labourers who re-dried and bagged the cocoa beans. Moreover, any cost incurred at the port was brought back to the PCs to pay even if it was caused by the DO's or the Quality Control Division (QCD) staff who were involved in certification. All these expenses were part of their little commission of GH₵3.30 per bag. |
| Weighing scale adjustment | The respondents also explained that District Officers deducted two kilogramme worth of cocoa beans from every 64 kg bag of cocoa purchased by the PC. This amount was deducted before the District Officer gave the money for the cocoa purchases. This resulted in the problem of scale adjustment. It was assumed that the two-kilogramme deducted was meant to cater for other official expenses (e.g., transport cost of beans to the depot), but that cost should not be borne by the purchasing clerk who operated on commission basis. However, with Produce Buying Company (PBC), the two-kilogramme deduction by the District Officers was disbursed on the basis of one kilogramme for cocoa sealing and grading and the other one kilogramme was used as buffer for the payment of debts of the PC's, otherwise the money was reserved for the PC's. |
| Incentives for purchasing clerks and farmers | According to the respondents, provision of no incentives to both PC's and farmers by some LBC's discouraged them from working hard. Some companies/LBCs often provided inadequate incentives to the PC's and the farmers. The insufficient incentives made the sharing difficult and often led to conflicts between the PC's and the farmers, resulting in some PCs losing their customers (farmers). In addition, some PC's used their money to provide some incentives for the farmers just to sustain the business relationship. |

Source: Survey Data

## 4. Discussion

### *4.1 Stakeholder Analysis*

A stakeholder analysis is a process for identifying stakeholders, understanding how they relate to an activity, their interests and needs, in order to identify opportunities and potential threats (Gosling & Edwards, 2003). The study revealed the different actors/stakeholders in the cocoa industry and their respective roles played by them, locations and relationships among them. A stakeholder is a person, group or organizations with interests in or affected positively/negatively by an activity (cocoa production) (Gosling & Edwards, 2003). The linkages among the stakeholders are cooperative and dependencies, which are indicated by numbers. These stakeholders can assist in the identification of technical and institutional constraints or issues during stakeholder workshops and serve as sources of members to innovation platforms such as the Concertation and Innovation Group (CIG) of CoS-SIS to be established in the cocoa districts.

### *4.2 Problem Tree Analysis*

Problem Tree Analysis is a process of identifying the causes and effects of a problem by representing the causes, effects and problem with the roots, leaves and trunk of a tree, respectively. The problem tree analysis indicated that low cocoa incomes were due to low cocoa yields which were in turn caused by high incidence of pest and diseases such as capsids/black pod/CSSVD, declined soil fertility and planting of unapproved materials. The root causes of these situations were observed to be poor access to credit, high cost of inputs, inadequate and late mass spraying due to late supply of inputs caused by non-liberalized input supply, poor or inadequate extension, limited resources of the Seed Production Unit, and inequity in the distribution of seed gardens. These results show the persistent nature of the pest and disease constraints to cocoa production despite the dissemination of the recommended cocoa production technologies to farmers. This situation suggests the failure of the Training and Visit (T&V) system of technology transfer; that is, the linear transfer approach of farm innovations (Research-Extension-Farmer linkage) (Asenso-Okyere *et al*., 2008; Hounkonnou et al., 2012). In addition, the causes of the constraints appear to be mostly institutional (input/output marketing, credit provision and extension services) inadequacies in the implementation of policies and programmes.

### *4.3 Seasonal Calendar Analysis*

The seasonal calendar analysis has indicated that most cocoa farmers were financially constrained in hiring labour which was available from May to July during which farm activities were high. This circumstance implies that farmers might need credit for the farm maintenance in this period. Hence, there is the need for further institutional changes to increase the efficiency of the support systems of cocoa production to enhance adoption of the technical innovations by the farmers.

### *4.4 Ranking of Constraints*

Concerning the grouping and ranking of constraints into technical, socio-economic, social and institutional categories, although respondents appeared to emphasize more on socio-economic constraints, some of these constraints are seen to be institutional such as poor standard of cocoa buying and marketing as well as poor availability of planting materials (seedlings).

### *4.5 Illegal Mining (Galamsey)*

The respondents identified *Galamsey* as one of the major constraint to cocoa production. By definition, it is an illegal mining involving extracting minerals with the absence of land rights, mining license, exploration and mineral transportation permit or any document that could legitimise the mining operations. In Ghana, land rights are held by the stool and families and concessions are granted to the illegal miners by the landowners, family heads and recently by individual family members. *Galamsey*, meaning “gather and sell” has gradually become serious problem in the areas that the miners operate. The problem involves environmental degradation including deforestation, land degradation, with water and air pollutions. Specifically, it can reduce cocoa yields and therefore cause economic insecurity because the topsoil which supports the growth of plants or a whole cocoa farm is destroyed. *Galamsey* is engaged in because of social and economic factors such as low income; lack of regulation enforcement; perverse incentives to avoid obtaining official land concessions for mining; and lack of education on environmental issues (Hilson, 2001). Though the communities highly appreciate the cash flow that illegal mining can bring, increased levels of social and medical ills, and disrespect for the rule of law are consequences associated with this mining (Amponsah-Tawiah & Dartey-Baah, 2011). The *galamsey* operators claim that their activities have guaranteed jobs for the youth and reduced crime rate among others in the mining communities. They seem to be careless about the danger their activities pose to the inhabitants and the environment. For example, their operations can lead to livelihood threats through environmental pollution including contamination with heavy metals such as cadmium and mercury and pollutants such as cyanide which have the potential of going into the atmosphere and leading to contaminated freshwater sources, drop in fish populations and declining crops yields (Hilson & Putter, 2005).

### *4.6 Innovation*

#### 4.6.1 Technical Innovations

The industry is supported with research by Cocoa Research Institute of Ghana which develops cocoa production technologies for adoption by farmers to increase cocoa output and yield per hectare. Technologies that have been developed encompass application of insecticides, fungicides, and herbicides to control capsids/mirids (Awudzi et al., 2009; Awudzi et al., 2012), black pod disease (Opoku et al., 2004; Opoku et al., 2007), and weeds, respectively (CRIG, 2014). There is also the cutting out and burning of cocoa trees infected with cocoa swollen shoot virus disease (CSSVD) (Domfeh et al., 2008; Ameyaw et al., 2013). Others include fertilizer application to replenish depleted soil nutrients of old cocoa soils (CRIG, 2011; CRIG, 2014), and the use of improved planting materials in the form of hybrid seeds/seedlings to enhance yields (CRIG, 2007). There is also the utilization of fermentation trays and boxes to ferment cocoa beans for improved quality (CRIG, 1996; Aneani & Asamoah, 2004; Anim-Kwapong et al., 2007; Adzaho et al., 2015).

#### 4.6.2 Institutional Innovations

The cocoa sector is one of the few with strong policies for effective management of the industry. There are clearly formulated policies and regulations to guide actors roles and actions completely from planting the seedlings through the tedious activities of cultivating the crop to harvesting and going into internal marketing and then through the ports to the external buyers. Some forms of institutional innovations emerged from the exploratory study of the cocoa sector. The Government/COCOBOD has implemented a number of policies and interventions in the cocoa sub-sector of the economy. These include cocoa producer price policy; cocoa pest and disease control programme (CODAPEC), that is, mass spraying exercise; Cocoa High Technology programme (Hi-Tech); Cocoa Swollen Shoot Disease Control (CSSVDC) programme; Mistletoe Removal programme; Cocoa Rehabilitation programme; cocoa extension public-private partnership; deregulation of the internal marketing; and promotion of organic and fair-trade cocoa

##### 4.6.2.1 Producer Price Policy

It is the policy of the government to adjust the cocoa producer price annually by COCOBOD as a percentage share of free on board (FOB) value to ensure a direct link between Ghana producer price and the world price. Also, this price adjustment is to achieve competitiveness of Ghana's in relation to prices in the neighbouring country (Ministry of finance, 1998). The main objectives of this pricing framework were to: improve upon farmers' real returns from cocoa to ensure the provision of adequate incentives for improved husbandry practices that will increase cocoa yields and output; maximize Ghana's foreign exchange earnings from cocoa while ensuring reasonable tax revenue for government; and providing adequate returns to other stakeholders. The Producer Price Review Committee (PPRC) is responsible for determination of producer price of cocoa considering US dollar, fluctuations in the exchange rate and the projected average exchange rate for the cocoa year. The major determinants of producer prices include international market prices, internal transportation, shipping periods, buying patterns, product quality, export taxes, packing and handling costs, farmers' cost of production and profit margins (COCOBOD, 2000). The constraints associated with the cocoa producer price policy are the problems of the Pan-Territorial system, namely, the bureaucracy cost of the system; farmers are paid the same price of cocoa irrespective of the grade of the cocoa beans and; encouragement of cocoa production in marginal forest areas at the expense of the environment and at high costs. The differential producer price in favour of that prevailing in the neighbouring countries causes cocoa smuggling (Ministry of finance, 1998)

##### 4.6.2.2 Cocoa Pest and Disease Control Programme (CODAPEC)

The CODAPEC programme was instituted by Government/COCOBOD to assist the cocoa farmers in the control of pests (capsids/mirids) (CRIG, 2006; CRIG, 2008) and diseases (black pod) (CRIG, 2006; CRIG, 2007; CRIG, 2008; CRIG, 2014) of cocoa in all the cocoa growing regions of the country in 2001/02 (Agyinah & Opoku, 2010; CRIG, 2011; CRIG, 2012). Additional aims were to train farmers and technical personnel on the cultural and chemical methods of pests and diseases control, educate and train local sprayers on safe pesticides application, increase farmers' income and reduce youth unemployment in the rural communities (Agyinah & Opoku, 2010). According to them, challenges of the CODAPEC programme include: lack of adequate co-operation from farmers; inadequate spraying gangs led to partial coverage of farms; lack of reliable statistical data on cocoa farmers and their farm sizes; charging of fees by some Spraying Gangs from farmers before farms were sprayed; and pilfering and diversion of inputs were the biggest challenges of the programme. Currently, CODAPEC continues to face challenges such as: late arrival of agro-inputs like chemicals (pesticides), fuel, motorized pneumatic spraying machines, etc.; late payment of allowances for CODAPEC sprayers; inadequate gangs; gang formation restricted to COCOBOD alone; huge cost of the programme; excessive involvement of politicians in the programme; and opinion leaders including some chief farmers 'hijack' the pesticides and other inputs (Agyinah & Opoku, 2010).

4.6.2.3 Cocoa High Technology Programme (Hi-Tech)

The Cocoa High Technology (Hi-Tech) programme was introduced by Government/COCOBOD in 2002/2003 season as a response to low soil fertility of cocoa farms because of prolonged depletion of plant nutrients in the soil by crop absorption (CRIG, 2011; CRIG, 2014). The programme entailed the provision of fertilizers such as *Sidalco* liquid fertilizer, *Cocofeed*, *Asaase wura* and Ammonium Sulphate ('Ammonia') to cocoa farmers for application to replenish the lost nutrients to increase cocoa output (CRIG, 2011). Currently, the Hi-Tech programme encounters some problems including: low subsidy on inputs, resulting in increased price of fertilizer; farmers do not stick to the recommended rates of application of the fertilizers; and late arrival of fertilizers. The latest fertilizer policy of the government, since 2014, has been the provision of free fertilizers to cocoa farmers to enhance its use on cocoa farms.

4.6.2.4 Cocoa Swollen Shoot Disease Control Programme

Currently, the Cocoa Swollen Shoot Virus Disease Control Unit (CSSVDCU) now renamed as Cocoa Health and Extension Division (CHED), previously the Cocoa Services Division (CSD), is responsible for the survey and control of the Cocoa Swollen Shoot Virus disease (CSSVD) (CRIG, 2014; Domfeh et al., 2008), and cocoa extension (COCOBOD, 2013). The Unit's activities include the removal and destruction of swollen shoot diseased cocoa trees from the farms and supply of CSSV resistant hybrid cocoa variety (CRIG, 2007) to the farmers for replanting. The Unit occasionally conducts rallies aimed at educating the farmers on the CSSVD to enable them to report such cases to the Unit for the necessary action to be taken. The CSSVD control programme has been facing some challenges including: opposition of some farmers to the cutting of the diseased trees because of lack of money to replant and to maintain the household, old age of some farmers who depend on the farm for survival, late payment of compensation as well as the land tenure systems, that is, caretaking/*abusa*/*abunu* systems (Aneani et al., 2013)

4.6.2.5 Mistletoe Control Programme

The mistletoe (*Tapinanthus bangwensis*) control programme was instituted in 2011. The purpose of this programme has been to remove all the mistletoes which are parasitic plants on cocoa trees (CRIG, 2012). Unfortunately, the contractors or team face problems such as lack of protective clothing especially goggles to protect the eyes and nose from the wood dust, insect bites, inadequate allowance paid to the casual workers for the mistletoe removal, weak standard pruners with lack of sharpening tool/file, non-payment of accommodation cost and traveling allowance (T&T) for the mistletoe team, leading to inefficient work, etc. (Aneani et al. 2013). Now the control programme has been integrated with the Cocoa Rehabilitation programme as a second component (COCOBOD, 2013).

4.6.2.6 Cocoa Rehabilitation Programme

The national cocoa rehabilitation programme was launched in Goaso, in the Brong-Ahafo Region by Ghana Cocoa Board (COCOBOD), on the theme: "Increased and Sustainable Cocoa Production for Enhanced Livelihood." The revamping programme started in the second quarter of 2011 and it is expected to continue to 2017. In the programme, Farmers are to register and be provided with the best seedlings and technical know-how to increase production and income levels in their various locations (COCOBOD, 2013). The project involves among other things, application of fertilizers, removal of mistletoes, cutting down over-aged and diseased trees, and replanting of farms with hybrid and high-yielding seedlings. There is also free supply of plantain suckers and economic tree seedlings so that after harvesting the cocoa, the farmers could also benefit financially from these species all year round (COCOBOD, 2013). The Government has put measures in place to ensure that cocoa trees planted more than 25 years ago are cut down, and the farmers would receive compensation for this. However, the establishment of new cocoa farms in the forest reserves is strictly not part of the rehabilitation programme. The 19 million-Ghana Cedi ($10 million) programme was expected to provide 20 million seedlings to farmers and create 2,000 jobs for the youth who will nurse the young trees (COCOBOD, 2013). However, farmers on the scheme complained of inadequate supply of seedlings and irregular payment of the compensation. The project has been encountering challenges including inadequate funds to support farmers to pay for labour cost and some difficulty in gaining the cooperation of some farmers in the diseased tree cutting process (Aneani et al., 2013).

4.6.2.7 Cocoa Extension

The Cocoa Services Division (CSD), now Cocoa Swollen Shoot Virus Disease Control Unit (CSSVDCU) which has been renamed as Cocoa Health and Extension Division (CHED), with its Head Office in Accra, controls the CSSVD in addition to providing extension services involving cocoa production technologies and best farm practices to farmers to solve problems and to obtain knowledge and information, skills, and technologies to improve their livelihoods and well-being (Asenso-Okyere *et al*., 2008; Birner *et al*., 2006). Traditional and unified extension services were criticized for being supply-driven, not driven by the users (farmers); highly centralized; non-participatory (dominated by a single channel of knowledge transfer); exclusive of the poor; inefficiency etc. (Asenso-Okyere, *et al*., 2008; Birner *et al*., 2006; Barrientos *et al*., 2008). In June 1998, Government of Ghana decided that the extension services of Ministry of Food and Agriculture (MoFA) and CSD be unified to reduce costs and improve efficiency in the delivery of extension services to farmers. Subsequently, a committee was put in place to draw up modalities for the merger. Government was to provide adequate financial logistic support to MoFA to enable it to provide effective agricultural extension services to the farmers (COCOBOD, 2001). Under this merger cocoa extension was inadequate due to insufficient logistic support.

Currently, a new cocoa extension programme, the Cocoa Extension Public-Private Partnership (CEPPP), has been introduced since 2011 to disseminate latest cocoa production technologies available to farmers (COCOBOD, 2012; COCOBOD, 2013). The operation of the new system is based on the principle of lean staff number who are professionally trained and highly qualified and motivated to deliver cost-effective and efficient cocoa extension service to business-oriented farmers ready to demand services and be owners of cocoa extension. The objectives of the CEPPP are to: provide an efficient and cost-effective extension to cocoa farmers to increase their productivity; assist farmers to acquire knowledge and skills to be able to adopt good agricultural practices (GAP); orientate and train cocoa farmers in basic farm economics for them to consider cocoa farming as a rewarding business; educate and encourage farmers to own cocoa extension; encourage the youth to take cocoa cultivation; strengthen Farmer Group (FGs) to access inputs/credits; build the capacity of extension staff to deliver training to farmers; and build the capacities for effective monitoring and evaluation (COCOBOD, 2012; COCOBOD, 2013) .

According to COCOBOD (2012) and COCOBOD (2013), the public sector partners of the CEPPP comprise Ghana Cocoa Board and its subsidiaries such as Cocoa Swollen Shoot Virus Control Unit (CSSVDCU), Cocoa Research Institute of Ghana (CRIG), Quality Control Co. Ltd (QCCL), Seed Production Unit (SPU). The private sector partners consist of Kraft Foods (Cadbury), West African Fair Fruit (WAFF), World Cocoa Foundation/Cocoa Livelihoods Programme (WCF/CLP) and allied agencies, Armajaro Ghana limited, Rainforest Alliance and Farmers. These partners fund the recruitment, remuneration, and training of the extension agents. Also, they jointly provide for training materials, publications and the cost of training farmers. In addition, *Deutsche Gesellschaft für Internationale Zusammenarbeit* (GIZ) GmbH/ Sustainable Cocoa Business in collaboration with the other partners support the training of farmers in Farmer Business School (FBS) and the design of extension tools. The CSSVDCU co-ordinates CEPPP and supported by partners and stakeholders. Also, the National Steering Committee for cocoa extension oversees the new Cocoa Extension system. The Cocoa Research Extension Technical Committee (CRETEC) ensures effective link between Farmer-Extension-Research (MASDAR, 1998; COCOBOD, 2001). Additionally, the Monitoring Unit at CSSVDCU and the Evaluation Unit at Cocoa Research Institute of Ghana, Social Science and Statistics Unit compile and evaluate data on the progress of the partnership's activities. As achievements since 2010, the CEPPP has documented all the technologies developed by CRIG into a cocoa sourcebook as its knowledge base (Opoku-Ameyaw et al., 2010). In addition, the programme has developed innovative extension tools of technical advice with management and social issues. The CEPPP has also adopted the Farmer Business School (FBS) Approach developed by GIZ in the framework of Cocoa Livelihoods Programme for the strengthening of farmers' capacities to understand the income potential of improved production techniques of cocoa and food crops (COCOBOD, 2012).

Another programme under the formation of public-private partnerships (PPPs) in cocoa extension is the Cadbury Cocoa Partnership. This partnership links the COCOBOD and Cadbury International to implement extension services in selected cocoa-producing communities to improve cocoa production. The main goals of the partnership are to: promote sustainable livelihoods for one million cocoa farmers; increase crop yields for farmers participating in the programme by 20 percent in 2012 and 100 percent in 2018; create new sources of income in 100 cocoa –farming communities in Ghana; and deal with major issues affecting the cocoa sector such as child labour, health, gender diversity, and environmental sustainability.

4.6.2.8 Deregulation of the Internal Marketing

A key institutional reform was the deregulation of the internal marketing of cocoa with the promotion of private involvement to allow competition. Also, the private involvement was meant to introduce efficiency into the market.

4.6.2.9 Promotion of Organic and Fair-trade Cocoa

Another institutional change was the promotion of farmers' involvement in the production of organic and fair-trade cocoa which attract higher premiums on the export market.

**5. Conclusions and Recommendations**

Conclusions drawn from the findings of this study are as follows:

- This study identified key stakeholders/actors such as Ghana Cocoa Board (COCOBOD) with the subsidiaries; the private licensed buying companies (LBCs); private processing companies; cocoa farmers; and farmer association, with their specific roles in the cocoa industry.
- Cocoa production activities identified could be categorized into farm establishment operations (including land acquisition, land clearing and preparation, lining and pegging of the farm, nursing of the seedlings in the nursery for later transplanting to the field, and planting at stake of cocoa seeds), farm maintenance operations (including manual weeding /herbicide application; pruning; capsid control, that is, spraying insecticides against capsids; black pod disease control, that is spraying fungicides; fertilizer application; shade management; and mistletoe control) and primary processing activities (including harvesting of cocoa pods, pod gathering and heaping, pod breaking, fermentation, removal of fermented beans, and drying of cocoa beans).
- Some cocoa production and marketing constraints were identified and the key constraints were: Black pod disease; Pests and parasites; Cocoa swollen shoot virus disease (CSSVD); Infrequent and inadequate extension service; Declined soil fertility; Marketing constraints; Lack of credit to farmers; High cost and unavailability of farm inputs; Illegal mining (*Galamsay*); and Inadequate seedlings/planting material supply

Recommendations based on the findings of this study include:

- The number of seed gardens should be increased and equitably distributed in cocoa districts and adequately resourced by Government/COCOBOD to enable them to produce sufficient hybrid seed pods. This would enhance the farmers' access to hybrid pods and reduce the possibility of planting unapproved seeds and planting materials.
- More extension agents should be employed, trained, well-resourced and adequately supervised to ensure effective, efficient and timely dissemination of improved cocoa production practices/technologies such as application of pesticides and fertilizers to the farmers for adoption.
- To increase the adoption rates of the improved production practices/technologies, Government/COCOBOD should encourage farmers to form village level associations which could provide some guarantee of payment and simultaneously encourage rural banks to provide effective, efficient and adequate credit through such arrangements.
- Government/COCOBOD should completely liberalized the chemical input and spraying machine supply by encouraging private sector participation and assisting these small businesses in underwriting loans, licensing, publicity, training, and ensuring reasonable input prices. This would increase accessibility and timely supply of inputs/agro-chemicals and enhance adequate implementation of improved disease and pest control practices at the right time by farmers.
- Illegal mining (*Galamsay*) causes much destruction to cocoa farms and adds to the uncertainty that farmers face when choosing to plant cocoa. Efforts should be made to identify illegal miners and to record cases where compensation has not been paid by legal concession holders. The misery that miners inflict on farmers in addition to the damage they cause to the soil means that punishment should be severe enough to serve as deterrent instead of the small financial compensations that are agreed on. Land rights are held by the stool and concessions are granted to the illegal miners by the landowners. If government could control illegal mining, only a proportion of the value of the gold would need to be paid to farmers without transferring rights from stool or concession holders. The illegal miners should be made to rehabilitate or reclaim the destroyed lands which are suitable for cocoa production. However, considering the negative impact on the ecosystem, the national economy, farmer insecurity at old age,

the inability to reclaim mined lands, water pollution, high cost of living in mining communities, health hazards and other possible threats to the cocoa industry, it is therefore not prudent for mining to be allowed on cocoa farms.

- The Cocoa Swollen Shoot Virus Disease (CSSVD) is an important disease which has no chemical cure, but the only remedy is cutting out of the diseased trees and their immediate contiguous ones. Therefore, Government/COCOBOD should improve the transparency, efficiency and timeliness of the tree cutting and ex-gratia payment. In addition, mass campaign/awareness building on the presence of the disease based on symptom identification and promotion of better agronomic practices should be continued.
- Market constraints such as weighing scale adjustment, low cocoa producer price, malpractices of the DOs and PCs of the LBCs, poor drying and admixture of beans by some farmers that compromise the quality of cocoa, etc. should be addressed by Government/COCOBOD in collaboration with the LBCs, PCs and farmers. For instance, the effort being made in the introduction and piloting of the weighing stone concept should be intensified and its usage made mandatory to the LBCs in their purchasing of cocoa.
- The Government/COCOBOD should intensify its efforts in implementing the opportunities identified in this study to enhance farmers' welfare and the development of the entire cocoa industry. Addressing these constraints requires collaboration among the various stakeholders in the sector, including the government, research and extension as well as smallholder farmers. Promoting cocoa sector development in Ghana requires institutional conditions that will encourage smallholder cocoa farmers to use modern technologies of production and marketing to improve their incomes.

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**References**

Adjie-Nsiah, S., Sakyi-Dawson, O., & Kuyper, I. W. (2012). Exploring opportunities for enhancing innovation in agriculture: the case of oil palm production in Ghana. *Journal of Agricultural Science, 4*(10), 212-223. https://doi.org/10.5539/jas.v4n10p212

Adjinah, K. O., & Opoku, I. Y. (2010). The national cocoa diseases and pest control (CODAPEC): Achievements and challenges. Retrieved on November 24, 2010.

Adzaho, D.K., Opoku-Asiama, Y., Adu-Ampomah, Y., & Takrama, J. F. (2015). Effect of fermentation on nib acidity, fermentation index and residual anthocyanin content in dry cocoa beans. *Journal of the Ghana Science Association, 16*(1), 16-25.

Akerlof, G. A. (1970). The market for "lemons": quality uncertainty and market. *Journal of economics, 84*, 488-500. https://doi.org/10.2307/1879431

Ameyaw, G. A., Johnson Victress, Dzahini-Obiatey, H., & Domfeh, O. (2013). A manual on laboratory transmission, inoculation and indexing for cocoa swollen shoot virus disease (CSSVD). *Technical Bulletin No. 25*. New Tafo-Akim, Ghana: Cocoa Research Institute of Ghana (CRIG) (Ghana Cocoa Board). 23pp.

Amponsah-Tawiah, K., & Dartey-Baah, K. (2011). The mining industry in Ghana: A blessing or a curse. *International Journal of Business and Social Science, 2*(12), 62-69.

Aneani, F., & Asamoah, M. (2004). Socio-economic survey on cocoa fermentation in Ghana. *Journal of Ghana Science Association, 6*(2), 90-97.

Aneani, F., Adu-Acheampong, R., & Oppong, F. K. (2013). *Convergence of sciences strengthening agricultural innovation systems (CoS-SIS) institutionalization research programme: An exploratory study of the cocoa industry in Ghana*. A Final Report Submitted to National Co-ordinator, CoS-SIS Secretariate, Extension Department, College of Agriculture and Consumer Science, University of Ghana, Accra. 73pp.

Aneani, F., Anchirinah, V. M., Asamoah, M., & Owusu-Ansah, F. (2007). Baseline socio-economic and farm managements survey. A Final Report for the Ghana Cocoa Farmers' Newspaper Project. New Tafo-Akim, Ghana: Cocoa Research Institute of Ghana (CRIG) (Ghana Cocoa Board).

Anim-Kwapong, E., Appiah, M. R., & Osei-Bonsu, K. (2007). A review of the factors affecting the quality of processed cocoa beans in Ghana. *Journal of the Ghana Science Association, 9*(1), 106-119.

Asenso-Okyere, K., Davis, K., & Aredo, D. (2008). Advancing agriculture in developing countries through knowledge and innovation. Synopsis of an international conference, Washington, D.C.: International Food Policy Research Institute.

Barrientos, S., Asenso-Okyere, K., Asuming-Brempong, S., Sarpong, D., Anyidoho, N. A., Leavy, J., & Kaplinsky, R. (2008). Mapping sustainable production in Ghanaian cocoa. London, UK: Cadbury.

Birner, R., Davis, K., Pender, J., Nkonya, E., Anandajayasekeram, P., Ekboir, J., Mbabu, A., Spielman, D., Horna, D., Benin, S., & Cohen, M. (2006). From best practice to best fit: a framework for designing and analyzing agricultural advisory services. ISNAR Discussion Paper 5, Washinton, D.C., USA: International Food Policy Research Institute.

COCOBOD (2001). Proceedings of the one-day seminar on the CSD/MOFA extension merger held at Bunso Cocoa College, 14^TH^ May 2000, CSD/MOFA Extension Merger Monitoring Committee, Ghana Cocoa Board, Accra. June, 2001.

COCOBOD (2012). *Cocoa extension public-private partnership in Ghana*. A report on a refresher training, 9-10th February 2012 at Bunso Cocoa College, Accra: Ghana Cocoa Board (COCOBOD). 50pp.

COCOBOD (2013). Focus on CSSVD-CU-Part II: National Cocoa Rehabilitation Programme an Opportunity for Increased and Sustainable Cocoa Production for Enhanced Livelihood of the Cocoa Farmers. *Ghana Cocoa Board (COCOBOD) News*, December 2013 edition.

COCOBOD. (2000). Comments by COCOBOD management on the LMC International school of administration, University of Ghana Report on Liberalization of External Marketing of Cocoa in Ghana, January 2000, Ghana Cocoa Board, Accra.

CRIG. (1996). A guide to harvesting, fermentation, drying and storage of cocoa. Farmers Guide No. 7. New Tafo-Akim, Ghana: Cocoa Research Institute of Ghana (CRIG)

CRIG. (2011). Ghana cocoa farmers newspaper. Bi-annual Technical Information for Cocoa Farmers, Issue No. 007, New Tafo-Akim. Ghana: Cocoa Research Institute of Ghana (Ghana Cocoa Board)

CRIG. (2012). Ghana cocoa farmers newspaper. Bi-annual Technical Information for Cocoa Farmers, Issue No. 008, New Tafo-Akim, Ghana: Cocoa Research Institute of Ghana (Ghana Cocoa Board).

CRIG. (2014). Ghana cocoa farmers newspaper. Bi-annual Technical Information for Cocoa Farmers, Special Edition, New Tafo-Akim, Ghana: Cocoa Research Institute of Ghana (Ghana Cocoa Board),.

Domfeh, O., Johnson Victress, Dzahini-Obiatey, H. & Akumfi-Ameyaw, G. (2008). Cocoa swollen shoot virus disease and control. *Technical Bulletin No. 17*. New Tafo-Akim, Ghana: Cocoa Research Institute of Ghana (CRIG) (Ghana Cocoa Board). 20pp.

Donkor, M. A., Henderson, C. P., & Jones, A. P. (1991). *Survey to quantify adoption of CRIG recommendations.Cocoa Research Institute of Ghana (CRIG)*, Farming Systems Unit Research Paper No. 3, p29.

Gosling, L., & Edwards, M. (2003). *Toolkits: A practical guide to planning, monitoring, evaluation and impact assessment*. Development Manual. London, UK: Save the Children. 302-307.

Henderson, C. P., & Jones, A. P. (1990). Analysis of constraints to the adoption of CRIG recommendations in Offinso Districts: results and discussion. CRIG farming systems Unit Research. Paper No. 1 CRIG, Tafo, Ghana, p15.

Hilson, G. (2001). A contextual review of the Ghanaian small-scale mining industry. *A report commissioned by Mining, (IIED), 76*, 29.

Hilson, G., & Putter, C. (2005). Structural adjustment and subsistence industry: artisanal gold mining in Ghana. *Development and Change, 36*(1), 103-131. https://doi.org/10.1111/j.0012-155X.2005.00404.x

Hounkonnou, D., Kossou, D., Kuyper, T. W., Leeuwis, C., Nederlof, N., Roling, N., Sakyi-Dawson, O, Traore, M., & van Huis, A. (2012). An innovation systems approach to institutional change: smallholder development in West Africa. *Agricultural Systems, 108*, 74-83. https://doi.org/10.1016/j.agsy.2012.01.007

Huis, A. van, Hounkonnou, D., & Roling. N. G. (2007). Preface. *International Journal of Agricultural Sustainability, 5*, 89-90. https://doi.org/10.1017/CBO9780511611070.001

Johnson, B. (1992). "Institutional learning". In : B-A. Lundvall (ed.). *National Systems of Innovation*. London:

Pinter Publishers.

Klein, P. (1996). *New International Economics*. Ghent: Edward Elgar and University of Ghent.

MASDAR (1998). *Socio-Economic Study*. A Final Report, Accra, Ghana: MASDAR Consultants/ Ghana Cocoa Board (COCOBOD).

Ministry of Finance (1998). *Ghana cocoa sector development strategy.* Task force report, Accra, Ghana:Ministry of finance. pp 61.

Ofosu, S. B. (1995). Ghana's cocoa rehabilitation project in the context of the economic recovery programme/structural adjustment programme: how successful? Visiting Research Fellow Series No. 251, Tokyo: Institute of Developing Economies.

Opoku, I. Y., Assuah, M. K., & Domfeh, O. (2007). Manual for the Identification and Control of Diseases of Cocoa. Technical Bulletin No. 16, Cocoa Research Institute of Ghana (CRIG), New Tafo-Akim, Ghana.

Opoku-Ameyaw, K., Baah, F., Gyedu-Akoto, E., Anchirinah, V., Dzahini-Obiatey, H., & Cudjoe, A. R. (2010). *Cocoa manual: a source book for sustainable cocoa production*. New Tafo-Akim, Ghana: Cocoa Research Institute of Ghana (CRIG) (Ghana Cocoa Board)

## Appendix A

Table 1. Prioritization of constraints perceived by participants

| Constraint | Frequency | Average score (%) | Multiplication of frequency and av. Score | Ranking/Position |
|---|---|---|---|---|
| Diseases: CSSV, Black Pod (P. *parmivora* and P. *megakarya*) | 4 | 44.4 | 177.6 | 22 |
| Pests and parasites: capsids, termites, stem borer, rodents, mistletoe. | 4 | 75.4 | 301.6 | 11 |
| Bush fires: aggravated by changes in land use, ecology and climate change | 2 | 9.1 | 18.2 | 35 |
| Drought: aggravated by changes in land use, ecology and climate change | 4 | 43.3 | 173.2 | 23 |
| Decline soil fertility | 4 | 73.1 | 292.4 | 13 |
| Low remuneration (rural incomes generally + real value of cocoa producer price). | 4 | 84.3 | 337.2 | 6 |
| Remuneration that is infrequent compared with other crops. | 4 | 59.2 | 236.8 | 19 |
| Perceived high cost and poor availability of chemical inputs and spraying machines. | 4 | 86.1 | 344.4 | 3 |
| Perceived high cost and poor availability of non-chemical inputs such as boots, cutlasses, pruners, spraying machines, etc. | 4 | 51.7 | 206.3 | 20 |
| Occasional poor availability and perceived high cost of seedlings and poly (rooting) bags. | 4 | 68.0 | 272.0 | 16 |
| Occasional poor availability and perceived high cost of casual labour | 4 | 66.2 | 264.8 | 17 |
| High rates of time preference leading to discounting of future incomes and risks | 4 | 64.2 | 256,8 | 18 |
| Poor standard of cocoa buying and marketing-widespread abuses | 4 | 85.3 | 341.2 | 5 |
| Infrequent and inadequate extension advice | 4 | 78.1 | 312.4 | 9 |
| High average age of farmers leading to poor husbandry | 4 | 79.9 | 319.6 | 7 |
| Poor status of farming, low incomes, employment opportunities & rural facilities | 4 | 92.7 | 370.8 | 1 |
| Poor health arising largely from poor standard of rural life and medical facilities | 1 | 17.9 | 17.9 | 36 |
| Low education standards and literacy rates | 4 | 74.2 | 296.8 | 12 |
| Lack of self-reliance (an expectation that government should or will provide) | 3 | 59.9 | 179.7 | 21 |
| Rising rural population and diminishing supply of new land, land for food crops, reduced fallow | 4 | 73.1 | 292.4 | 14 |
| Ill-defined inheritance systems | 3 | 26.0 | 78.0 | 31 |
| Farm fragmentation | 4 | 73.1 | 292.4 | 15 |
| Insecurity of tenure, especially among migrants-harassment by local chiefs/ landowners | 2 | 32.1 | 64.2 | 33 |
| Disenfranchment of local people | 2 | 68.7 | 137.4 | 24 |
| Low remuneration from *abusa* caretaking | 1 | 92.6 | 92.6 | 29 |
| Social obligations, funerals-restricting time available for active farming | 2 | 46.3 | 92.6 | 30 |
| Illegal logging | 2 | 53.9 | 107.8 | 25 |
| Gender: Unequal access to inputs and labour | 2 | 33.0 | 66.0 | 32 |
| Poor access to credit facilities | 4 | 79.5 | 318.0 | 8 |
| Poor road network in their communities | 4 | 85.6 | 342.4 | 4 |
| Delays in bonus payment | 4 | 89.0 | 356.0 | 2 |
| Incidence of epiphytes in cocoa farms | 4 | 78.1 | 312.4 | 10 |
| Cherewilt | 1 | 53.6 | 53.6 | 34 |
| Destruction of cocoa by *galamsey* (small-scale mining) | 1 | 100.0 | 100.0 | 26 |
| Poor association | 1 | 100.0 | 100.0 | 27 |
| Scholarship | 1 | 100.0 | 100.0 | 28 |

Table 2. Categorization of constraints perceived by farmers into technical, socio-economic, social and institutional

| Category | Constraint |
|---|---|
| Technical | Diseases: CSSV, B lack Pod (P. *parmivora* and P. *megakarya*). |
| | Pests and parasites: capsids, termites, stem borer, rodents, mistletoe. |
| | Bush fires: aggravated by changes in land use, ecology and climate change. |
| | Drought: aggravated by changes in land use, ecology and climate change. |
| | Decline soil fertility. |
| | Incidence of epiphytes in cocoa farms |
| | Cherewilt |
| Socio-economic | Low remuneration (rural incomes generally + real value of cocoa producer price). |
| | Remuneration that is infrequent compared with other crops. |
| | Perceived high cost and poor availability of chemical inputs and spraying machines. |
| | Perceived high cost and poor availability of non-chemical inputs such as boots, cutlasses, pruners, spraying machines, etc. |
| | Occasional poor availability and perceived high cost of seedlings and poly (rooting) bags. |
| | Occasional poor availability and perceived high cost of casual labour |
| | High rates of time preference leading to discounting of future incomes and risks |
| | Poor standard of cocoa buying and marketing-widespread abuses. |
| | Delays in bonus payment. |
| Social | High average age of farmers leading to poor husbandry. |
| | Poor status of farming, low incomes, employment opportunities & rural facilities. |
| | Poor health arising largely from poor standard of rural life and medical facilities. |
| | Low education standards and literacy rates. |
| | Lack of self-reliance (an expectation that government should or will provide). |
| | Rising rural population and diminishing supply of new land, land for food crops, reduced fallow. |
| | Poor association of farmers. |
| Institutional | Ill-defined inheritance systems |
| | Farm fragmentation |
| | Insecurity of tenure, especially among migrants-harassment by local chiefs/ landowners |
| | Disenfranchment of local people by migrants |
| | Low remuneration from *abusa* caretaking. |
| | Social obligations, funerals-restricting time available for active farming. |
| | Illegal logging. |
| | Gender: Unequal access to inputs and labour and Unequal time spent on social obligations |
| | Poor access to credit facilities. |
| | Poor road network in their communities. |
| | Infrequent and inadequate extension advice. |
| | Destruction of cocoa by *galamsey* (illegal small-scale mining). |
| | COCOBOD Scholarship. |

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# Velvet Bean and Cowpea Residual Effects on Maize Crop in Smallholder Farming Areas of Zimbabwe

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**Abstract**

On-farm research was conducted in Dendenyore Communal Land and Zana Resettlement areas of Hwedza District, Zimbabwe from 1999 to 2001. The objective of the study was to evaluate the effects of velvet bean and cowpea on growth and yield of maize in legume-maize rotation system. A total of 14 treatments, which consisted of forage legume and maize crops were examined. The experiment was established in a randomized complete block design with 9 replicates. On-farm sites were the replicates. The results show a significant residual effect of velvet bean and cowpea, when grown with single super phosphate fertiliser, on the maize stover and grain yield. They indicate significant phosphorus residual effects on a subsequent maize crop on sandy soils. Forage legumes contribute to residual soil fertility in fallen leaves and roots that increases yield of subsequent crops. The results also reveal that biomass production in perennial leys, grazed during the dry season, would be greater in the second season than in the establishment year. The results also indicate that in the velvet bean systems, especially green manure, nitrogen is lost very early in the season. This may lead to lack of synchrony between nutrient availability and crop uptake. The maize after green manure system had a nitrogen use efficiency of about 11 kg/kg of nitrogen applied. These results show the residual potential of forage legumes in reducing nitrogen fertiliser need for subsequent maize crops in mixed livestock-cropping systems.

**Keywords:** *Mucuna pruriens, Vigna unguiculata,* livestock-cropping systems, residual effect, yield, soil fertility

## 1. Introduction

In Zimbabwe, for improved fallow (or forage legume ley) management practice to be adopted by crop - livestock farmers, the practice should enhance dry season feed supply for livestock and improve soil fertility for the intended cropping systems. Recently, McCarty *et al.* (2016) indicated that an improvement of existing fallow management systems with sown legumes has the potential to enhance the restoration of soil fertility through the accumulation of organic matter and fixation of atmospheric $N_2$ thereby improving N availability in the soil as well as improving soil physical properties (McCarty *et al*., 2016). Suitable crops include legumes with multiple uses (e.g. grain, feed or fodder) with potential to alleviate feed constraints for cattle, especially during the dry season, where crop residues are used to feed cattle (Dubeux *et al*., 2015). This is because legume crop residues have higher nutritive value compared with most forage materials that would normally be found on natural fallow (Dubeux *et al.*, 2015). Testing of suitable legumes for both livestock production and cropping has been attempted in a few cases in Thailand, Sri Lanka and Syria (IRRI, 2009). However, due to different climatic conditions the technologies may not be easily adapted to Zimbabwe conditions. In sub-humid West Africa, where Annan-Afful *et al* (2004) measured the effects of fodder bank pastures on subsequent crop production, strategic research on improved fallow or ley systems for crop livestock systems started only relatively recently.

This study evaluated the effects of velvet bean and cowpea on growth and the biomass and grain yield of maize in legume - maize rotation system. The results are compared with the response of maize on the same sites to nitrogen fertilisation after natural fallow, and after maize.

## 2. Materials and Methods

### *2.1 Sites Description*

On-farm research was conducted at selected sites in Dendenyore Communal Land and Zana Resettlement Areas of Hwedza District, Zimbabwe (18°41' S latitude; 31°42' E longitude; 1400 m asl), about 140 km south east of Harare and 70 km from Grasslands Research Station, Marondera, in Natural Regions IIb and III. The research was done over two cropping seasons, 1999/2000 and 2000/2001 seasons. The soils in the district are generally deep brown sands formed from granitic rocks and classified as Ferralic Arenosol (Giller, 2001) with small patches of sandy clays classified as Chromic Luvisols derived from ultramafic lava and intrusion parent material. Mean annual rainfall ranged from 600-1000 mm/annum with most rain falling between November and March. Mid-season droughts were not uncommon during the research period. During the 1999/2000 season, total rainfall recorded for Zana resettlement and Dendenyore communal areas in Hwedza District averaged about 900 mm (Figure 1). This amount was more than the average annual precipitation in the last three years (810 mm). The season was favourable for nearly all crops, though the lack of rain soon after the first effective rainfall in November and December affected the establishment of some of the crops, and the unusually copious rains during the month of February interfered with weeding operations, increased pest incidence and prolonged the days to maturity for most of the crops. However, this allowed late-planted crops to reach normal maturity. Despite some dry spells, all crops made satisfactory growth.

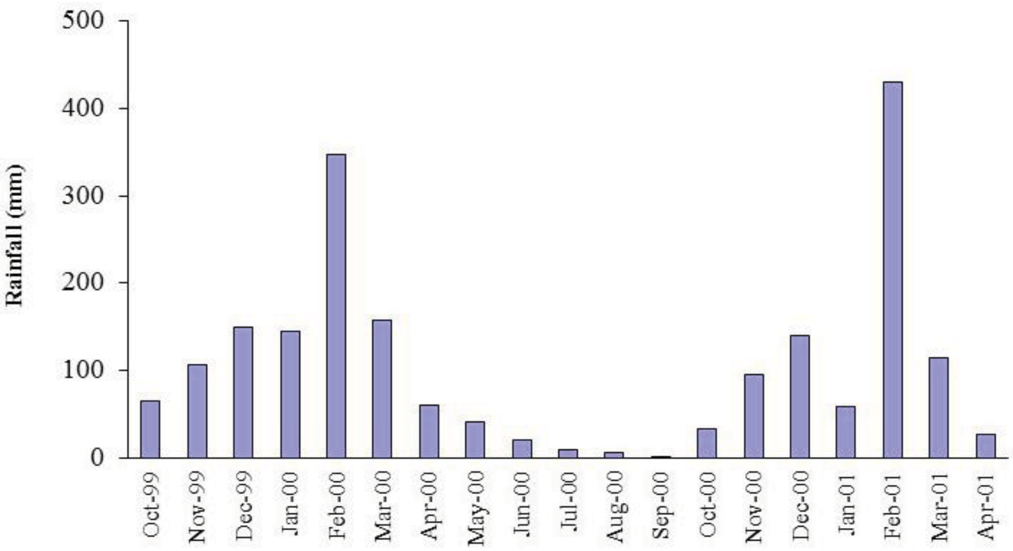


Figure 1. Rainfall data (mm) for the two experimental seasons (1999/00 and 2000/01) for Hwedza district

### *2.2 Trial Details*

The trial to compare legume integration systems was conducted at nine on-farm sites which included two clay and six sandy sites, and one sand loamy site. This variation between the sites enabled the comparison of a large number of treatments over a wide range of soils and management. The trials involved a legume phase as well as weed fallow and sole maize as controls, followed by a maize cropping phase for all annual legume treatments.

### *2.3 Experimental Design and Number of Replications*

The experiment was established in a randomized complete block design with 9 replicates (one replicate per farmer). This was a compromise between the small land areas at the sites and the number of treatments and technologies that were to be explored. Having one replicate per site allowed for comparison of a large number of treatments per given area. It also allowed broader testing of promising treatments across different soil conditions and allowed for the examination of the relationship between soil factors and responses to SSP and lime.

### *2.4 Treatments List and Descriptions*

A comparison was made of forage supply and subsequent rotational benefits of *Mucuna pruriens* var. *utilis* (velvet bean), *Vigna unguiculata* (cowpea) and *Zea mays* (maize) grown as leys, intercrops or green manure. *Macrotyloma axillare* cv. *Archer* (archer) mixed with *Chloris gayana* (Katambora Rhodes grass) was grown as a ley in both seasons to compare its forage production with velvet bean and cowpea. With maize-velvet bean intercropping, velvet bean was planted two weeks after maize to reduce competition effects. Partial nutrient balances were determined during the trial period.

The experiments commenced with the first effective rainfall. The different forage legume cropping systems were initiated in the 1999/2000 season. During the 2000/2001 season maize yield and soil fertility, under the different season 1 treatments, were monitored. Legumes were inoculated with appropriate rhizobia and received single superphosphate (SSP), which was broadcast and incorporated before planting at the rate of 200 kg/ha (except for the without SSP treatments). Farmers had indicated their willingness to use some fertilizer even on the forages. As per farmer practices, fields were to be accessible to livestock during the dry season. All maize was fertilized with basal (300 kg/ha Compound D) and top dressings (200 kg/ha Ammonium Nitrate) as per the farmer practice.

*2.5 Varieties of Forage Legumes, Grass and Maize*

The following legumes were used in the trials:

1. *Mucuna pruriens* var. *utilis* (velvet bean): the main crop in this project, obtained from local seed sources
2. *Vigna unguiculata* (cowpea, ex-Matopos variety)
3. *Macrotyloma axillare* cv. Archer (Archer): a perennial legume.

The following grasses were used:

1. *Chloris gayana* (Katambora Rhodes grass): a grass used for grazing and for nematode control.
2. *Zea mays* (maize, a Seed Co-op medium season hybrid variety (SC513) recommended for Hwedza farming area and tolerant to grey leaf spot).

A list of the treatments tested in this experiment are shown in Table 1.

Table 1. List of treatments used in the main trials in 1999/00 and 2000/01 seasons.

| **1999/00 treatments** | **2000/01 treatments** |
|---|---|
| Weed fallow | Maize (30 kg N $ha^{-1}$ applied as AN) |
| Sole maize (full rate inorganic fertiliser [1]i.e. 93 kg N/ha: 18 kg P/ha: 18 kg K/ha and 19.5 kg S/ha) | Maize (full rate inorganic fertiliser i.e. 93 kg N/ha: 18 kg P/ha: 18 kg K/ha and 19.5 kg S/ha) |
| Maize-velvet intercrop (full fertiliser rate) | Maize (full fertilizer rate) |
| Ley velvet bean with SSP[2] | Maize (30 $kgNha^{-1}$ applied as AN) |
| Ley velvet bean without SSP | Maize (30 $kgNha^{-1}$ applied as AN) |
| Ley velvet bean with SSP | Ley velvet bean without SSP |
| Ley velvet bean without SSP | Ley velvet bean with SSP |
| Ley cowpea with SSP | Maize (30 $kgNha^{-1}$ applied as AN) |
| Ley cowpea without SSP | Maize (30 $kgNha^{-1}$ applied as AN) |
| Perennial ley with SSP | Perennial ley without SSP |
| Perennial ley without SSP | Perennial ley with SSP |
| Green manure velvet bean with SSP | Maize (30 $kgNha^{-1}$ applied as AN) |
| Green manure velvet bean without SSP | Maize (30 $kgNha^{-1}$ applied as AN) |
| Ley velvet bean with SSP and lime[3] | Maize (30 $kgNha^{-1}$ applied as AN) |

[1]Applied as 300 kg/ha Compound D (8%N, 6%P, 6%K, 6.5%S) and 200 kg/ha ammonium nitrate (34.5%N)

[2]Applied as 200 kg/ha Single superphosphate (SSP) (9% P, 11% S, 20% Ca and 0.5% Mg)

[3]Dolomitic lime was applied at 500 kg/ha

The trailing cowpea (ex Matopos) was included as a traditional variety with a unique characteristic of being able to grow well on less fertile soils. Archer was included as a perennial forage legume that has been shown to be among the forage legumes best adapted to the soil and climatic conditions such as are found in Hwedza (Muza, 1998). Velvet bean is a promising green manure and forage legume (Muza, 1998; Vissoh *et al*., 1998). Katambora Rhodes grass helps in the control of nematodes, which are common in continuous maize cropping systems.

There were nine farmers participating in the area. Gross plot size was 9 x 8 m, with a net plot of 7 x 6 m.

*2.6 Field Management*

All fields were ox-ploughed. Maize was overplanted at two seeds per station and thinned to one plant per station at the three emerged leaf stage. Legumes were planted at two seeds per station and thinned to one plant per station during first weeding. Planting was done at 90 cm x 30 cm, inter-row and in-row spacing, respectively, for maize, velvet bean and cowpea. Maize and velvet bean were intercropped in-row. Weeding was done manually at two and five weeks after crop emergence (WACE). Dolloping of fertilizer to maize, at 300 kg/ha Compound D and 200 kg/ha AN, was done at planting and at five WACE, respectively, to sole and intercropped maize in season 1, and to the maize following these crops in season 2. Ammonium nitrate was split applied to maize at 3 and 6 WACE in season 2. Single superphosphate (SSP) and lime, in season 1, were applied at the rate of 200 kg/ha and 500 kg/ha, respectively. Spraying was done against leaf eaters and aphids in legumes using a combination of carbaryl 85% WP and dimethoate to reduce pest and disease effects on crop performance and yield.

*2.7 Seasonal Characteristics*

One distinct feature in the 2000/2001 season was the long mid-season drought that occurred soon after the first effective rainfall. This led to most of the crops not attaining their maximum potential in terms of growth and yield. The average rainfall for Hwedza District was about 864 mm. The mid-season drought in December and January negatively affected crop growth and the unusually copious rains during the month of February interfered with weeding operations, increased pest incidence and prolonged the days to maturity for most of the crops.

*2.8 Pests and Diseases*

No major pests were encountered despite the long dry spell that induced rapid aphid (species of Aphididae) infestation on velvet bean and cowpea. The velvet bean variety used, however, showed less susceptibility to pests and diseases compared to the other legumes. Dipterex was used for stalk borer control on maize. No pests were identified on Archer and Katambora Rhodes grass.

*2.9 Harvesting Procedures and Measurements*

Harvesting was done 130 days after planting from an area measuring 42 $m^2$. The border area (1 m) was excluded from the harvested area. The maize and the legume components of the intercrop were harvested separately. The maize ear was removed from the stalk, dehusked and the kernels extracted. The legumes were cut at ground level and weighed immediately after cutting. Archer and Katambora Rhodes grass were cut at about 10 cm above the ground to facilitate regrowth. Sub-samples were taken from freshly harvested materials, weighed, dried at $60^0$C for 48 hours and then re-weighed for dry matter (DM) content determination and estimation of DM yield. The dry samples were used for N and P analysis. Maize grain and stover sub-samples were also collected from the bulk sample and weighed immediately to enable maize stover and grain DM yield determination.

*2.10 Soil and Plant Analyses*

Composite soil samples were collected in season 1 from each replication, i.e. samples were collected from each plot and mixed for each replicate (thus 18 samples: 9 replicates x 2 depths of 0-15 cm and 15-30 cm). After this first sampling all other samplings (at harvesting in year 1 and at planting in year 2) were done per plot. Soil sampling in all the plots was done at Year 1 harvest. Soil samples were analysed for available P, total N, K, C, Mg, Ca and pH $_{(CaCl2)}$. The soils were analysed for total soil N by acid digestion (Bruce, 1997), total organic carbon by combustion, P using the Bray II method, while K, Ca and Mg were done by analyzing leachate using spectroscopy and pH was determined by the calcium method (Bruce, 1997). In the second season, soil sampling in the weed fallow, green manure velvet bean (with P) and velvet bean hay (with lime and P) plots was done at selected sites, representing different soil conditions, to determine N leaching. This sampling was done at pre-planting, planting, 1 week after crop emergence (WACE), 2 and 4 WACE. The samples were analyzed for mineral N and carbon. This decision to reduced analysis in year 2 was based to cost and known behaviour of certain nutrients within short time periods.

*2.11 Maize Harvesting*

Harvesting was done 132 days after planting in the net plots after removing a 1 m border row on the gross plot size. The maize cobs were then removed from the stalk and de-husked. The legumes and maize stover (maize crop residue without kernels) were cut at ground level and weighed immediately after cutting. Six samples for dry matter (DM) determination and chemical analysis were collected per plot. They were weighed at the same time as the bulk weighing and taken to the laboratory and dried at $60^0$C for 48 hours and then reweighed for DM content determination as well as estimation of the respective DM yields.

*2.12 Statistical Analysis*

Minitab statistical package was used to analyse the data. Treatment differences were tested in an Analysis of

Variance and least significant difference was used to calculate mean separation. Significance in treatment differences was declared at P≤0.05.

## 3. Results and Discussion

### *3.1 Soil Chemical Properties*

The samples taken at the time of harvesting in Year 1 (April 2000), to trace the effects of the different systems on soil chemical properties, indicated a similar pattern in the levels of the nutrient irrespective of the system examined. The light clay soils still had relatively higher concentrations of N, C, Ca and Mg, and low P levels (Table 2). The other soils maintained low levels of all the nutrients. There was, however, a noticeable increase in the percentage of C in the velvet bean plots at some sites. The light clay soils averaged a C content of 1% while the sandy soil sites ranged from 0.2 to 0.5%.

Overall, mineral N concentrations were lower at pre-planting sampling than at planting (after rainfall). This could be because mineralization had been slow before the rains but had accelerated with moisture availability. The lowest pre-planting mineral N concentrations were obtained in the weed fallow system. This could be due to the lack of purely leguminous species in the weed composition, which differed from site to site. Mineral N pre-planting tended to be higher with green manure incorporation. The biggest difference between the mineral N concentration at pre-planting and at planting was observed in the weed fallow system. There was more mineral N in the green manure treatments at planting at the sandy and clay soil sites as compared to the velvet bean hay (with P and lime) and weed fallow treatments. The reason for the similarities in mineral N concentrations between the weedy fallow and green manure velvet bean systems at planting could be due to rapid release and leaching of nitrate N at the time when the rains came and before samples were collected (Giller, 2001).

Table 2. Soil chemical properties at the different sites before planting in the 1999/2000 season, Dendenyore and Zana, Zimbabwe

| Site | Soil Type | Soil Depth (cm) | pH | K | Mg | Ca | avai. P | Total N | C | C/N ratio |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cmol$_c$/kg)[1] | | | (µg/g)[2] | % | | |
| Mbavha | Sand | 0-15 | 4.28 | 0.12 | 0.06 | 0.32 | 17 | 0.06 | 0.32 | 5.3 |
| | | 15-30 | 4.02 | 0.06 | 0.03 | 0.12 | 6 | 0.05 | 0.25 | 5 |
| Ruzane | Sand | 0-15 | 4.32 | 0.08 | 0.04 | 0.19 | 24 | 0.03 | 0.29 | 9.7 |
| | | 15-30 | 4.20 | 0.10 | 0.03 | 0.12 | 16 | 0.04 | 0.24 | 6 |
| Mumvana | Sand | 0-15 | 4.42 | 0.12 | 0.06 | 0.29 | 11 | 0.04 | 0.34 | 8.5 |
| | | 15-30 | 3.97 | 0.10 | 0.04 | 0.23 | 3 | 0.04 | 0.20 | 5 |
| Mapira C | Sandy loam | 0-15 | 4.53 | 0.22 | 0.11 | 0.41 | 10 | 0.04 | 0.40 | 10 |
| | | 15-30 | 4.28 | 0.13 | 0.14 | 0.59 | 4 | 0.04 | 0.27 | 6.8 |
| Mapira A | Sand | 0-15 | 4.35 | 0.13 | 0.09 | 0.17 | 8 | 0.05 | 0.44 | 8.8 |
| | | 15-30 | 4.27 | 0.08 | 0.04 | 0.15 | 3 | 0.04 | 0.28 | 7 |
| Chikumbirike | Sand | 0-15 | 4.27 | 0.11 | 0.06 | 0.06 | 4 | 0.03 | 0.40 | 13.3 |
| | | 15-30 | 4.21 | 0.11 | 0.06 | 0.07 | 3 | 0.04 | 0.32 | 8 |
| Dzuna | Blackish clay | 0-15 | 5.20 | 0.26 | 2.67 | 3.74 | 1 | 0.11 | 1.24 | 11.3 |
| | | 15-30 | 5.14 | 0.20 | 3.54 | 4.36 | 1 | 0.10 | 1.19 | 11.9 |
| Gunzvenzve | Red clay | 0-15 | 4.42 | 0.20 | 1.69 | 2.89 | 1 | 0.09 | 1.03 | 11.4 |
| | | 15-30 | 5.22 | 0.12 | 2.70 | 4.78 | 1 | 0.08 | 0.89 | 11.1 |
| Munamati | Sand | 0-15 | 4.23 | 0.12 | 0.06 | 0.26 | 11 | 0.05 | 0.33 | 6.6 |
| | | 15-30 | 4.15 | 0.10 | 0.08 | 0.31 | 4 | 0.04 | 0.25 | 6.3 |

[1]equivalent to meq/100g [2]Bray P

### *3.2 Biomass Yield Assessment*

Sole maize stover yield increased significantly (P<0.05) in year 2 when compared with year 1 maize stover yield (3.9 and 4.3 t DM/ha respectively), probably due to differences in seasonal rainfall temporal distribution. Maize stover yield was lowest in the maize following weed fallow plot (2.9 t ha$^{-1}$) and the highest maize stover yield was in the maize following velvet bean with SSP application. Compared with maize following the weed fallow, maize stover yield was significantly increased following velvet bean with SSP (with or without lime), cowpea with SSP and green manure velvet bean with or without SSP (Table 3). Maize stover yield was higher when maize was grown after velvet bean with SSP than after velvet bean without SSP (Table 3).

Table 1 shows the yields (maize stover and grain, velvet bean and perennial ley DM) obtained in year 2 after the various year 1 treatments. Yields from clay and sandy loam soils were generally higher than yields from sandy soils. This could be due to generally higher inherent soil fertility in clay and loam soils compared to sandy soils (Bationo, 2007).

When velvet bean with SSP was grown after velvet bean (biomass removed) without SSP an 8% increase in the total DM yield was effected (comparing years 1 and 2) (Table 4). However, when velvet bean (biomass removed) was grown without SSP after velvet bean with SSP, the total DM yield was reduced by 39%. There was no response to P in year 1, which could imply that factors other than P might be limiting DM yield (Bationo, 2007).

The Archer and Katambora Rhodes grass plots gave interesting results. There were significant increases in total DM ($P<0.05$) in the Archer and Katambora Rhodes plots in the second season as compared to the first season (Table 4). There was a three-fold increase in the DM yield of the perennial plot in the second year, with no significant differences between plots fertilized with P in the first or second year.

Table 3. Hay, maize stover and grain yield (t/ha DM) in the different cropping systems at different sites in season 2

| Treatment | | Mbavha (Sandy) | Mumvana (Sandy) | Mapira A (Sandy) | Chikumbirike (Sandy) | Mapira C (Sandy Loam) | Gunzvenzve (Clay) | Dzuna (Clay) | Treatment means |
|---|---|---|---|---|---|---|---|---|---|
| Maize (full rate) after sole maize (full rate): stover | | 1.3 | 2.1 | 4.8 | 2.4 | 7.3 | 7.8 | 5.2 | 4.3 |
| maize grain | | 0.9 | 1.8 | 4.2 | 1.8 | 5.7 | 4.6 | 4.3 | 3.3 |
| Maize (+ 30 N) after weed fallow: stover | | 0.9 | 1.8 | 5.3 | 2.7 | 4.5 | 4.1 | 3.5 | 2.9 |
| maize grain | | 0.6 | 1.0 | 1.9 | 1.2 | 2.3 | 3.2 | 2.0 | 2.1 |
| Velvet bean after velvet bean (SSP) | | 3.7 | 6.9 | 8.9 | 6.0 | 9.8 | 9.4 | 8.8 | 7.6 |
| Velvet bean (SSP) after velvet bean | | 2.3 | 2.0 | 4.4 | 2.7 | 5.6 | 6.2 | 6.3 | 4.2 |
| Maize (+ 30 N) after velvet bean: stover | | 3.2 | 2.8 | 3.2 | 2.6 | 3.8 | 3.8 | 3.1 | 3.2 |
| maize grain | | 2.9 | 1.1 | 0.7 | 1.1 | 1.3 | 2.8 | 3.2 | 1.8 |
| Maize (+ 30 N) after velvet bean (SSP): stover | | 4.2 | 9.0 | 9.4 | 6.9 | 9.1 | 9.8 | 8.9 | 8.1 |
| maize grain | | 3.9 | 3.1 | 2.3 | 2.6 | 3.7 | 3.1 | 2.9 | 3.1 |
| Maize (+ 30 N) after velvet bean (SSP + lime): stover | | 3.2 | 3.1 | 4.9 | 4.8 | 4.5 | 6.5 | 6.7 | 4.8 |
| maize grain | | 3.0 | 2.6 | 3.6 | 2.7 | 2.8 | 4.9 | 5.6 | 3.6 |
| Perennial ley after perennial ley (SSP) | | 7.4 | 11.0 | 14.6 | 4.6 | 15.7 | 15.6 | 14.4 | 11.9 |
| Perennial ley (SSP) after perennial ley | | 7.2 | 12.5 | 14.1 | 5.6 | 10.4 | 14.6 | 9.8 | 10.6 |
| Maize (+ 30 N) after cowpea: stover | | 1.4 | 2.1 | 5.3 | 2.6 | 6.2 | 5.6 | 3.9 | 3.8 |
| maize grain | | 1.0 | 1.5 | 2.3 | 2.0 | 4.2 | 3.9 | 2.6 | 2.5 |
| Maize (+ 30 N) after cowpea (SSP): stover | | 4.2 | 4.8 | 5.8 | 3.7 | 6.9 | 5.8 | 5.5 | 5.2 |
| maize grain | | 2.8 | 2.9 | 3.5 | 2.8 | 3.2 | 4.1 | 4.4 | 3.4 |
| Maize (+ 30 N) after green manure velvet bean: stover | | 2.9 | 2.2 | 5.9 | 4.0 | 4.1 | 6.5 | 7.6 | 4.7 |
| maize grain | | 1.4 | 1.9 | 2.8 | 1.3 | 3.8 | 3.5 | 4.5 | 2.8 |
| Maize (+ 30 N) after green manure velvet bean (SSP): stover | | 4.9 | 2.6 | 6.5 | 4.2 | 6.4 | 7.1 | 6.8 | 5.5 |
| maize grain | | 3.2 | 2.2 | 3.2 | 1.9 | 3.6 | 4.1 | 3.7 | 3.1 |
| Maize (full rate) after maize velvet intercrop (full rate) | | 3.9 | 1.6 | 6.7 | 1.2 | 5.4 | 5.1 | 4.7 | 4.0 |
| maize grain | | 0.3 | 0.9 | 3.6 | 0.9 | 3.7 | 3.7 | 3.6 | 2.4 |
| **Site means:** | **Maize stover** | **3.0**[a] | **3.2**[a] | **5.8**[b] | **3.5**[a] | **5.9**[b] | **6.2**[b] | **5.6**[b] | |
| | **Maize grain** | **2.0**[a] | **1.9**[a] | **2.8**[b] | **1.9**[a] | **3.5**[b] | **3.8**[b] | **3.7**[b] | |

Means followed by the same letter are statistically similar ($P \leq 0.05$)

Table 4. Dry matter yield (t/ha) for legumes grown following legumes with or without P fertilization and with biomass removal

| Year 1 treatment | Year 1 DM yield (t/ha) | Year 2 treatment | Year 2 DM yield (t/ha) | Year 1 + Year 2 DM (t/ha) |
|---|---|---|---|---|
| Velvet bean (-P) | 7.1 [b] | Velvet bean (+P) | 7.7[b] | 14.8 [y] |
| Velvet bean (+P) | 6.9[b] | Velvet bean (-P) | 4.3[a] | 11.1 [x] |
| Archer + Katambora Rhodes grass (-P) | 2.8[a] | Archer + Katambora Rhodes grass (+P) | 11.9[c] | 14.6 [y] |
| Archer + Katambora Rhodes grass (+P) | 3.2[a] | Archer + Katambora Rhodes grass (-P) | 10.6[c] | 13.8 [y] |

Year 1: CV = 42.72%; S.E of treatment means =764.5

Year 2: CV = 32.85%; S.E of treatment means = 1247.37

Means followed by the same letter are statistically similar ($P \leq 0.05$)

### *3.3 Grain Yield*

Due to the mid-season drought in the second year, sole maize grain yields in the first and second years were similar (stover yields in year 2 were greater than year 1). There were significant differences ($P<0.05$) between the maize grain yields following the different season 1 treatments. The highest grain yields were obtained in the fully fertilised maize after sole and intercropped maize plots (3.1 - 4.3 t $ha^{-1}$) and maize with low N following velvet bean with SSP and lime (Table 3). Cowpea with SSP resulted in a significantly higher ($P<0.05$) maize grain yield as compared to the cowpea without SSP. Velvet bean without SSP also led to significantly lower ($P<0.05$) yields as compared with velvet bean with SSP irrespective of whether the velvet bean was incorporated or not. The lowest was obtained in the maize following velvet bean without SSP plot (1.6 t $ha^{-1}$). Presence of legume in the intercrop did not apparently benefit the following maize crop. Thus, there were no apparent soil fertility benefits to the following maize crop.

The amount of green manure biomass incorporated was strongly related to the maize grain yield obtained. Overall, there was an increase of more than 300kg in maize grain yield for every tonne of green manure incorporated (Figure 2). This was a nitrogen use efficiency of about 11 kg grain/kg N applied (Figure 3).

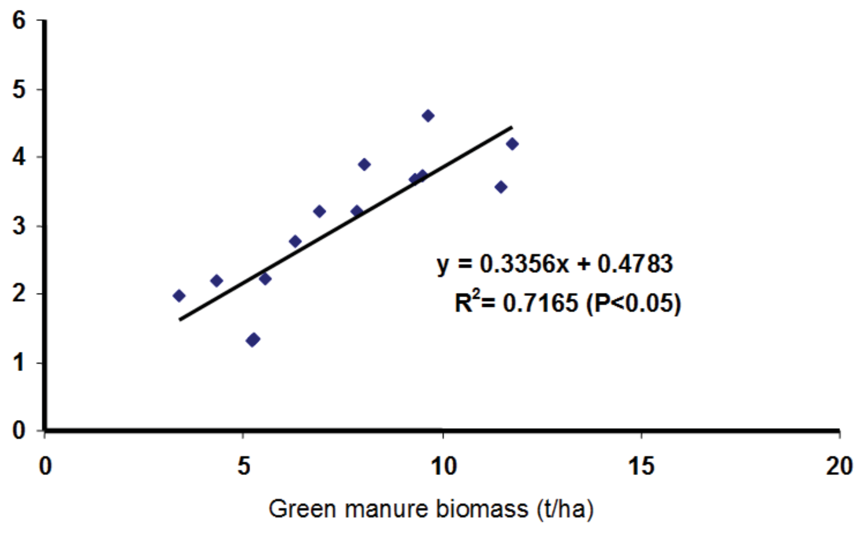


Figure 2. Response of maize grain yield to previous velvet bean green manure biomass yield

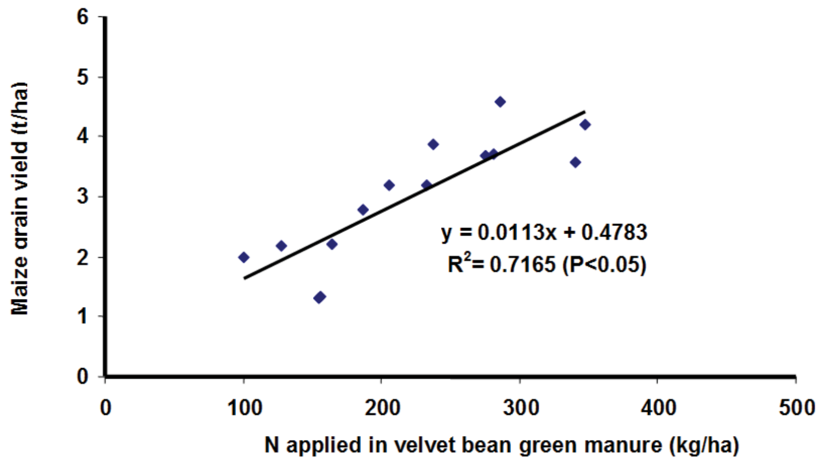


Figure 3. Response of maize grain yield to the amount of N in previous velvet bean green manure

Comparison was also made of the maize grain yield responses after cowpea hay, velvet bean hay (i.e. above ground biomass was removed to simulate a farmer who would make hay from cowpea and velvet bean) and velvet bean green manure (all without SSP) relative to maize grain yield after weed fallow (Figure 4). Removal of velvet bean above-ground biomass led to low (negative or just positive) relative maize grain yield in the following maize crop, while removal of cowpea above-ground biomass (for hay) or incorporating velvet bean biomass led to positive relative maize grain yield over maize after weed fallow (Figure 4). It was not possible to compare the legume systems with SSP to weed fallow, as there was no weed fallow with SSP. Relative maize grain yield was most positive after green manure velvet bean without SSP on the sandy soils, indicating possible P residual effects on these soils. On the clay soils, the just-positive value indicates that there may be no residual P effect on these soils (Figure 4).

A comparison of the maize grain yield responses after cowpea hay, velvet bean hay (i.e. above-ground biomass removed) and velvet bean green manure (all without SSP) relative to maize grain yield after weed fallow indicated that removal of velvet bean above-ground biomass led to low relative maize grain yield in the following maize crop. This was because in the second season, the only source of nutrient before application of top dressing N were decomposed roots and fallen leaves as well as from $N_2$ fixation.

Although there was a strong correlation between maize grain yield in season 2 and the amount of green manure biomass applied in season 1 (Figure 2), enhancements in grain yield would have been expected but the mid-season drought resulted in poorer yields than anticipated from early crop growth. Until the mid-season drought, large differences in maize growth were observed. Velvet bean green manure led to variable but generally positive increases in the grain yield when compared with situations where the above ground biomass was removed (Figure 4). However, the N use efficiency was only about 11 kg/kg N applied. This was probably due to lack of synchrony between release of the nitrogen and crop uptake since the biomass was incorporated in April 2000 and the crops were planted end November 2000. Velvet bean green manure was incorporated soon after harvesting (mid-April 2000) to avoid being eaten by stray livestock. At that time of the year the soils will still be moist and some decomposition of the plant residues will occur before the onset of the hot dry months of August to November. Some of the mineralized nitrogen could have been lost through leaching, erosion, volatilization and denitrification, while some of it becomes part of the recalcitrant organic matter (Giller, 2001; Mapfumo *et al*., 2013). There was some significant leaching in the weed fallow, velvet bean with SSP and in velvet bean with lime systems. This is supported by findings from Whitbread *et al.*, (2004).

Removal of above ground biomass led to variable but generally positive increases in the grain yields as the green manure systems. This response means the significant contribution of roots and fallen leaves (already decomposed) by the time of harvest. Although there were no measurements taken to ascertain the contribution of the below ground biomass, these results show that the root biomass has more incremental effect on maize stover and grain yield in velvet bean systems when left intact than when the above ground biomass is incorporated and roots ploughed up. This could possibly be due to slower decomposition of hay crop roots compared with green manure, enhancing synchrony in cases where the above ground biomass was removed. At some sites there were no significant differences in those plots where the above ground biomass was removed and those where it was incorporated, pointing to the fact that it may not be economic to use the above ground biomass for green manure. It can be used for livestock feed, for instance, and the remaining below ground biomass would still contribute significantly to soil fertility. Of course, there could be long term benefits of the above ground biomass such as increase in organic matter, but this was beyond the scope of this project.

Green manure velvet bean with P led to similar maize stover yields to green manure without P. Cowpea with P led to a 34% stover yield increment compared with cowpea without P. The velvet bean hay systems without P did not seem to have any positive effects on the following maize stover DM yields compared with maize after weed fallow. These results indicate the importance of P application to the legume prior to a subsequent maize crop on sandy soils. They precisely show that P has significant residual effects on sandy soils. Although maize grain yield was grossly affected by the mid-season drought that occurred, a comparison of the maize grain yield from the different systems reveals that the velvet bean without P systems led to the least yields. The P-fertilized legume systems (green manure, velvet and cowpea) resulted in similar grain yields. This shows the great residual effect P-fertilized legumes had on the following maize crop on sandy soils. However, there would be no residual benefit in applying SSP to a previous legume crop on the clay soils as of the P would be fixed and unavailable for crop use. However, applying P to the legume would generally promote legume growth and, therefore, subsequent maize growth. Furthermore, the application of P to legumes may stimulate nitrogen fixation and may have carry-over effects in terms of C, N and P on the main crop (Olsen *et al*., 2015).

There were large increases in Archer and Katambora Rhodes grass mixture in the second year (Table 4). The DM yield levels averaged 11.2 t ha$^{-1}$ in the second season. This shows the potential of this system for forage production. It also supports the argument that biomass production in this system would be higher from the second season onwards as the perennial Archer and Katambora Rhodes grass would then be growing more vigorously. Farmers can apply P to the first year Archer and Katambora Rhodes grass and the residual P would be enough for the second season.

Better fallow and residue management can help accelerate soil restoration and improve traditional cropping systems (*Waddington*, 2003). An improved fallow, if properly managed, would add substantial amounts of fixed N and organic matter to the soil, recycle nutrients from the subsoil, provide an effective cover against soil erosion, suppress weeds and pests, and improve soil physical conditions (*Vanlauwe* et al., 2013).

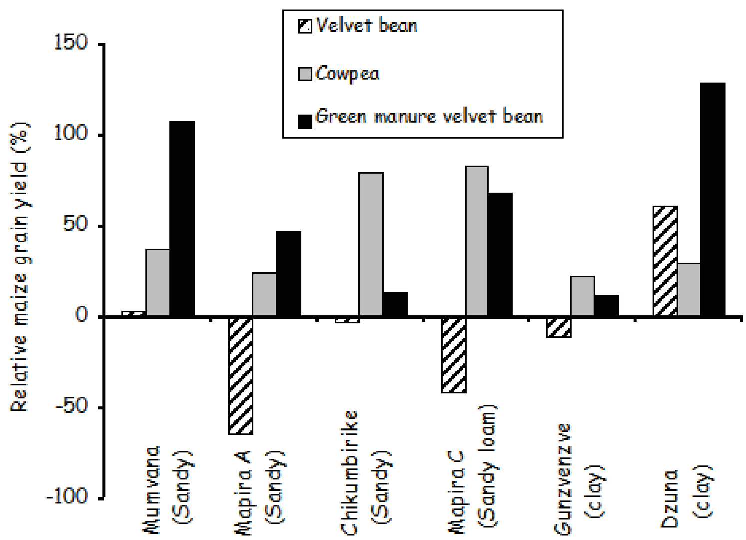


Figure 4. Relative maize grain yield following velvet bean (biomass removed), velvet bean (green manured) and cowpea (biomass removed), all without SSP (maize grain yield after weed fallow as the control)

## 4. Conclusion

These results show a significant residual effect of velvet bean and cowpea, when grown with SSP, on the maize stover and grain yield. They indicate significant P residual effects on a subsequent maize crop on sandy soils. Farmers would need to apply P every season on clay soils. Forage legumes contribute much to residual soil fertility in fallen leaves and roots that increases yield of subsequent crops. The results also indicate that in the velvet bean systems, especially green manure, N is lost very early in the season. This leads to lack of synchrony between nutrient availability and crop uptake. From these results, however, farmers would benefit, in terms of maize grain yields, from adopting the velvet bean green manure systems than systems where the above ground biomass was removed. The maize after green manure system had a nitrogen use efficiency of about 11 kg/kg N applied. However, the mid-season drought may have overruled treatment differences due to reduced overall N demand due to decreased growth potential. The results also reveal that biomass production in perennial leys, grazed during the dry season, would be greater in the second season than in the establishment year. Good growth of the perennial leys indicates that the plants survived the grazing well.

## References

Annan-Afful, E., Iwashima, N., Otoo, E., Asubonteng, K. O., Kubota, D., Kamidohzono, A., & Wakatsuki, T. (2004). Nutrient and bulk density characteristics of soil profiles in six land use systems along topo-sequences in inland valley watersheds of Ashanti region, Ghana. *Soil Science And Plant Nutrition\rSoil Sci. Plant Nutr.*, *50*(5), 649-664. https://doi.org/10.1080/00380768.2004.10408522

Bationo, A. (2007). *Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities: Challenges and Opportunities*. Springer Science & Business Media. https://doi.org/10.1007/978-1-4020-5760-1

Bruce, R. Hoskins. (1997). *Soil Testing Handbook For Professionals In Agriculture, Horticulture, Nutrient And Residuals Management*. (Bruce R. Hoskins, Ed.)*University of Maine* (3rd ed.). Maine Forestry & Agricultural Experiment Station University of Maine. http://doi.org/10.1017/CBO9781107415324.004

Dubeux Jr, J. C., Muir, J. P., Nair, P. R., Sollenberger, L. E., Silva, H. M., & de Mello, A. C. (2015). The advantages and challenges of integrating tree legumes into pastoral systems. *Forages in Warm Climates*, 141. Retrieved from http://www.neforufla.com.br/upimg/ck/files/Proceedings_CONFOR_2015.pdf#page=141

Giller, K. E. (2001). *Nitrogen fixation in tropical cropping systems*. *CABI Publishing* (2nd ed.). CABI Publishing. https://doi.org/10.1079/9780851994178.0000

IRRI. (2009). The importance of legumes in cereal cropping systems. *Central Knowledge Bank*. https://doi.org/10.1007/978-3-319-24226-2_1

Mapfumo, P., Adjei-Nsiah, S., Mtambanengwe, F., Chikowo, R., & Giller, K. E. (2013). Participatory action research (PAR) as an entry point for supporting climate change adaptation by smallholder farmers in Africa. *Environmental Development*, *5*, 6-22. https://doi.org/10.1016/j.envdev.2012.11.001

McCarty, L. B., Hubbard, L. R., & Quisenberry, V. (2016). Applied Soil Physical Properties, Drainage, and Irrigation Strategies. (pp. 1-72). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-24226-2

Olsen, D. J. R., Endelman, J. B., Jacobson, A. R., & Reeve, J. R. (2015). *Compost carryover: nitrogen, phosphorus and FT-IR analysis of soil organic matter*. *Nutrient Cycling in Agroecosystems*. https://doi.org/10.1007/s10705-015-9680-y

Vanlauwe, B., Wendt, J., Giller, K., Corbeels, M., Gerard, B., & Nolte, C. (2013). A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research*. https://doi.org/10.1016/j.fcr.2013.10.002

Waddington, S. R. (2003). *Grain Legumes and Green Manures for Soil Fertility in Southern Africa: Taking Stock of Progress*. *Proceedings of a Conference Held 8-11 October 2002 at the Leopard Rock Hotel, Vumba, Zimbabwe. Soil Fert. Net and CIMMYT-Zimbabwe, Harare, Zimbabwe.* Retrieved from https://books.google.com/books?id=x0bNhhtdUicC&pgis=1

Whitbread, A. M., Jiri, O., & Maasdorp, B. (2004). The effect of managing improved fallows of Mucuna pruriens on maize production and soil carbon and nitrogen dynamics in sub-humid Zimbabwe. *Nutrient Cycling in Agroecosystems*, *69*(1), 59-71. https://doi.org/10.1023/B:FRES.0000025291.62043.11

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# Effect of Mineral Nitrogen and Legume Intercrops on Maize (*Zea Mays* L.) Nitrogen Uptake, Nutrient Use Efficiency and Yields in Chitedze and Zomba, Malawi

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**Abstract**

Nitrogen (N) is the most critical plant nutrient. Maize has a high nitrogen demand. Low maize (*Zea mays* L.), yields in smallholder farms of Malawi, the country's staple, is attributable to declining N fertility aggravated by the ever increasing price of fertilizer. Little effort has been made to establish the best nitrogen rate in a maize-cowpea and maize-bean intercrop under variable soil conditions as a way of improving production, and was the objective of the current study. Field experiments were conducted at Chitedze Agricultural Research Station in Lilongwe and Makoka Agricultural Research Station in Zomba during the 2016/17 growing season. A split plot layout in a randomized complete block design, with three replicates was used. The main plots were; sole maize, sole bean, sole cowpea, bean/maize and cowpea/maize intercrop systems. The sub plots were N fertilizer rates (0, 52.5, 78.75 and 105 kg N ha$^{-1}$), applied as urea. The data collected was subjected to analysis of variance using SAS software version 9.3 (SAS Institute Inc.) at P<0.05. Means were separated using Duncan Multiple Range (DMRT) test at 95% significance level. The results showed that application of N increased maize N uptake and grain yield. NUE however decreased with increasing N fertilizer rate.

**Keywords:** common beans, cowpea, urea

## 1. Introduction

Nitrogen (N) is a critical component of organic molecules such as amino acids, proteins and nucleic acids (Walworth, 2013) and promotes vigorous vegetative growth (Havlin, Tisdale, Beaton, & Werner, 2008; Paul, 2008). It is the most frequently deficient plant nutrient in Malawian soils. This has resulted into low maize (*Zea mays* L.) yields, the country's staple (Munthali & Mazuma, 2010). The deficiency of N in soil is as a result of continuous cropping without adequate replenishment of nutrients lost through harvesting. Nitrogen (N) is one of the essential nutrients affected by increased soil cropping (Gachene & Kimaru, 2003; Mbewe, 2011). Alternative ways of improving nitrogen fertility of soil and subsequently increase maize yield should be identified.

Studies conducted on legumes have reported that legumes have the potential to significantly contribute to soil nitrogen, through biological nitrogen fixation, and increase yields of either subsequent or associated non-nodulating crops such as cereals through biological nitrogen fixation (Hayat, Safdar, Siddique, & Chatha, 2008).

Cowpea (*Vigna unguiculata* L) is a legume of African origin and one of the most ancient crops ever domesticated by man. It is an important source of food and income (Food and Agriculture Organisation [FAO], 2004). Africa produces 96% of the more than 5.4 million tons of the global cowpea production. Cowpea is highly adaptable to grow in different soil types and intercropping systems. It also has the following advantages; it is drought resistant and has the ability to improve soil fertility through biological nitrogen fixation and also reduces the risk of soil erosion (International Institute of Tropical Agriculture [IITA], 2016). In Malawi cowpea is an important legume crop for small holder farmers and the crop is adapted to grow in a wide range of local conditions (Nkongolo, Bokosi, Malusi, Vokhiwa, & Mphepo, 2009). The production of cowpea in Malawi is estimated to be 50 249 million tons on average between the years 2000 to 2013 (FAOSTAT, 2013).

Common bean (*Phaseolus vulgaris* L) is the most important food legume for direct consumption in the world and it is a major source of dietary protein in Malawi. It is also an important cash crop for smallholder farmers in Malawi (FAO, 1999; Magreta & Jambo, 2012). International Crops Research Institute for the Semi-Arid Tropics [ICRISAT] (2013) estimated the production of beans in Malawi to be about 111 889 million tones on average between 2000- 2011. There is a gap in information on the best nitrogen rate in a maize- cowpea and maize-bean intercrop under variable soil conditions as a way of improving production.

The current study investigated the effect of legume intercrops and mineral nitrogen on nutrient uptake, nutrient use efficiency and grain yield of maize (*Zea mays* L.) in Malawi.

## 2. Method

### 2.1 Site

Field experiments were conducted in two sites in 2016/17 growing season. The first site was the Chitedze Agricultural Research Station, near Lilongwe in the Central part of Malawi. It is located at about 13$^{o}$ 59`S longitude and 33$^{o}$ 38 ` E latitude at an elevation of 1146 m asl. Chitedze research station has a mean annual temperature of 20$^{o}$C and receives an average annual rainfall of 800 to 900 mm, 85% of which falls from November to April. The station is a representative of Lilongwe plain, which is a major maize producing agro-ecology of the country. The terrain is flat to gently undulating. The soils are chromic Luvisols. They have a well-developed structure with a dark, reddish brown top soil. The pH ranges from 4.5 to 6.0.

The second site was Makoka Agricultural Research Station near Zomba, in the southern region of Malawi. The soil is classified as a Ferric Lixisol (FAO/UNESCO) or Oxic Hapleustalf (USDA). It is situated at about 15$^{o}$ 30'S longitude and 35$^{o}$ 15'E latitude at an elevation of 1030m above sea level. The soil texture is 46% sand, 46% clay and 8% silt. Total annual rainfall ranges from 560 to 1600 mm, with a mean of 1024 mm. The site experiences unimodal type of rainfall with most of the rains falling from November to April.

Chemical and physical characteristics of soils at Chitedze and Makoka Agricultural research stations are shown in Table 1.

Table 1. Initial physical and chemical characteristics of soils at Chitedze and Makoka Agricultural Research Stations

| | | Chitedze | | Makoka | |
|---|---|---|---|---|---|
| Property | Units | Value | Interpretation* | Value | Interpretation* |
| PH | - | 6.09 | Medium | 4.91 | Deficient in Ca |
| Organic Carbon | % | 1.58 | Medium | 0.32 | Low |
| Organic Matter | % | 2.75 | Adequate | 0.53 | Low |
| Total N | % | 0.20 | Medium | 0.10 | Low |
| Available P | ppm | 39.54 | High | 72.98 | High |
| K | $cmol_c\ kg^{-1}$ | 0.11 | Low | 0.11 | Low |
| Ca | $cmol_c\ kg^{-1}$ | 0.45 | Low | 0.16 | Low |
| Mg | $cmol_c\ kg^{-1}$ | 0.05 | Low | 0.04 | Low |
| Zn | ppm | 0.31 | Low | 0.10 | Low |
| Clay | % | 19.20 | | 19.33 | |
| Silt | % | 13.00 | | 6.83 | |
| Sand | % | 67.80 | | 73.84 | |
| Textural class | | Sandy clay loam | | Sandy clay loam | |

*Chemical characteristics of soil were classified according to Landon (1991)

### 2.2 Treatments and Experimental Design

A split plot layout in a randomized complete block design (RCBD), with three replications, was used. The main plots were; cropping systems (sole maize, sole bean, sole cowpea, bean/maize and cowpea/maize intercrops). The sub plots were four rates of N (0, 52.5, 78.75 and 105 kg N ha$^{-1}$), applied as urea fertilizer. The inorganic fertilizer rates correspond to zero, one-half (50%), 75 % and 100% of the recommended national fertilizer rate for maize in Malawi. The recommended rate for Malawi is 105 kg N ha$^{-1}$ by side dressing (MAIFS, 2004). The sub plot sizes measured 1m × 7.5 m. Space for foot path (0.5 m) between plots and blocks (1 m), was provided.

### 2.3 Land Preparation and Planting

Land was prepared manually using hand implements. Maize was planted at spacing of 75cm between rows and

25 cm between planting stations. Two seeds were planted per hill and later thinned to 1 seedling, when plants were 10cm tall (53,000 plants/ha). The maize variety SC 403 was planted. In the intercropping system, the legume seeds were sown between two maize rows, at spacing of 75 cm between rows and 25 cm between planting stations. Two seeds were planted per station, and then thinned to one plant. A medium duration common bean variety (Mwaiwathu alimi) was planted. The cowpea variety planted was IT82E-16. Sole legumes were sown at a spacing of 75 cm between rows and 25 cm between planting stations.

*2.4 Fertilizer Application and Field Management*

Urea fertilizer was applied as a source of nitrogen, in two equal splits; 7 and 30 days after planting, to minimize potential leaching losses. Triple superphosphate (TSP) was applied at a rate of 40 kg P $ha^{-1}$ as basal dressing fertilizer. Careful and superficial manual weeding was done three times, after crop emergence. Pesticides (Dimethoate and Cypermethrin) were applied twice. The first application was done when the plants were two weeks old and the second when the maize was tasseling and the legumes were flowering. The pesticides were applied at a rate of 3litres/hectare.

*2.5 Soil and Plant Sampling*

Soil samples were collected using Edelman soil augers (0-30 cm) from experimental fields using traverse method, before application of treatments, and then composited. Thereafter top soil samples (0-30 cm) were collected at harvest of maize, randomly from three locations in each plot between planting stations within a row, and composited.

Maize plant samples were collected at 50 % tasseling stage. The leaf opposite the ear was taken from five plants per plot. The plants were selected randomly from the plot border rows. At physiological maturity the above ground portion of the maize was harvested from two internal rows. Maize samples were divided into stover (stalk and leaves), cob and grains. For legumes at harvest, samples were collected from two internal rows and divided into stover and pods.

*2.6 Soil and Plant Analysis*

Soil samples were air dried to constant weight, for at least 96 hours, ground to pass through a 2mm sieve and analyzed for organic N, C, extractable P and exchangeable Ca, Mg and K, following standard procedures stipulated by Anderson and Ingram (1993). Exchangeable cations were determined by using 1N ammonium acetate. Soil pH was read in a suspension of 1:2.5 soils: distilled water. Texture was determined using a hydrometer in a dispersant solution of 3% sodium hexametaphosphate (Anderson & Ingram, 1993).

Plant samples collected (maize and legumes) were weighed and chopped into small pieces. Sub-samples oven dried at 65$^{o}$C for 72 hours. The weights of the oven dry sub-samples were recorded. The dried maize samples were ground and digested in sulphuric acid- selenium extractant and analyzed for total nitrogen according to standard procedures stipulated by Anderson and Ingram (1993).

*2.7 Calculation Procedures*

*Maize nutrient uptake*: was calculated from nutrient concentrations and dry matter measured using the following formulae (Peterburgski, 1986);

$$\text{Total nutrient uptake} = \text{nutrient concentration x dry matter yield} \quad (1)$$

*Maize and legume Yield:* Grain yield was expressed at 13% moisture content, determined by moisture meter. The weight of grains and dry matter were measured by an analytical balance and yield converted into kg $ha^{-1}$ using the following formulae:

$$\text{Yield (kg/ha)} = \text{yield (kg)/m}^2 \text{ (kg) x 10000} \quad (2)$$

*Nutrient use efficiency:* using treatment yield (NUE) was calculated using the following formula (Brentrup & Palliere, 2010):

$$\text{NUE= yield with nitrogen- yield without nitrogen/ total nitrogen added} \quad (3)$$

*2.8 Statistical Analysis*

Data was subjected to analysis of variance (ANOVA) conducted using statistical package SAS version 9.3. The treatment means were separated using Duncan's Multiple Range Test (DMRT) tests at $P<0.05$.

## 3. Results

*3.1 Effect of Cropping System, Nitrogen Level, Location and Their Interaction on Maize Grain Yield*

The main effects of nitrogen levels and locations on maize grain yield were significant (Table 2). Significantly higher values ($P<0.05$) were obtained with application of 105 kg N $ha^{-1}$ (N3), followed by 78.75 kg N $ha^{-1}$ (N2), N1 (52.5kg N $ha^{-1}$) and N0 (0 kg N $ha^{-1}$), in that order. Maize grain yield was significantly higher at Chitedze than at Makoka. Effect of cropping system was not significant for maize grain yield .The effect of interaction of cropping systems x levels of nitrogen was not significant for maize grain yield (Table 3). The nitrogen levels x cropping systems x location interactions effects were not significant ($P<0.05$) for maize yield grain yield (Table 4). The interactive effects of cropping system x location and nitrogen levels x location maize grain yield were not significant (Table 5).

Table 2. Effect of nitrogen level, cropping system and location on maize grain yield, DM yield and weight of cobs

| Treatment | Maize grain Yield(Mt/ha) |
|---|---|
| Nitrogen Level | |
| N3 | 6.25a |
| N2 | 5.37b |
| N1 | 3.99c |
| N0 | 1.54d |
| Cropping system | |
| Maize- monocropping | 4.47a |
| bean/maize- intercropping | 4.16a |
| cowpea/maize- intercropping | 4.23a |
| Location | |
| Chitedze | 5.04a |
| Makoka | 3.54b |

Means with the same letter are not significantly different ($P<0.05$) according to Duncan test

Key: N0 = 0 kg N $ha^{-1}$, N1 = 52.5 kg N $ha^{-1}$, N2 = 78.75 kg N $ha^{-1}$, N3 = 105 kg N $ha^{-1}$

Table 3. Effect of the interaction between cropping systems and levels of nitrogen on maize grain yield (means ± std. error)

| Cropping system | Nitrogen level | Maize grain yield (Mt/ha) |
|---|---|---|
| maize monocropping | | |
| | N0 | 1.77±0.36 |
| | N1 | 4.49±0.54 |
| | N2 | 5.62±0.90 |
| | N3 | 6.02±0.35 |
| bean/maize intercropping | | |
| | N0 | 1.27±0.41 |
| | N1 | 3.53±0.92 |
| | N2 | 5.84±0.51 |
| | N3 | 6.03±0.81 |
| cowpea/maize intercropping | | |
| | N0 | 1.59±0.50 |
| | N1 | 3.95±0.41 |
| | N2 | 4.67±0.44 |
| | N3 | 6.71±0.33 |

Key: N0 = 0 kg N $ha^{-1}$, N1 = 52.5 kg N $ha^{-1}$, N2 = 78.75 kg N $ha^{-1}$, N3 = 105 kg N $ha^{-1}$

Table 4. Effect of interaction between cropping system x nitrogen level x location on maize yield (means ± std. error)

| Cropping system | Nitrogen level | Location | Maize Yield (Mt/ha) |
|---|---|---|---|
| maize monocropping | | | |
| | N0 | Chitedze | 2.24±0.48 |
| | | Makoka | 1.30±0.43 |
| | N1 | Chitedze | 5.41±0.61 |
| | | Makoka | 3.57±0.46 |
| | N2 | Chitedze | 7.10±1.00 |
| | | Makoka | 4.14±0.95 |
| | N3 | Chitedze | 6.03±0.77 |
| | | Makoka | 6.00±0.14 |
| bean/maize intercropping | | | |
| | N0 | Chitedze | 2.01±0.35 |
| | | Makoka | 0.52±0.42 |
| | N1 | Chitedze | 4.97±1.37 |
| | | Makoka | 2.10±0.55 |
| | N2 | Chitedze | 6.90±0.12 |
| | | Makoka | 4.77±0.40 |
| | N3 | Chitedze | 7.03±0.93 |
| | | Makoka | 5.03±1.18 |
| cowpea/maize intercropping | | | |
| | N0 | Chitedze | 1.82±0.71 |
| | | Makoka | 1.35±0.85 |
| | N1 | Chitedze | 4.44±0.70 |
| | | Makoka | 3.46±0.31 |
| | N2 | Chitedze | 5.17±0.83 |
| | | Makoka | 4.16±0.21 |
| | N3 | Chitedze | 7.38±0.25 |
| | | Makoka | 6.05±0.13 |

Key N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha$^{-1}$, N2 = 78.75 kg N ha$^{-1}$, N3 = 105 kg N ha$^{-1}$.

Table 5. Effect of the interactions between cropping systems and location, nitrogen levels and location on maize yield (means ± std. error)

| Treatment | Location | Maize grain yield (Mt/ha) |
|---|---|---|
| Cropping system | | |
| maize monocropping | | |
| | Chitedze | 5.19±0.63 |
| | Makoka | 3.75±0.56 |
| bean/maize intercropping | | |
| | Chitedze | 5.23±0.71 |
| | Makoka | 3.11±0.64 |
| cowpea/maize intercropping | | |
| | Chitedze | 4.71±0.66 |
| | Makoka | 3.75±0.54 |
| Nitrogen level | | |
| N0 | Chitedze | 2.02±0.27 |
| | Makoka | 1.06±0.33 |
| N1 | Chitedze | 4.94±0.50 |
| | Makoka | 3.04±0.33 |
| N2 | Chitedze | 6.39±0.48 |
| | Makoka | 4.35±0.32 |
| N3 | Chitedze | 6.82±0.41 |
| | Makoka | 5.69±0.38 |

Key N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha$^{-1}$, N2 = 78.75 kg N ha$^{-1}$, N3 = 105 kg N ha$^{-1}$

### *3.2 Effect of Cropping System, Nitrogen Level, Location and Their Interaction on Nitrogen Uptake by Maize*

There were significant (P<0.05) main effects of nitrogen levels and location on N uptake by maize. The highest uptake was observed in N3 (105 kg N $ha^{-1)}$ nitrogen level, followed by N2 (78.75 kg N $ha^{-1)}$.The lowest amounts of nutrient uptake were recorded in N0 (0 kg N ha $^{-1}$) and N1 (52.5 kg N $ha^{-1}$) nitrogen levels. Significantly higher uptake was observed at Chitedze than Makoka. Cropping systems did not have any significant effect on nutrient uptake (Table 6). The interactive effect of cropping systems x nitrogen levels on N uptake by maize was significant (P<0.05) (Table 7). The uptake was significantly higher in bean/maize intercropping system followed by cowpea/maize intercropping under N3 level of nitrogen in both cropping systems and in maize monocropping when the nitrogen levels were N1 and N2.

The effect of cropping systems x location interaction on N uptake in maize was significant only under maize monocropping system. The uptake was significantly higher at Chitedze than at Makoka in maize monocropping system at both sites (Table 8). The interaction of nitrogen levels x location on N uptake by maize was not significant (P<0.05).The interaction effects of nitrogen level x cropping system x location on N uptake by maize was significant (P<0.05) (Table 9). Uptake was significantly higher under maize monocropping system combined with N3 level of nitrogen at Chitedze. The values were significantly lower under cowpea/maize intercropping system combined with N0 level of nitrogen at Makoka.

Table 6. Effects of cropping systems, nitrogen levels and locations on nutrient uptake in maize

| **Treatments** | Nutrient uptake (mg-N/plant) |
|---|---|
| **Cropping system** | |
| maize monocropping | 132.13a |
| bean/maize intercropping | 117.92a |
| cowpea/maize intercropping | 122.68a |
| **Nitrogen level** | |
| N0 | 56.05c |
| N1 | 103.36bc |
| N2 | 139.41b |
| N3 | 198.15a |
| **Location** | |
| Chitedze | 163.03a |
| Makoka | 85.45b |

Means with the same letter within a column are not significantly different (P<0.05) according to Duncan test

Key: N0 = 0 kg N $ha^{-1}$, N1 = 52.5 kg N $ha^{-1}$, N2 = 78.75 kg N $ha^{-1}$, N3 = 105 kg N $ha^{-1}$.

Table 7. Effect of interaction between nitrogen levels x cropping system on nutrient uptake in maize (means ± std. error)

| Cropping system | Nitrogen level | Nutrient uptake (mg-N/plant) |
|---|---|---|
| maize monocropping | N0 | 53.07±10.53 |
| | N1 | 123.49±25.02 |
| | N2 | 132.39±16.65 |
| | N3 | 219.57±38.86 |
| bean/maize intercropping | N0 | 49.66±16.30 |
| | N1 | 79.94±19.24 |
| | N2 | 154.56±49.26 |
| | N3 | 187.49±44.08 |
| cowpea/maize intercropping | N0 | 65.42±25.32 |
| | N1 | 106.65±41.92 |
| | N2 | 131.28±39.25 |
| | N3 | 187.38±55.81 |

**Key:** N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N $ha^{-1}$, N2 = 78.75 kg N $ha^{-1}$, N3 = 105 kg N $ha^{-1}$.

Table 8. Effects of cropping system x location, nitrogen levels x location on nutrient uptake in maize (means ± std. error)

| Treatments | Location | Nutrient uptake (mg N/plant) |
|---|---|---|
| Cropping System | | |
| maize monocropping | Chitedze | 151.85±28.00 |
| | Makoka | 112.41±18.82 |
| bean/maize intercropping | Chitedze | 156.23±35.27 |
| | Makoka | 79.60±13.61 |
| cowpea/maize intercropping | Chitedze | 181.02±35.21 |
| | Makoka | 64.34± 9.95 |
| Nitrogen Levels | | |
| N0 | Chitedze | 75.35 ±16.39 |
| | Makoka | 36.75 ± 8.59 |
| N1 | Chitedze | 136.63±27.61 |
| | Makoka | 70.09±13.72 |
| N2 | Chitedze | 180.17±34.55 |
| | Makoka | 98.65±13.72 |
| N3 | Chitedze | 259.98±39.85 |
| | Makoka | 136.31±15.81 |

**Key:** N0 = 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha$^{-1}$, N2 = 78.75 kg N ha$^{-1}$, N3 = 105 kg N ha$^{-1}$.

Table 9. Effect of the interaction between nitrogen levels x cropping system x location on nutrient uptake in maize (means ± std. error)

| Cropping System | Nitrogen levels | Location | Nutrient uptake (mg N/plant) |
|---|---|---|---|
| maize monocropping | N0 | Chitedze | 64.98± 8.73 |
| | | Makoka | 41.15±18.33 |
| | N1 | Chitedze | 147.37±39.42 |
| | | Makoka | 99.62±31.73 |
| | N2 | Chitedze | 136.78±29.40 |
| | | Makoka | 128.00±22.43 |
| | N3 | Chitedze | 258.27±72.06 |
| | | Makoka | 180.86±29.32 |
| bean/maize intercropping | | | |
| | N0 | Chitedze | 59.12±31.09 |
| | | Makoka | 40.20±16.51 |
| | N1 | Chitedze | 97.79±37.84 |
| | | Makoka | 62.10±10.02 |
| | N2 | Chitedze | 223.72±79.01 |
| | | Makoka | 85.40±33.23 |
| | N3 | Chitedze | 244.27±78.38 |
| | | Makoka | 130.71±18.60 |
| cowpea/maize intercropping | | | |
| | N0 | Chitedze | 101.94±40.52 |
| | | Makoka | 28.91±15.18 |
| | N1 | Chitedze | 164.75±70.40 |
| | | Makoka | 48.55±21.28 |
| | N2 | Chitedze | 179.99±72.97 |
| | | Makoka | 82.56± 1.71 |
| | N3 | Chitedze | 277.41±86.27 |
| | | Makoka | 97.35± 5.18 |

**Key: N0 =** 0 kg N ha $^{-1}$, N1 = 52.5 kg N ha$^{-1}$, N2 = 78.75 kg N ha$^{-1}$, N3 = 105 kg N ha$^{-1}$

### *3.3 Nutrient Use Efficiency (NUE) of Maize*

The results in table 10 indicate that N2 (78.75 kg N ha$^{-1)}$ had the highest nitrogen use efficiency followed by N1

(52.5 kg N $ha^{-1}$) and N3 (105 kg N $ha^{-1}$) in that order.

Table 10. Nutrient Use Efficiency of maize at different nitrogen levels

| Nitrogen level | Maize yield(Mt/ha) | NUE (%) |
|---|---|---|
| N0 | 1.54 | |
| N1 | 3.99 | 46.67 |
| N2 | 5.37 | 48.63 |
| N3 | 6.25 | 44.86 |

### *3.4 Effect of Cropping System, Nitrogen Level, Location and Their Interaction on Legume Biomass and Number of Nodules*

The main effect cropping systems on legume DM yield and number of nodules was significant (P<0.05). The results in table 11 indicate that significantly higher values of legume DM yield were obtained under sole cowpea while significantly higher values of number of nodules were recorded under sole bean and bean/maize intercropping. On the other hand significantly lower values of legume DM yield were recorded under bean/maize intercropping system while significantly lower values of number of nodules were recorded under sole cowpea. From the same table the main effect of location was significant (P<0.05) for DM yield, and number of nodules. Significantly higher number of nodules was reported at Chitedze. On the other hand significantly higher values of DM yield were recorded under Makoka.

The interactive effect of cropping systems x levels of nitrogen was significant (P<0.05) on legume DM yield and number of nodules (Table 12). Significantly higher values were obtained under the following treatment combinations: cowpea/maize intercropping x N3 and bean/maize intercropping x N1, respectively. On the other hand significantly lower values were obtained under the following treatment combinations; bean/maize intercropping system x N2 and cowpea/maize intercropping x N2 for legume DM and number of legumes, respectively (Table 13).

The effect of interaction of cropping system x nitrogen level x location was significant (P<0.05) on legume dry matter (Table 14). From the same table it was observed that the interaction was significant under cowpea/maize intercropping and it was not significant under bean/maize intercropping system. The interactions that produced significantly higher values of legume DM and number of nodules were observed under the following treatment combinations; cowpea/ maize intercropping x N3 x Makoka, and cowpea/ maize intercropping x N3 x Chitedze.

The effect of the interaction of cropping system x location was significant for legume DM yield (Table 15). The results indicated that significantly higher values of legume yield DM yield were obtained under the treatment combination of sole cowpea x Makoka. From the same table significantly higher values for number of nodules were obtained under the following treatment combinations; cowpea/maize intercropping x Chitedze. The interaction of nitrogen levels x location was significant for legume yield DM yield (Table 15). Significantly higher values were obtained under the following treatment combinations; N3 level of nitrogen x Makoka.

Table 11. Effect of Nitrogen level, cropping system and location on legume dry matter (DM) yield and number of nodules

| Treatments | Legume DM yield (Mt/ha) | Number of nodules/plant |
|---|---|---|
| Nitrogen Level | | |
| N0 | 1.00a | 14.58a |
| N1 | 1.05a | 12.08a |
| N3 | 1.16a | 13.75a |
| N2 | 0.93a | 9.08a |
| Cropping system | | |
| Sole cowpea | 2.66a | 5.66c |
| Sole bean | 1.75b | 26.33a |
| cowpea/maize intercropping | 1.26c | 7.33bc |
| bean/maize intercropping | 0.81d | 17.41ab |
| Location | | |
| Chitedze | 0.98b | 19.40a |
| Makoka | 1.56a | 6.80b |

Means with the same letter within a column are not significantly different (P<0.05) according to Duncan test

**Key:** N0 = 0 kg N $ha^{-1}$, N1 = 52.5 kg N $ha^{-1}$ , N2 = 78.75 kg N $ha^{-1}$ , N3 = 105 kg N $ha^{-1}$.

Table 12. Effect of the interaction of cropping systems x levels of nitrogen on legume DM yield, and number of nodules (means ± std. error)

| Cropping System | Nitrogen Level | DM Yield(Mt/ha) | Number of Nodules/plant |
|---|---|---|---|
| bean/maize intercropping | | | |
| | N0 | 0.83± 0.08 | 18.83±6.54 |
| | N1 | 0.87± 0.17 | 19.00±6.10 |
| | N2 | 0.65± 0.09 | 13.67±2.74 |
| | N3 | 0.88±0.16 | 18.17±10.84 |
| cowpea/maize intercropping | | | 10.33±1.36 |
| | N0 | 1.17± 0.24 | |
| | N1 | 1.4± 0.22 | 5.17±0.65 |
| | N2 | 1.21± 0.31 | 4.50±0.89 |
| | N3 | 1.45± 0.29 | 9.33±5.94 |

**N0 =** 0 kg N $ha^{-1}$, N1 = 52.5 kg N $ha^{-1}$, N2 = 78.75 kg N $ha^{-1}$, N3 = 105 kg N $ha^{-1}$

Table 13. Effect of interaction of cropping system x nitrogen level x location on legume DM yield, and number of nodules (means ± std. error)

| Cropping System | Nitrogen Level | Location | DM (Mt/ha) | Number of nodules/plant |
|---|---|---|---|---|
| bean/maize intercropping | | | | |
| | N0 | Chitedze | 0.94±0.04 | 31.00±7.94 |
| | | Makoka | 0.72±0.13 | 6.67±1.67 |
| | N1 | Chitedze | 0.86±0.15 | 32.00±4.04 |
| | | Makoka | 0.88±0.34 | 6.00±1.00 |
| | N2 | Chitedze | 0.76±0.09 | 19.67±0.88 |
| | | Makoka | 0.55±0.15 | 7.67±0.88 |
| | N3 | Chitedze | 0.83±0.19 | 31.33±20.34 |
| | | Makoka | 0.94±0.31 | 5.00±0.58 |
| cowpea/ maize intercropping | | | | |
| | N0 | Chitedze | 0.89±0.23 | 10.33±1.86 |
| | | Makoka | 1.44±0.41 | 10.33±2.40 |
| | N1 | Chitedze | 0.85±0.19 | 5.00±1.15 |
| | | Makoka | 1.62±0.26 | 5.33±0.88 |
| | N2 | Chitedze | 0.66±0.06 | 3.33±0.67 |
| | | Makoka | 1.75±0.44 | 5.67±1.45 |
| | N3 | Chitedze | 1.10±0.15 | 14.67±12.17 |
| | | Makoka | 1.79±0.53 | 4.00±0.00 |

**Key:** N0 = 0 kg N $ha^{-1}$, N1 = 52.5 kg N $ha^{-1}$, N2 = 78.75 kg N $ha^{-1}$ , N3 = 105 kg N $ha^{-1}$

Table 14. Effect of the interactions between cropping systems and location, nitrogen levels and location on legume DM yield, and number of nodules (means ± std. error)

| Treatments | Location | DM (Mt/ha) | Number of Nodules/plant |
|---|---|---|---|
| Cropping System | | | |
| bean/maize intercropping | | | |
| | Chitedze | 0.84±0.06 | 28.50±4.98 |
| | Makoka | 0.77± 0.12 | 6.33±0.56 |
| cowpea/maize intercropping | | | |
| | Chitedze | 0.88± 0.09 | 8.33±2.97 |
| | Makoka | 1.65± 0.18 | 6.33±0.96 |
| cowpea monocropping | | | |
| | Chitedze | 1.84± 0.39 | 5.67±3.18 |
| | Makoka | 3.47±1.00 | 5.67±1.76 |
| bean monocropping | | | |
| | Chitedze | 1.11±0.08 | 41.00±13.89 |
| | Makoka | 2.39±0.83 | 11.67± 2.40 |
| Nitrogen level | | | |
| N0 | Chitedze | 0.92±0.11 | 20.67±5.89 |
| | Makoka | 1.08±0.25 | 8.50±1.54 |
| N1 | Chitedze | 0.86±0.15 | 18.50±6.32 |
| | Makoka | 1.25±0.25 | 5.67±0.61 |
| N2 | Chitedze | 0.71±0.05 | 11.50±3.69 |
| | Makoka | 1.15±0.34 | 6.67±0.88 |
| N3 | Chitedze | 0.97±0.18 | 23.00±11.24 |
| | Makoka | 1.36±0.33 | 4.50± 0.34 |

**Key: N0 =** 0 kg N $ha^{-1}$, N1 = 52.5 kg N $ha^{-1}$, N2 = 78.75 kg N $ha^{-1}$, N3 = 105 kg N $ha^{-1}$

## 4. Discussion

### *4.1 Main Effects of Cropping System, Nitrogen Level, Location on Maize Grain Yield*

N fertilizer application (52.5, 78.75 and 105 kg N $ha^{-1}$) resulted in significant increases in maize grain yield compared to control (no fertilizer). Nitrogen is a critical macronutrient for the growth of maize and its application enhances vigorous vegetative growth (Havlin *et al*., 2008). Many authors including Sebetha (2015), Abayomi, George-Arijenja and Kolawole (2006), Mahdi and David (2005), Morgado and Willey (2003) and Muchow (1988), similarly reported that application of N fertilizer generally resulted in increases in maize grain yield. Significant increases in maize grain yields occurred with increase in N level, from 0 to 105 kg N $ha^{-1}$, an indication that application of 105 kg N $ha^{-1}$ was optimal for maximum yield per unit area. Elevated N concentration results to healthier plant growth (Legg, Stanford & Bennett, 1979: Meisinger, Bandel, Stanford, & Legg, 1985). The reduction in maize grain yield under maize without N fertilizer is in agreement with the findings of Ding *et al.,* (2005) and Lucas (1986).

Maize grain yields were not significantly increased by inclusion of bean and cowpea. Maize has a C4 carbon assimilation pathway and may have had a competitive edge over legumes, which are C3 plants (Kitonyo, Chemining'wa, & Muthomi, 2013; Sage & Zhu, 2011). In addition, maize was more competitive for soil nitrogen because its roots are distributed in both shallow and deeper layers (Carruthers *et al*., 2000). This is in contrast to the root systems of legumes which are smaller and confined to the upper layers (Hauggaard-Nielsen, Ambus & Jensen, 2001). Contrarily, most studies report that intercropped systems yield more than maize monocropping due to the ability of intercropped legumes to fix most of their nitrogen from the atmosphere (Chabi-Olaye, Nolte, Schulthess, & Borgemeister, 2005; Hauggaard-Nielson & Jensen, 2001). Common beans are, however, poor N fixers, in comparison to other legumes; hence they do not contribute significantly towards the N requirement by maize (Westermann, Kleinkopf, Porter, & Leggett, 1981, Bliss, 1993; Martinez-Romero, 2003). Mineral nitrogen may have reduced the rate of nitrogen fixation by cowpea in this study (Houwaard, 1979).

Results showed significantly higher maize grain yield at Chitedze than Makoka. This may be attributed to lower rainfall amounts and higher temperature at Makoka. The optimal temperature for warm season maize is 15−20 °C for planting and 20−30 °C for the regular growing season (Bird, Cornelius, & Keys, 1977). The temperature range for Makoka during the growing season was 17.84- 28.06 $^{0}$C (Table 1). The higher temperature led to higher rates of evapotranspiration and therefore increased competition for moisture (Ben-Asher, Garcia, Garcia, & Hoogenboom, 2008). Water forms an integral part of plant body and plays an important role in growth initiation, maintenance of developmental process of plant life and hence has pivotal function in crop production (Aslam *et al*., 2012).

4.1.1 Interaction Effects of Cropping System, Nitrogen Level, Location on Maize Grain Yield

The interaction effect of cropping systems × N level was not significant for maize grain yield. This may possibly have been due to inhibition of symbiotic nitrogen fixation by the legumes due the application of N fertilizer (Erker &Brick, 2014). This is in agreement with the findings of Omokanye, Kelleher, and McInnes, (2013) who reported that the interaction effect of cropping system x nitrogen levels on maize grain yield was not significant. The results further indicated that maize grain yield was not significantly affected by the interaction of cropping system x location because maize faced stiff competition for resources from legumes. These findings are contrary to the findings of Sebetha (2015) who reported that the interaction had a significant effect on maize DM yield.

The interaction effect of cropping system x location x nitrogen level on maize grain yield was not significant. These findings suggest that cropping system did not play a vital role in dry matter accumulation. This finding is not in agreement with Sebetha (2015), who reported the significance of the interaction on maize grain yield.

*4.2 Main Effects of Cropping System, Nitrogen Level, and Location On Nitrogen Uptake By Maize*

The results indicated that an increase in N uptake by maize occurred with increasing rates of N fertilizer applied. The maximum value (198.15 mg-N/plant) was recorded with the highest N fertilizer level (105 kg N ha$^{-1}$) while the lowest (56.05 mg-N/plant) at zero fertilizer rate. Rahman (2011) and Morgado and Willey (2003) similarly reported that N uptake by maize plant was influenced significantly by N fertilizer application rate. They reported lowest uptake in control (no N fertilizer) treatment. Chirnogeanu, Badea, Petcu, and Picu (1997) also documented that high levels of soil nitrogen had a significant positive influence on the nutrient uptake and translocation in leaves. Thus, the N content in maize plants increased in variation with high fertilizer rates.

The results of this study indicated that there were no significant differences in nutrient uptake by maize in the different cropping systems. Common bean being a poor N fixer did not supply enough N to be taken up by both the legume and the cereal crop involved. Application of nitrogen fertilizer might have hindered symbiotic nitrogen fixation by cowpea (Henson & Bliss, 1991; Erker & Brick, 2014). Contrarily, Eskandari and Ghanbari (2009) reported significantly greater nitrogen uptake in intercropping than sole maize. They reported that intercropping was more efficient at exploiting a larger soil total volume if component crops have different rooting habits, especially depth of rooting.

Nitrogen uptake by maize was significantly greater at Chitedze than at Makoka. This difference may be attributed to the differences in total soil N at the sites. The levels at Chitedze and Makoka were medium (0.20%) and low (0.10%), respectively (Table 2), according to the nutrient classification of Landon (1991).

4.2.1 Interaction Effects of Cropping System, Nitrogen Level, Location on Nitrogen Uptake by Maize

The effect of cropping system × N level interaction on N uptake by maize was significant. Significantly higher N uptake by maize was observed in the bean/maize intercropping system than cowpea/maize intercropping under N3 level of N, in both cropping systems, and maize monocropping combined with nitrogen levels of N1 and N2. This might have been due to enhanced supply nitrogen from fertilizer. Additionally, there may have occurred greater exploitation of a larger soil total volume for nutrients and water due to different rooting habits of the component crops in an intercropping system.

The effect of cropping systems × location interaction on N uptake in maize was significant only under maize monocropping system. The higher uptake in maize monocropping system at both sites was because the maize did not face competition for nutrients from legumes, as they were sole crops.

N uptake by maize was not significantly affected by the interaction of nitrogen levels × location. It is possible that this finding might be influenced by the location conditions such as moisture, soil aeration, soil drainage and soil textures which have an impact on N-transport and N -transformation processes that limit N availability to crops or lead to losses such as through leaching.

The nitrogen level × cropping system × location interaction effect on N uptake by maize was significant. The higher uptake observed under combination of maize monocropping system, N3 level of nitrogen at Chitedze was because sole maize did not have any competition from legumes for resources such as nutrients. N uptake was significantly lower under cowpea/maize intercropping system combined with N0 level of nitrogen at Makoka research station. It is possible that maize suffered stiff competition for resources from legumes.

### *4.3 Nutrient Use Efficiency (NUE) of Maize*

Maximum maize NUE (48.63 kg/kg) was obtained at application rate of 78.75 kg N ha$^{-1}$ and the minimum value (44.86 kg/kg) was recorded at the highest N rate (105 kg N ha$^{-1}$). The decrease in NUE with increasing N fertilizer rate was because yield rises less than the N supply in soil and fertilizer (Lopez-Bellido & Lopez-Bellido (2001), Raun & Johnson (1999), Pierce & Rice (1988), Sowers, Pan, Miller, & Smith (1994) and Zhao *et al*., (2006) also reported that high rates of N decreased NUE in cereals. The findings of Kanampiu, Raun and Johnson (1997) generally indicated decreases in NUE but increases grain protein content and N loss with increasing N fertilizer rate.

### *4.4 Main Effects of Cropping System, Nitrogen Level, Location on Legume DM Yield and Number of Nodules*

The main effect of cropping system on legume DM yield, and number of nodules was significant. Higher values of legume DM yield were reported under sole cowpea (2.66 Mt/ha) and sole bean (1.75Mt/ha) while lower values were obtained under cowpea/maize intercropping (1.26Mt/ha) and bean/maize intercropping system (0.81Mt/ha).These findings might be attributed to the well-known idea that cereals take up nutrients, especially N, mainly during the vegetative growth stage and associated vigorous growth may cause shading of the legume and thereby reduce its growth during later growth stages resulting in low yielding ability (Banik *et al*., 2006). These results are supported by the findings of Birteeb, Addah, Jakper, and Addo-Kwafo (2011) who reported significantly reduced legume DM yield of intercropped legumes.

The main effect of N level on legume DM yield and number of nodules was not significant. These findings may be attributed to the fact that application of mineral nitrogen reduces both nodulation and the rate of nitrogen fixation by legumes (Houwaard, 1979). These findings are in agreement with the findings of Bagayoko, Buekert, Lung, Bationo and Romheld (1996) who observed that cowpea DM yield was not influenced by N application. Legume number of nodules per plant were higher under N0 (0 kg N ha$^{-1}$) than 52.5, 78.75 and 105 kg N ha$^{-1}$, however, they were not significantly different from the parameters obtained under 0 kg N ha$^{-1}$. It was expected that legume DM yield, and number of nodules under N fertilizer application would be lower than the control since N fertilization has a negative effect of legume growth, development and yield.

Legume DM yield was significantly affected by location. Legume DM yield was higher at Makoka than at Chitedze. It was also observed that the number of nodules per legume plant was affected by the location of the study site. Legumes planted at Chitedze research station had significantly higher number of nodules per plant (19.40) than at Makoka (6.80). This may be attributed to different soil structure and climatic conditions of these two sites. On the other hand N fertilizer application has a well-established negative effect on nitrogen fixation of legume root nodules. It is also reported that with increasing doses of N there is a nearly linear decrease in the number of root nodule (Becker, Alazard, & Ottow, 1986) This finding concurs with what Sebetha (2015) observed. He reported that number of nodules per cowpea plant was affected by location. The effect of location on number of number nodules can be attributed to fluctuations in pH, nutrient availability, temperature, and water status, among other factors that greatly influence the growth, survival, and metabolic activity of nitrogen fixation bacteria and plants, and their ability to enter into symbiotic interactions (Werner & Newton, 2005).The results on the number of nodules per plant concur with the ranges reported by Bhuvaneswari, Lesniak, and Bauer (1998).

#### 4.4.1 Interaction Effects of Cropping System, Nitrogen Level, Location on Legume DM Yield and Number of Nodules

Legume DM yields and number of nodules were significantly affected by the interaction effect of cropping systems × levels of nitrogen. Findings of the study agree with the study of Sebetha (2015) who reported that the interaction of nitrogen and location significantly affected the number of nodules per cowpea plant. In addition common beans are poor N fixers, in comparison to other legumes; hence they do not contribute significantly towards the N requirement by maize (Westermann *et al*., 1981, Bliss, 1993; Martinez-Romero, 2003).

Significantly higher values were obtained under the following treatment combinations:, cowpea/maize intercropping x N3, and bean/maize intercropping x N1, respectively. On the other hand significantly lower values were obtained under the following treatment combinations; bean/maize intercropping system x N2 and cowpea/maize intercropping x N2 for legume DM yield and number of nodules, respectively. This might be attributed to cowpea having a higher potential of fixing N from the atmosphere through biological nitrogen fixation than beans (Freitas, Sampaio, Santos, & Fernandes, 2010).

The interaction effect of cropping system × location was significant for legume DM yield. The results indicate that significantly higher values of legume DM yield were obtained under the treatment combination of sole cowpea x Makoka. This might be attributed to good environmental factors present at Makoka such conducive as temperature, good moisture content and good soil structure which were conducive for the production of cowpeas. Legume DM yield was significantly affected by the interaction effect of nitrogen levels and location. These findings contributed to the significance of comparing cropping systems towards improvement of legume yields since such interaction effect on legume yield was not revealed during previous studies.

The interaction effect of cropping system x nitrogen level x location was significant on legume DM yield. The interaction was however significant for number of nodules per cowpea plant (cowpea/maize intercropping).This is in agreement with what was reported by Sebetha (2015) that the interaction significantly affected the number of nodules per cowpea plant.

## 5. Conclusions

Diminishing land sizes, due to the ever increasing human population, and continuous cultivation practices have led to declining soil fertility and maize yield in Malawi. The study to determine effects of mineral N fertilizer application and legume integration on maize nutrient uptake and yield, demonstrated that N absorption by maize occurred with application of the water soluble urea fertilizer. N uptake increased with increase in fertilizer rate. Higher values were obtained with the application of 105 kg N ha$^{-1}$. The integration of legumes did not have any significant effect on uptake. This may have been because N fixation was not optimal. Nodulation in cowpea and common bean, a major conduit for available nitrogen into the biosphere, was not significantly increased by N application. Additionally, common bean is a poor N fixer. The study further showed that the effect of cropping system × N level interaction on N uptake by maize was significant. Significantly higher values were recorded under cowpea/maize intercropping system and N3 nitrogen level (105 kg N ha$^{-1}$). It was observed that NUE decreased with increasing N fertilizer rate. The minimum value (44.86 kg/kg) was recorded at the highest N rate (105 kg N ha$^{-1}$). Most of the fertilizer remains unutilized leading to nutrient toxicity. On the other hand, there was a tremendous reduction in maize development and yield when no N fertilizer was applied to the maize. Cropping system did not have an effect on maize development and yield..

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## References

Abayomi, Y., George-Arijenja, A., & Kolawole, I.A. (2006). Comparative leaf growth and grain yield responses of hybrid and open-pollinated maize genotypes to nitrogen fertilizer application. *Agro Search, 8*(1 and 2): 13-26. http://dx.doi.org/10.4314/agrosh.v8i1.39435

Anderson, J. M., & Ingram, J. S. I. (1993). *Tropical Soil Biology and Fertility*. A hand book of Methods. 2ended. Wallingford, UK; CABI Publishing.

Aslam, M., Zamir, M. S. I., Afzal, I., Yasee, M., Mubeen, M., & Shoaib, A. (2012). Drought stress, its effect on maize production and development of drought tolerance through potassium application. *Agronomical Research in Moldavia, 2*(154).

Bagayako, M., Buekert, A., Lung, G., Bationo, A., & Romheld, V. (2000). Cereal/legume rotation effects on cereal growth in Sudano-Sahelian West Africa: Soil mineral nitrogen, mycorrhizae and nematodes. *Plant Soil, 218*, 103-116. https://doi.org/10.1023/A:1014957605852

Banik, P., Midya, A., Sarkar, B. K., & Ghose, S. S. (2006). Wheat and chickpea intercropping systems in an additive series experiment: Advantages and weed smothering. *European Journal of Agronomy, 24*, 325-332. https://doi.org/10.1016/j.eja.2005.10.010

Becker, M., Alazard, D., & Ottow, J. C. G. (1986). Mineral nitrogen effect on nodulation and nitrogen fixation of the stem-nodulating legume *Aeschynomene afraspera*. *Z. Pflanzenernaehr. Bodenk, 149*, 485-491. https://doi.org/10.1002/jpln.19861490411

Ben-Asher, J., Garcia A., Garcia, Y., & Hoogenboom, G. (2008). Effect of high temperature on photosynthesis and transpiration of sweet corn (*Zea mays* L. var. *rugosa*). *Photosynthetica, 46*(4), 595-603. https://doi.org/10.1007/s11099-008-0100-2

Bhuvaneswari, T. Y, Lesniak, A. P., & Bauer, W. D. (1998). Efficiency of nodule initiation in cowpea and soybean. *Plant Physiology Journal, 86*, 1210-1215. https://doi.org/10.1104/pp.86.4.1210

Bird, I. F., Cornelius, M. J., & Keys, A. J. (1977). Effects of temperature on photosynthesis by maize and wheat. *Journal of Experimental Botany, 28*, 519524. https://doi.org/10.1093/jxb/28.3.519

Birteeb, P. T., Addah, W., Jakper, N., & Addo-Kwafo, A. (2011). Effects of intercropping cereal-legume on biomass and grain yield in the savannah zone. *Livestock Research for Rural Development Journal, 23*(198).

Bliss, F. A. (1993). Breeding common bean for improved biological nitrogen fixation. *Plant Soil Journal, 152*, 71-79.

Brentrup, F., & Palliere, C. (2010). *Nitrogen use efficiency as an agro-environmental indicator*. OECD workshop

Carruthers, K., Prithiviraj, B., Fe, O., Cloutler, D., Martin, R. C., & Smith, D. L. (2000). Intercropping corn with soybean, lupin and forages: yield component responses. *European Journal of Agronomy, 12*, 163-115. https://doi.org/10.1016/s1161-0301(99)00051-9

Chabi-Olaye, A., Nolte, C. F., & Borgemeister, C. (2005). Relationships of intercropped maize, stem borer damage to maize yield and land-use efficiency in the humid forest of Cameroon. *Bulletin of Entomological Research, 95*, 417-427. https://doi.org/10.1079/ber2005373

Chirnogeanu I., Badea, E Petcu E., & Picu I. (1997). The effect of mineral fertilization on uptake of some nutrients in maize under irrigated conditions. Romania: *Romanian Agricultural Research*, 55-66

Ding, L., Wang, K. J., Jiang, G. M., Biswas, D. K., Xu, H., Li, L. F., & Li, Y. H. (2005). Effect of nitrogen deficiency on photosynthetic traits of maize hybrids released in different years. *Annals of Botany, 96*(5), 925-930. https://doi.org/10.1093/aob/mci244

Erker, B., & Brick, M. A. (2014). CSU Homepage. Retrieved November 05, 2014, from Colorado State University Extension: http:www.ext.colostate.edu/pubs/crops/00305.html

Eskandari, H., & Ghanbari, A. (2009). Intercropping of maize (*Zea mays*) and cowpea (*Vigna sinensis*) as whole-crop forage: Effect of different planting pattern on total dry matter production and maize forage quality. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 37*(2), 152-155.

FAOSTAT. (2013). Cowpea. Retrieved from http://faostat.fao.org/cowpea.

Food & Agriculture Organization (FAO) of the United Nations. (1999). *Phaseolus* Bean: Post-harvest operations

Food & Agriculture Organization (FAO) of the United Nations. (2004). COWPEA: Post-harvest operations

Freitas, A.D.S. Sampaio, E.V.S.B. Santos, C.E.R.S.& Fernandes, A.R.(2010). Biological nitrogen fixation in legume trees of the Brazilian caatinga. *Journal of Arid Environments*, 74:344 – 349. https://doi.org/10.1016/j.jaridenv.2009.09.018

Gachene, C. K. K., & Kimaru, G. (2003). Soil fertility and land productivity: A guide for extension workers in the eastern region of Africa RELMA Technical Handbook Series 30. Nairobi, Kenya

Hauggaard-Nielsen, H., & Jensen E. S. (2001). Evaluating pea and barley cultivars for complementarity in intercropping at different levels of soil N availability. *Field Crops Research, 72*, 185-196. http://dx.doi.org/10.1016/S0378-4290 (01)00176-9

Hauggaard-Nieson, H., Ambus, P., & Jensen, E. S. (2001). Temporal and spatial distribution of roots and competition for nitrogen in pea-barley intercrops. A field studies employing 23 P techniques. *Plant and Soil, 236*, 63-74. https://doi.org/10.1023/a:1011909414400

Havlin, J. L., Tisdale, S. L, Beaton, J. D., & Werner, L. N. (2008). *Soil Fertility and Fertilizers*. *An introduction to Nutrient Management*. Seventh edition. Pearson Education, Inc, Publishing. Prentice Hall

Hayat, R., Safdar, A., Siddique, M. T., & Chatha, T. H. (2008). Biological Nitrogen Fixation of Summer Legumes and their Residual Effects on Subsequent Rain fed Wheat Yield. *Pakistan Journal of Botany, 40*(2), 711-722.

Henson, R. A., & Bliss, F. A. (1991). Effects of N fertilizer application timing on common bean production. *Fertilizer Research, 29*, 133-138. https://doi.org/10.1007/bf01048951

Houwaard, F. (1979): Effect of combined nitrogen on symbiotic nitrogen fixation in pea plants. (PhD. Thesis, Agricultural University Wageningen, Netherlands.)

International Crops Research Institute for Semi-arid Tropics [ICRISAT] (2013). Bulletin of tropical legumes.

International Institute of Tropical Agriculture (IITA). (2016). http://www.iita.org/cowpea; jsessionid. Accessed on 20/03/2016.

Kanampiu, F. K., Raun, W. R., & Johnson, G. V. (1997). Effect of Nitrogen Rate on Plant Nitrogen Loss in Winter Wheat Varieties. *Journal of Plant Nutrition, 20*, 389-404. https://doi.org/10.1080/01904169709365259

Kitonyo, O. M., Chemining'wa, G. N., & Muthomi, J. W. (2013). Productivity of farmer-preferred maize varieties intercropped with beans in semi-arid Kenya. *International Journal of Agronomy and Agricultural Research, 3*(1), 6-16.

Landon, J. R. (Ed.) (1991) .*Booker Tropical Soil Manual*. *A Handbook for Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics*. John Wiley and Sons, Inc., New York. 474pp.

Legg, J. O., Stanford, G., & Bennett, O. L. (1979). Utilization of labelled N fertilizer by silage corn under conventional and no-till culture. *Agronomy Journal, 71*, 1009-1015. https://doi.org/10.2134/agronj1979.00021962007100060028x

Lopez-Bellido, R. J., & Lopez-Bellido, L. (2001). Efficiency of nitrogen in wheat under Mediterranean conditions: effect of tillage, crop rotation and N fertilization. *Field Crops Research, 71*, 31-46. https://doi.org/10.1016/s0378-4290(01)00146-0

Lucas, E. O. (1986). The effect of density and nitrogen fertilizer on the growth and yield of maize (Zea mays L.) in Nigeria. *The Journal of Agricultural Science, 107*(3), 573- 578.

Magreta, R., & Jambo, J. (2012). A critique on research priotisation on new bean markets and the youth in Malawi: Transforming the region. Paper prepared for the conference Young People, Farming and Food, 19-21 March 2012, Accra Ghana.

Mahdi, A. K., & David, K. M. (2005). Effect of tillage system and nitrogen source on corn yield. *Australia Society of Agronomy, 2*(1), 04-13.

MAIFS (Ministry of Agriculture, Irrigation and Food Security) (2004). Guide to agricultural production and natural resources management in Malawi. Published and printed by Agricultural Communication Branch, Ministry of Agriculture, irrigation and Food Security Lilongwe, Malawi.

Martinez-Romero, E. (2003). Diversity of Rhizobium-Phaseolus vulgaris symbiosis: overview and perspectives. *Plant and Soil, 252*, 11-23.

Mbewe, E. C. (2011). *The efficacy of Jatropha seed cake as organic manure (Unpublished master's thesis).* University of Malawi, Bunda College.

Meisinger, J. J., Bandel, V. A., Stanford, G., & Legg. J. O. (1985). Nitrogen utilization of corn under minimum tillage and moldboard plow tillage. I. Four years results using labelled N fertilizer on an Atlantic Coastal plain soil. *Agronomy Journal, 77*, 602-61. https://doi.org/10.2134/agronj1985.00021962007700040022x

Morgado, L. B., & Willey, R. W. (2003). Effects of plant population and nitrogen fertilizer on yield and efficiency of maize-bean intercropping. *Pesquisa Agropecuária Brasileira, 38*(11). https://doi.org/10.1590/s0100-204x2003001100002

Muchow, R. C. (1988). Effect of nitrogen supply on the comparative productivity of maize and sorghum in a semi-arid tropical environment. *Field Crops Research, 18*, 1-16.

Munthali, M. W., & Mazuma, E. D. (2010). Evaluation of TwinN as a source of nitrogen for maize production. Chitedze Agricultural Research Station, Malawi.

Nkongolo. K. K., Bokosi, J., Malusi, M., Vokhiwa, Z., & Mphepo, M. (2009*).* Agronomic, culinary and genetic characterization of selected cowpea elite lines using farmer's breeder's knowledge: A case study from Malawi. *African Journal of Plant Science, 3*(7), 147-156.

Omokanye, A. T., Kelleher, F. M., & McInnes, A. (2013). Crop residues for mulch, feed yield and quality as influenced by low-input maize-based cropping systems and N-fertilizer. *Agricultural Journal, 8*(5), 222-231.

Paul, E. A. (2008). *Soil Microbiology, Ecology, and Biochemistry*, 3rd Edition. Academic Press, Boston.

Peterburgski, A. V. (1986). Practical Guidance on Agro-chemistry. Kolos Publ., Moscow.

Pierce, F. J., & Rice, C. W. (1988). Crop rotation and its impact on efficiency of water and nitrogen use. In: Hargrove (ed) Cropping strategies for Efficient Use of Water and Nitrogen. ASA, Special Publication No. 15, Wisconsin. pp. 101-113

Rahman, M. M., Sofian-Azirun, M., & Boyce, A. N. (2013). Response of nitrogen fertilizer and legumes residues on biomass production and utilization in rice-legumes rotation. *The Journal of Animal & Plant Sciences, 23*(2), 589-595.

Raun, W. R., & Johnson, G. V. (1999). Improving nitrogen use efficiency for cereal production. *Agronomy Journal, 91*, 357-363. https://doi.org/10.2134/agronj1999.00021962009100030001x

Sage, R. F., & Zhu, X. G. (2011). Exploiting the engine of C4 photosynthesis. *Journal of experimental botany, 62*(9), 2989-3000.

Sebetha, E. (2015). *The effect of maize-legume cropping system and nitrogen fertilization on yield, soil organic carbon and soil moisture*. (Master's thesis, University of KwaZulu-Nata, South Africal ).

Sowers, K. E., Pan, W. L., Miller, B. C., & Smith, J. L. (1994). Nitrogen use efficiency of split nitrogen applications in soft white winter wheat. *Agronomy Journal, 86*, 942-948. https://doi.org/10.2134/agronj1994.00021962008600060004x

Walworth, J. (2013). *Nitrogen in soil and the environment*. University of Arizona, college of Agriculture and life sciences. Retrieved from www.cals.Arizona.edu/pubs. Accessed on 13/03/2016.

Werner, D., & Newton, W. E. (2005). *Nitrogen fixation in agriculture, forestry, ecology, and the environment*. Springer Publication. https://doi.org/10.1007/1-4020-3544-6

Westermann, D. T., Kleinkopf, G. E., Porter, L. K., & Leggett, G. E. (1981). Nitrogen sources for bean seed production. *Agronomy Journal, 73*, 660-664. https://doi.org/10.2134/agronj1981.00021962007300040022x

Zhao, R. F., Chen, X. P., Zhang, F. S., Zhang, H., Schroder, J., & Romheld, V. (2006). Fertilization and N balance in a wheat-maize rotation system in North China. *Agronomy Journal, 98*(4), 938-945. https://doi.org/10.2134/agronj2005.0157

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# Beyond Striga Management: Learning Videos Enhanced Farmers' Knowledge on Climate-Smart Agriculture in Mali

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**Abstract**

This paper assesses the climate smart agricultural practices triggered by learning videos on integrated striga management, soil fertility and cost-benefit evaluation practices. Using household head interviews and focus group discussions, this study revealed that farmers have similar perceptions of climate change and related impacts in video-villages and in non-video-villages. However, farmers' observation of climate change and related impacts are influenced by gender; men perceived more climate change and related impacts than women. In non-video villages, few respondents adopted crop rotation, intercropping, crop diversification, improved short-cycle seed varieties and zaï techniques as climate change adaptation strategies. Videos contribute more to the adoption of crop rotation, intercropping and fertiliser application for men than for women. Videos on accounting (managing money) enable more women than men to enhance their cost-benefit evaluation practices for income improvement. During the interviews, women farmers in video-villages were eager to demonstrate their knowledge about cost-benefit evaluation. We also found that the yield of sorghum, millet and maize is higher in video-villages than in non-video-villages. Thus, using videos as an extension tool is suitable for knowledge development and leads to the high adoption of climate-smart agricultural practices for food security.

**Keywords**: climate change, climate-smart agriculture, learning video, agricultural innovation, striga and soil fertility management, food security, Mali

## 1. Introduction

Agriculture contributes on average 34% to the GDP of Sub-Saharan African (SSA) countries and employs 64% of the labour force (World Bank, 2007). It accounts for about 40% of exports and provides various ecosystem services. Agriculture and rural development are thus key pillars of the SSA economy. With subsistence agriculture practiced by most smallholder farmers, yield gaps are high and poor soils, among other constraints, add to the difficulties for sustainable agriculture and incomes. Cereals such as maize, sorghum, millets and rice remain the most consumed staple foods of most African countries (Adebayo & Ibraheem, 2015; Macauley & Ramadjita, 2015).

In Mali, cereals such as sorghum, millet and maize are produced for subsistence by 90% of farmers (UNDP, 2012). Sorghum and millet have considerable further potential to make food and beverages in Mali. Despite the high importance of cereals to the livelihood of people in Mali, their production has been limited by various constraints of which Striga is ranked first. Striga is a parasitic weed that infests cereals and is responsible for crop losses estimated at about 11 million tons of cereals in West Africa (Gressel et al., 2004). In addition, farmers in Mali face the problems of declining soil fertility which is a serious threat to sustainable agricultural land use (Kidron, Karnieli, & Benenson, 2010). It is widely admitted that degraded land, depleted soil fertility and water stress contribute to low crop productivity and affect food security (Natcher et al., 2016). Striga is also a more severe problem in poor soils, one reason why Striga and soil fertility are best managed together.

In order to manage Striga and improve soil fertility for ensuring food security, a comprehensive series of ten learning videos (Table 1) related to practical and profitable integrated striga and soil fertility management (ISSFM) were developed by Agro-Insight (an agricultural communication enterprise) for ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). These videos were produced according to the zooming-in, zooming out method (Van Mele, 2006) whereby underlying scientific principles of technologies and local innovations are explained by a narrator in easy-to-understand language, interspersed with farmer interviews. In each video at least 4 experienced men and women farmers show and explain various aspects of the techniques. ICRISAT supported the distribution and use of some 10,000 copies of the “Fighting Striga” videos in Mali through many local NGOs, farmer groups, cooperatives, and extension workers. Almost all of these groups watched the videos, which had 8 language soundtracks, so everyone in Mali could understand them (Bentley et al., 2017; Van Mele, Bentley, Harun-ar-Rashid, Okry, & van Mourik, 2016). The aim of the videos was to strengthen farmers’ capacity to manage Striga and to enable them to benefit from integrated soil fertility management. Farmers were not aware of the danger of Striga seeds before watching the videos and they unconsciously let the Striga plants flower, and disperse their seeds. But after watching the videos, farmers realised that they needed to pull up the striga plants before they set seed. Many farmers have changed their farming practices to manage Striga after watching videos (Bentley et al., 2017; Van Mele et al., 2016). However, Africa faces many challenges in agricultural production. One of the key is the impact of climate change.

Indeed, climate change in many parts of the world has led to changes in temperature and rainfall patterns, depleted soils, change in wind direction and increased intensity and frequency of extreme events like droughts, floods and cyclones (Trenberth, 2007). The impacts of climate change on agriculture and food security are mainly felt through changes in crop yields, water availability, pests and diseases, and animal health (Pedercini Kanamaru, & Derwisch, 2012). Adaptation to climate change is therefore imperative (IPCC, 2007). Changes in climate affect food and livelihood security and reverse development achievements, for example, crop failure due to frequent droughts increases poverty (Speranza, 2010).The reality of climate change demands action not just to try to slow down the process, but also to help those affected to cope with the changes taking place. The 4th assessment report of the IPCC (2007) identifies sub-Saharan Africa as extremely vulnerable because these economies are highly dependent on natural resources and rain-fed agriculture.

Mali, where the use of videos in the agricultural extension system helped farmers to control Striga and improve their cereal yields (Van Mele et al., 2016) is subject to climate issues like other African countries. Therefore, beyond Striga and soil fertility management, this study aims to assess innovation towards the climate smart agriculture practices triggered by learning videos since the videos’ content focused on integrated weed management, soil fertility and conservation agriculture which constitute the key elements of mitigating climate change (Dinesh, 2016).

## 2. Conceptual Framework

Climate smart agriculture (CSA) is a concept developed by the Food and Agricultural Organisation of the United Nations (FAO) in 2010; it is aimed at adapting agriculture to climate change and to mitigating the causes of climate change (FAO, 2010). CSA practices address climate change challenges, while supporting economic growth and development of the agriculture sector. This integrative approach combines adaptation and mitigation of climate change, through “triple win” practices contributing to (i) reducing farmers’ vulnerability to climatic risks (ii) reducing agricultural greenhouse gas (GHG) emissions from land use changes, deforestation, etc. (iii) and increasing farmers’ incomes (World Bank & CIAT, 2015; FAO, 2013). However, CSA has been criticised, mainly by farmer associations and civil society for focusing more on mitigation than on adaptation and for lacking specific indicators (Stabinsky, 2014). The scope of the concept has been broadening in response to this criticism and now links environmental, social and economic pillars of sustainability, and covers farm level practices, landscape level approaches, and institutional/policy level frameworks (Lipper et al., 2014). To achieve CSA there is a need to ensure proper management of resources such as soils, water, genetic resources, pest and disease control that will increase productivity, protect the environment, adapt and mitigate climate change (FAO & World Bank, 2011). The theoretical framework of this study is based on adaptation, productivity and mitigation (APM), three interlinked pillars which are necessary for achieving CSA (Lipper et al., 2014). We build here on the APM framework (World Bank & CIAT, 2015; FAO, 2013; Knaepen, Torres, & Rampa, 2015) which focuses on farmers’ practices or innovations to:

(i) Adapt and build resilience to climate change (Adaptation): improve soil fertility and efficiency of water use, adjust crop calendars, use different crop varieties and animal species, integrated pest, disease and weed management, empower women and the poor etc.;

(ii) Increase agricultural productivity and food security (Productivity): a combination of adapted practices leading to better yields and stability of production and enhancing farmer's income.

(iii) Reduce or remove greenhouse gases emissions (Mitigation): land use changes and tree planting, cover cropping, crop rotation, conservation tillage, less use of agrochemicals etc., leading to reduced greenhouse gas emissions.

According to the FAO (2013), farmers' practices are considered CSA if they maintain or achieve increases in productivity as well as at least one of the other objectives of CSA (adaptation and mitigation). Drawing on the above, this study focuses on CSA by considering farmers' practices or innovations related to adaptation to climate change and agricultural productivity (food security). An innovation is the application of knowledge to achieve desired social and economic ends (Hall et al., 2001). Looking at CSA practices in the perspective of innovation systems which are made up of a range of actors involved in generating and using new knowledge, technologies, management practices and institutional relationships (Matsaert, Ahmed, Islam, & Hussain, 2005) is important to understand the role played by interconnected actors in the adoption of CSA practices. In this perspective, the actors/institutions such as ICRISAT, video dissemination organisations, and farmers are seen to play an important role in the adoption of CSA practices, since innovations do not emerge by themselves but may be triggered by a technical novelty, policy initiative or a new social arrangement (Leeuwis, 2004).

## 3. Method

### *3.1 Research Area*

The present study was carried out in Republic of Mali (Figure 1) which is a landlocked country in West Africa. It is a large, flat and arid nation with about 1,240,000 sq. km. The weather is dry and hot from February to June, wet and relatively mild from June to November, and dry and cooler from November to February. Mali has three climate zones. The northernmost Saharan zone has almost no rainfall with mean daily temperature highs of 48°C and lows of 5°C. In the Sahel, the continent-spanning transitional region between the Sahara and equatorial Africa, annual rainfall averages 100–200 mm with a mean daily temperature of 29°C. The third, Sudanic or Sudanian climate zone averages 700–1,300 mm of annual rainfall with a mean daily temperature of 27°C. Climate change is already a significant threat to the country's development, due in part to erratic rainfall, increased crop pests, rainfall shortages, and breaks during critical growing periods, as well as desertification over the last 50 years (FAO, 2008). The most highly stressed regions of the country are in the south where agriculture is concentrated, including Sikasso and Segou which are included in this study. Agriculture in Sikasso is cotton-based, with maize, sorghum and millet as major traditional staple cereal crops. The Sikasso Region is in transition from a largely low input, subsistence agriculture to an increasingly intensified commercial farming system. The Ségou Region is crossed by two important waterways: the Niger and the Bani Rivers, allowing irrigation. The main rain-fed crop is millet, with cowpea as an important secondary crop, and sorghum cultivated in lower, wet and heavier soils. The Sikasso and Ségou regions were chosen for the study because of their similar societal features as well as comparable climate and seasonal variability patterns (Kergna & Dembele, 2016).

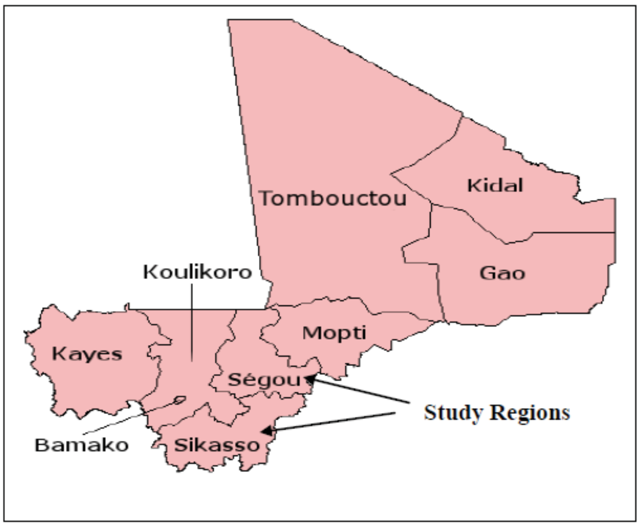


Figure 1. Map of Mali with different regions

Source: Adapted from Wikimedia, 2017

### *3.2 Research Methods*

The study was conducted from September 2016 to October 2016 in the regions of Segou and Sikasso of Mali, where ICRISAT in partnership with the farmers' organization Union des Agriculteurs du Cercle de Tominian (UACT) and NGO Association Malienne d'Eveil au Développement Durable (AMEDD) operate to improve the livelihood of farm families. UACT and AMEDD both disseminated new technologies through the "Fighting Striga" videos. UACT showed the videos by identifying a farmer in each village who owned video viewing equipment and organising a public screening, while AMEDD set appointments with the villages and took enough equipment to screen the video. Both organisations left copies of DVDs with the "Fighting Striga" videos for community members to watch on their own. A short description of the "Fighting Striga" videos is presented in Table 1.

Table 1. Short description of Fighting Striga videos

| Video title | Short description |
|---|---|
| 1- Striga Biology | Striga is a parasite weed of cereal crops. The weed develops from tiny seeds, and not (as many farmers believe) from the roots of the cereal crops. Rather than merely competing for space and nutrients like other weeds, Striga attaches itself to the host's root, and remains underground and unseen for weeks. Knowing its life cycle is the start of proper control |
| 2- Integrated approach against striga | Striga causes more damage to cereal crops in poor soil, so both problems have to be tackled together. Organic and chemical fertiliser can help to manage striga. A legume intercrop can kill Striga. Remaining Striga plants can be hand pulled before they flower. |
| 3- Succeed with seeds | Farmers can test crop varieties to identify Striga-resistant ones that perform well under local conditions. Growing resistant varieties is one of the strategies of integrated Striga and soil fertility management |
| 4 Composting to beat striga | Compost helps to fight Striga. Farmers can make compost from manure and crop residues, even in arid places. |
| 5- Micro-dosing | Application of small amounts of fertiliser to the base of the plant can save fertiliser while improving yields. |
| 6- Animals and trees for a better crop | Cattle that browse on leaves and seed pods of trees can fertilise the crops with their manure. Trees and livestock play a crucial role in obtaining a productive soil and crop. |
| 7- Storing cowpea seed | Techniques to prevent damage by insect pests in cowpea seed, so cereals can be intercropped with this useful legume. Intercropping a cereal crop with legumes is part of integrated Striga and soil fertility management. |
| 8- Grow row by row | Legumes like cowpeas are trap crops. Striga germinates near legumes, but cannot attach to their roots. A legume crop helps to manage striga. |
| 9- Joining hands against striga | Farmers can avoid the drudgery of weeding by working together. |
| 10- Let's talk money | A participatory tool to measure the cost-benefit of new technologies, like Striga management, with farm communities. This tool helps farmers to make decisions |

Source: Access Agriculture (www.accessagriculture.org)

The field work covered four villages (Daga and Hasso in Segou, Sirakelé and N'Tonasso in Sikasso) where the videos had been intensively shown (video-villages) in late 2012 and two control villages (Bolimasso in Segou and N'Togonasso in Sikasso) where no videos were screened (non-video-villages). Villages were selected based on the importance of cereal crop growing and the accessibility of the village.

This study included semi-structured interviews with 122 farmer household heads who participated on a voluntary basis. The sampled households comprise farmers who had lived all or most of their life in the selected villages, and were able to assess changes in climate. Household head interviews were combined with focus group discussions (FGD) (Kitzinger, 1994), organised in each selected village to crosscheck information. The FDG group consisted of village leaders, women's representatives, village counsellors, youth representatives and other persons involved in agricultural decision-making at the local level. Three FGD were organised with about eight farmers in each village, per Greenbaum (2000) who suggested that a focus group should be with seven to ten people. We conducted 18 FGD with 151 participants (Table 2). The focus group discussions were recorded, translated (from Bambara to French) and transcribed as literally as possible. All respondents were of age 40 or above and their main economic activity was subsistence agriculture. Key informant interviews were conducted with 21 extension workers, representatives of institutions and non-government organisations working with farmers in the selected villages. Interviews with extension workers were used to triangulate the information from household interviews and focus group discussions. The data collection methods are summarised in Table 2.

Table 2. Overview of data collection methods

| Study Area | | Data collection methods | | |
|---|---|---|---|---|
| | | Household head interviews (n=122) | FGD participant (n=151) | Extension workers interviews (n=21) |
| Video-villages | Daga | 21 | 27 | 21 |
| | Hasso | 20 | 24 | |
| | Sirakelé | 20 | 26 | |
| | N'Tonasso | 19 | 23 | |
| Non-video- villages | Bolimasso | 22 | 25 | |
| | N'Togonasso | 20 | 26 | |
| **Total** | **-** | **122** | **151** | **21** |

Source: Field data, 2016

Qualitative data were analysed by using the climate-smart agriculture framework (APM) presented above. For quantitative data, pairwise comparison was used to evaluate the difference between the proportion of household heads who used the videos to learn and those who did not use the videos. The correlation between video watching and adoption of climate-smart agricultural practices was evaluated with Chi-square tests. This was also performed on a contingency table of gender and climate-smart agricultural practices to evaluate the dependence between these variables. For cereal yields, ANOVA (General Linear Model) was performed to assess the difference between the household types and gender. When significant difference between types of household was found, a Student-Newman and Keuls test (SNK-test) was applied in the R package agricolae. All the statistical analyses were performed using R 3.4 (R Core Team, 2017).

## 4. Results and Discussion

### *4.1 Respondents' Socio-demographic Characteristics*

Most of the household heads interviewed were men (75%). In most West African cultures, males are considered to be the heads of households (see, for example Amaza et al., 2008). Most of the household heads (73%) were between 40 and 50 years old. Few of the household heads (15%) received basic education (primary school) and 85% had no formal education. This shows the importance of making farmers' training materials in their own language, using the spoken rather than the written word (Mundy & Sultan, 2001). The socio-demographic characteristics of household heads are summarised in Table 3.

Table 3. Household head' socio-demographic characteristics (n=122)

| Characteristics | | n=122 | % |
|---|---|---|---|
| Age | 40-50 | 89 | 72.95 |
| | 51-60 | 22 | 18.03 |
| | >61 | 11 | 9.01 |
| Gender | Male | 91 | 74.59 |
| | Female | 31 | 25.49 |
| Education | No formal education | 104 | 85.24 |
| | Finished primary school | 18 | 14.75 |

Source: Field data, 2016

### *4.2 Farmers' Observation of Climate Change and Related Impacts*

Before we carried out this study, 87% of male-headed households and 19% female-headed household had heard of climate change. The women said that they were unaware of climate change because the agricultural extension services do not always consider them to be farmers and women are left out of the community discussions or meetings organised by the extension workers. In a similar vein, Katungi, Edmeades and Smale (2008) reported that women do not benefit from extension programs for farmers in Uganda. Furthermore, social norms in most West African constrain many women from communicating freely with men who are not from their families. In order to overcome this gender gap in accessing extension services, policy makers must promote the use of videos which facilitate information access to all rural people (Zoundji et al., 2016).

During the interview, all respondents expressed interested in discussing climate variability and wanted to know what strategies they could adopt to increase their ability to cope with the change. However, the following changes in seasons and climate were observed over the past 10-20 years by respondents. The rainy seasons are becoming shorter and the rains start later or end earlier, as reported by most households (80%), followed by increasingly strong winds and higher temperatures, mentioned by 78% of households. Severe droughts are becoming more frequent, as reported by 69% of respondents. Farmers have observed negative impacts of climate, as disaggregated by gender in Figure 2.

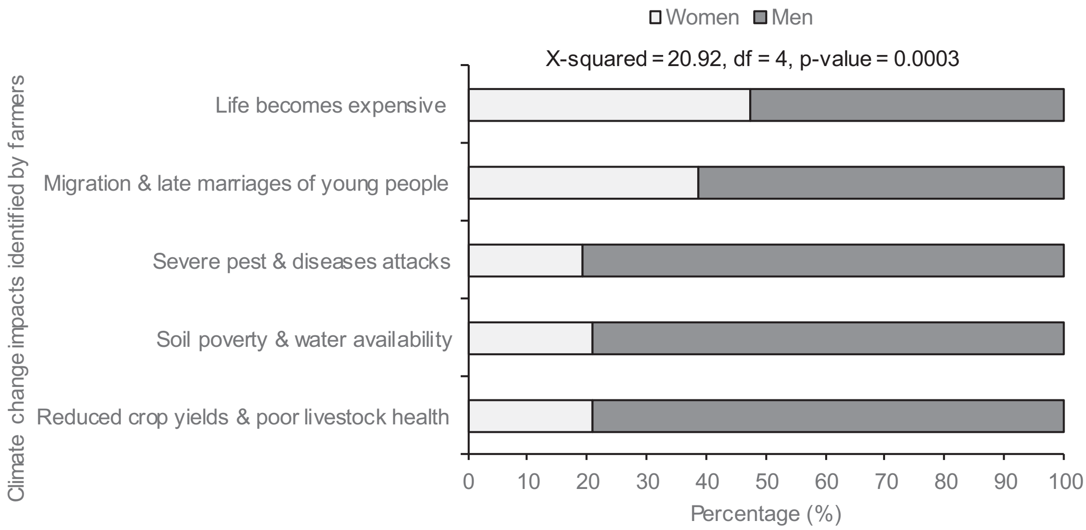


Figure 2. Impacts of climate change identified by farmers

Source: Field data, 2016

Men noticed reduced crop yields and poor livestock health, soil poverty, less water availability, and more pest and disease problems (as the impacts of climate change), while households headed by women noted that cost of living increases, more migration and delayed marriages. Men pay attention to climate change's impacts on agriculture, while women are more likely to notice social change. There are gendered patterns of impacts of climate change. This may be because in West Africa, many women do not control revenue from agriculture, but they are active in small trade (Diiro et al., 2016; Fafchamps, Gabre-Madhin, & Minten, 2005). Farmers in the focus group discussions (FGD) identified pest and disease problems (54%), followed by reduced crop yields, poor livestock health (52%) impoverished soil and difficulties of water management (42%). Interviews with extension workers confirmed the men's observations and described declining crop yields, scarcity of water, increased pest and disease problems, deteriorating animal health and others as mainly impacts of climate change on rural development (see Zoundji et al., 2017 for similar observations). Other studies of farmers' observations confirmed the above as the main climate change impacts in Mali (Ebi et al., 2011; Diiro et al., 2016).

Farmers in video-villages and in non-video-villages made similar observations of climate change and its impacts, probably because all the villages are receiving about the same quality and quantity of climate information. Conflict between farmers and pastoralists was only mentioned by some farmers in N'Togonasso, the non-video-village of Sikasso. This is probably because Sikasso is most suitable for arable farming and has become a region for livestock rearing and transhumance in Mali. The clashing interests of pastoralists and farmers often lead to conflicts, which are quite common in Mali, especially when livestock damage crops.

Household heads' observations of climate change corroborated focus group responses and confirmed what was described as climate change impacts in other areas in Mali and other rural Sahel (Pedercini et al., 2012). Farmers' must observe climate change before they can sustainably adapt to it (Koch, Vogel, & Patel, 2006).

### *4.3 Farmers' Adaptation and Resilience Building to Climate Change*

Farmers use various techniques to adapt to climate change, with differences between video-villages and non-video-villages (Table 4). Theses coping strategies build on farmers' adaptation and resilience to climate change. In the video-villages, our informants said the most common agricultural adaptation strategies include crop rotation, intercropping, fertiliser application, crop diversification, use of improved short-cycle seed varieties, tree planting and use of zaï pits (shallow planting pits to capture water).

Fertiliser application in zaï pits were not mentioned during individual and group discussions in non-video villages. Farmers had no information on this practice, but were willing to learn more about it. Very few respondents had adopted crop rotation, intercropping, crop diversification, improved short-cycle seed varieties and zaï pits as climate change adaptation strategies in non-video villages, which received little or no information about these innovations.

Farmers in video-villages were more likely to report easy contact with extension workers who visit the village and more community meetings. Video-villages were more likely to mention other adaptation methods such as income generating activities, including savings-and-loan activities, cost-benefit analysis before selling products and hand-pulling of Striga as a paid service (i.e. charging farmers to uproot the weeds in their fields). Making money through hand-pulling of Striga was not mentioned in non-video villages. The difference observed in video-villages and non-video-villages was explained by Madam Nakisso, of Hasso village, who said "*learning videos help us to see a visual, convincing demonstration and practical explanation from other farmers in our own language of the entire process of technology and facilitated it adoption*". Farmers' adaptation to climate change involves an array of technical and institutional responses, which can be stimulated by local or outside knowledge (FAO, 2010). The "Fighting Striga" videos disseminated by local NGOs inspired farmers to engage in alternative ways of crop and soil fertility management, off-farm activities etc. As results of these practices, farmers improved their resilience, increased yields and can sequester more carbon. The farming practices which preserve and improve soil (crop rotation, use of compost or residue management etc.) contribute to carbon sequestering (Govaerts et al., 2009). So, these agriculture practices are adaptive responses to climate change. However, these practices demand labour. For example, composting with organic matter requires work, especially to build and maintain a compost pit. Nevertheless, the use of manure has proven highly effective as a low-cost CSA technique (Nkwake, Magistro, & Horjus, 2014).

During the interview, women farmers in particular were eager to demonstrate their experiences with the analysis of cost-benefit evaluation. Some women's groups in the villages of Daga and Sirakélé have started selling improved cereal seed since farmers' demands of it were increased after watching videos. Farmers usually spent 2-3 USD to travel to a town where they could buy improved seed. So, the knowledge acquired from the videos 'Let's talk money' inspired two women's group to become seed dealers in the village. This initiative started in 2014 in Daga village with a woman leader, Madam Dembelé. In 2015, women in Sirakélé village also started to sell improved seed because of Madam Dembelé. She is from Sirakélé village and married into Daga village. Madam Dembelé is a key element for the social network which triggers innovation in two villages. The development of improved seed trading at the village level reinforces farmers' access to improved technology and can be a strong driver in facilitating the widespread diffusion of new technologies or information for sustainable livelihoods (see Van Mele et al. 2011). This is in line with findings of Leeuwis and Hall (2013) who report that agricultural extension should not only focus on sharing information, but should also engage in development tasks such as facilitating farmers' access to inputs.

Farmer knowledge development of CSA practices is strongly connected to an agricultural extension approach. However, many farmers do not acknowledge the results of frequent visits from extension agents in their villages; while in the field, we met several development partners such as World Neighbours, World Vision, and the NGO IRD, which were working intensively with farmer leaders. As explained by Madam Bohan in Daga village, *"Toubab (white people) used to come to this village and discussed or worked with our farmer leaders and their relatives. We heard that those external people were implementing agricultural projects with farmer leaders*". So, most of information or agricultural practices promoted by development partners were not always shared with other farmers. Farmers' access to relevant CSA practices or improved agricultural technology is limited by institutions which exclude many farmers who need agricultural information. In order to overcome this constraint, learning video as an agricultural extension tool may be the best and most cost effective method to reach more farmers and to give a fair chance to anyone who is interested in agriculture (Zoundji et al., 2016).

Table 4 shows that the households who viewed the videos were more likely to adopt climate-smart agricultural practices. In the video-villages, farmers are more likely to crop adopt rotation, intercropping and fertiliser application, and men are more likely to adopt than women. For accounting (cost-benefit evaluation practices), videos enable more women than men to enhance their accounting practices for income improvement.

Table 4. Farmers' practices towards sustainable agricultural productivity and incomes

| Categorization | Climate-smart agricultural practices | ***Video villages*** (n=80) | | ***Non-video villages*** (n=42) | | ***Video villages*** (n=80) | ***Non-video villages*** (n=42) |
|---|---|---|---|---|---|---|---|
| | | Women (%) | Men (%) | Women (%) | Men (%) | (%) | (%) |
| Crop and soil Management (X-squared = 18.43, df = 5, p-value = 0.002) | Crop rotation combined with intercropping | 26 | 77 | 17 | 40 | 99a | 57b |
| | Fertiliser application: adding compost, manure or micro-doses of mineral fertiliser to the base of the plants | 20 | 79 | 0 | 0 | 99a | 0b |
| | Crop diversification | 20 | 73.75 | 7.14 | 45.23 | 93.75a | 52.38b |
| | Use of improved short-cycle seed varieties | 13.75 | 63.75 | 2.38 | 14.28 | 77.5a | 16.66b |
| | Tree planting | 11.25 | 56.25 | 0 | 64.28 | 67.5a | 64.28b |
| | Use of zaï pots for water capture & fertiliser application | 5 | 46.25 | 0 | 0 | 51.25a | 0b |
| Social learning (X-squared = 0.95, df = 1, p-value = 0.329) | Easy contact with extension workers | 15 | 71.25 | 0 | 45.23 | 86.25a | 45.23b |
| | More community meetings for knowledge exchange and decision making | 6.25 | 66.25 | 0 | 38.09 | 72.5a | 38.09b |
| Income generating activities for empowerment (X-squared = 13.80, df = 2, p-value = 0.001) | Farmers engage in saving & loan activities | 26.25 | 2.5 | 11.9 | 0 | 28.75a | 11.9b |
| | Use of accounting knowledge to analyse cost & benefits before selling products | 25 | 33.75 | 16.66 | 14.28 | 58.75a | 30.95b |
| | Hand-pulling of Striga as paid service | 26.25 | 0 | 0 | 0 | 26.25a | 0b |

NB: The line with different letters means significant difference between video village and non-video village

In video villages, the adoption of income generating activities for empowerment depend on gender (P-value<0.001) contrary to crop and soil management (P-value=0.455) and social learning (P-value=0.236). In non-video villages, the adoption of crop and soil management practices depend on gender (P-value=0.013) contrary to income generating activities for empowerment (P-value=0.114), and social learning (P-value=1)

### *4.4 Farmers' Responses to Food Security under Climate Change Condition*

Reduction of crop yields was the most important impact of climate change mentioned by farmers and extension workers (see Figure 2). Innovative practices (see Table 5) were used by farmers to increase agricultural productivity and reduce food insecurity in the face of the newly unpredictable climate. Table 4 shows the yield of sorghum, millet and maize, which are high in video-villages and low in non-video villages. Sorghum, millet and maize yields in the video-villages have increased by 14%, 30% and 15% respectively when compared to non-video villages. There is no influence on the increase of the yield between female and male-headed households. Only the type of household (video or non-video) significantly influences cereal yields (Table 5). Increased yields would contribute to food security and improvement of farmers' social and economic status. The yields in the video villages are higher than the national averages which were 1048 kg/ha for sorghum, 959 kg/ha for millet and 2538 kg/ha for maize (Ministère de l'Agriculture [MA], 2016). Among the factors contributing to high productivity of cereal crops are the crop and soil management practices developed by farmers after watching the videos. Farmers recognised the increase of yield and link it is mainly to the adoption of crop rotation and intercropping with fertiliser application using composted manure and zaï pits. Therefore, the increases in yield might be related to the use of videos as an agricultural extension tool, which stimulates and inspires farmers to consider new ideas and apply knowledge in farming. Furthermore, in three out of four video villages, household heads explained that technologies developed in the videos are based on farmers' existing technical knowledge. This facilitates the adoption of technology (Van Mele, 2006). Taking advantage of farmers' existing knowledge to develop a new technology would be a key element to enhance its adoption. Bishop-Sambrook et al., (2004) found that adoption of rippers for conservation tillage to set up seedbeds was higher in villages with experience with draught animals than where farmers used only hand hoes. Using videos as extension tools, which are based on farmers' experiences and combine visual and verbal communication methods is suitable for knowledge development and lead to high adoption of CSA practices.

Table 5. Farmers' estimation of crop yield (kg/ha) for growing season 2015

| Crops | Videos villages | | | Non videos villages | | | Statistic W of Mann-Whitney Test |
|---|---|---|---|---|---|---|---|
| | Mean | CV (%) | Median | Mean | CV (%) | Median | |
| Maize | 2598.10±24.70 | 8.49 | 2500 | 2247.60±23.50 | 6.77 | 2250 | 267.5*** |
| Millet | 1065.00±10.30 | 8.69 | 1050 | 813.10±17.00 | 13.52 | 800 | 74*** |
| Sorghum | 1082.30±8.42 | 6.96 | 1050 | 945.20±19.50 | 13.36 | 950 | 523.5*** |

***significant at 0.001

Source: Field data, 2016

Table 6**.** Analysis of variance performed on yield

| Source of variation | Sorghum | | Millet | | Maize | |
|---|---|---|---|---|---|---|
| | Df | F-value | Df | F-value | Df | F-value |
| Type of household (videos or non-videos) | 1 | 55.81*** | 1 | 176.69*** | 1 | 83.43*** |
| Gender | 1 | 0.97ns | 1 | 0.38ns | 1 | 0.12ns |
| Type of household x Gender | 1 | 0.05ns | 1 | 0.14ns | 1 | 0.17ns |

*** significant vat 0.001, ns non-significant

## 5. Conclusion

Both women and men are concerned about climate change and use diverse strategies to adapt to it. The most common ones include crop rotation, intercropping, crop diversification, use of improved seed varieties, use of compost, and use of zaï pits for water storage and fertiliser application. Organisations like ICRISAT, UACT and AMEDD facilitated video screening, which inspired farmers to try and adapt CSA innovations. Organisations played an important role and served as channels through which farmers accessed reliable and credible information to adopt CSA practices. For the farmers, it is not merely the information that is important, but also how they acquired it. Watching the videos played an important role in farmer innovation. After public screenings, UACT and AMEDD left copies of the DVDs with "Fighting Striga" videos which the rural people could watch when they wanted to. In the villages covered by UACT, farmers promptly continued to watch videos a day after the public screening, while it took about two months before farmers watched videos after public screening in the villages covered by AMEDD. Recall that UACT showed the videos on equipment borrowed from community members, which may have increased their confidence to screen videos for their neighbours, while AMEDD supplied the video viewing gear. Involving farmers in the process of screening videos may encourage them to show videos later, to other community members.

We observed a significant difference between video villages and others as responses to climate change. Although the "Fighting Striga" videos were not focused explicitly on CSA technologies, the sustainable practices adopted by farmers did respond to climate change and CSA objectives. By managing Striga, farmers achieve agricultural resilience to climate change which improved agricultural productivity. Farmers attribute increased crop yields to the adoption of the sustainable practices of soil and crop management, contributing to food security under a changing climate. Farmers' practices are considered CSA if they maintained or achieved increases in productivity (FAO, 2013). Agricultural extension services using videos as learning tools proved successful because the learning videos went beyond showing how to use each technology and also explained why they would work. Thus, farmers went beyond just repeating what was shown in videos, and engaged in the learning process and drew lessons from their own experiences. As climate change presents challenges to farmers that demand innovative responses, using learning videos in agricultural extension to communicate climate information will increase farmers' adaptation capacities which are crucial for climate smart agriculture development.

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**References**

Adebayo, O. O., & Ibraheem, I. O. (2015). The current status of cereals (maize, rice and sorghum) crops cultivation in Africa: Need for integration of advances in transgenic for sustainable crop production. *International Journal of Agricultural Policy and Research, 3*(3), 233-245.

Amaza, P.S., Adejobi, A.O., and Kwaghe P.V. 2008 Poverty and its determinants among farming households in West Africa: Empirical evidence from Borno State, Nigeria. *Journal of Food, Agriculture & Environment* 6 (3&4): 406-411.

Bentley, J. W., Van Mele, P., Touré, S., van Mourik, T., Guindo, S., & Zoundji, G. (2017). Seeds of the devil weed. Local knowledge and learning from videos in Mali. Chapter 7. In P. Sillitoe (Ed.), *Indigenous Knowledge: Enhancing its contribution to Natural Resources Management.* Wallingford, UK: CABI.

Bishop-Sambrook, C., Kienzle, J., Mariki, W., Owenya, M., & Ribeiro, F. (2004). Conservation Agriculture as a Labour Saving Practice for Vulnerable Households. A Study of the Suitability of Reduced Tillage and Cover Crops for Households under Labour Stress in Babati and Karatu Districts, Northern Tanzania. IFAD, FAO, 80p.

Diiro, G., Petri, M., Zemadim B., Sinare, B., Dicko, M., Traore, D., & Tabo, R. (2016). Gendered Analysis of Stakeholder Perceptions of Climate Change, and the Barriers to its Adaptation in Mopti Region in Mali. Research Report no. 68. Patancheru 502 324. Telangana, India: International Crops Research Institute for the Semi-Arid Tropics. 52 pp.

Dinesh, D. (Ed). (2016). *Agricultural practices and technologies to enhance food security, resilience and productivity in a sustainable manner: Messages to SBSTA 44 agriculture workshops*. CCAFS Working Paper no. 146. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Ebi, K. L., Padgham, J., Doumbia, M., Kergna, A., Smith, J., Butt, T., & McCarl., B. (2011). Smallholders' adaptation to climate change in Mali, *Climatic Change*. https://doi.org/10.1007/s10584-011-0160-3

Fafchamps, M., Gabre-Madhin, E., & Minten, B. (2005). Increasing returns and market efficiency in agricultural trade. *Journal of Development Economics* 78:406-442. https://doi.org/10.1016/j.jdeveco.2004.10.001

FAO, & World Bank. (2011). Identifying Opportunities for Climate-Smart Agriculture Investments in Africa, FAO & World Bank Final report.

FAO. (2008). *Climate Change Adaptation and Mitigation in the Food and Agriculture Sector*. Technical Background Document from the Expert Consultation held on March 5-7, 2008. In High-level Conference on Food Security: The Challenges of Climate Change and Bioenergy, June 3-5, 2008, Rome.

FAO. (2010). *Climate Smart Agriculture Policies, Practices and Financing for Food Security, Adaptation and Mitigation.* FAO, Rome.

FAO. (2013). *Climate-Smart Agriculture - Sourcebook on Climate-Smart Agriculture, Forestry and Fisheries.* Rome: FAO.

Govaerts, B., Verhulst, N., Castellanos-Navarrete, A., Sayre, K. D., Dixon, J., & Dendooven, L. (2009). Conservation Agriculture and Soil Carbon Sequestration: Between Myth and Farmer Reality. *Critical Reviews in Plant Science, 28*, 97-122, 2009. https://doi.org/10.1080/07352680902776358

Greenbaum, T. L. (2000). *Moderating focus groups: A practical guide for group facilitation;* Thousand Oaks, CA: Sage Publications. https://doi.org/10.4135/9781483328522

Gressel J., Hanafi A., Head, G., Marasas W., Obilana A. B., Ochanda J., Souissi T., & Tzotzos, G. (2004). Major heretofore intractable biotic constraints to African food security that may be amenable to novel biotechnological solutions. *Crop Protection, 23*, 661-689. https://doi.org/10.1016/j.cropro.2003.11.014

Hall, A.J., Sivamohan, M.V.K., Clark, N., Taylor, S., & Bockett, G. (2001). Why Research Partnerships Really Matter: Innovation Theory, Institutional Arrangements, and Implications for Developing New Technology for the Poor. *World Development, 29*(5), 783-797. https://doi.org/10.1016/S0305-750X(01)00004-3

IPCC. (2007). *Climate Change, Synthesis Report, an Assessment of the Intergovernmental Panel on Climate Change.*

Katungi, E., Edmeades, S., & Smale, M. (2008). Gender, social capital and information exchange in rural Uganda. *Journal of International Development, 20*(1), 35-52. https://doi.org/10.1002/jid.1426

Kergna, A. O., & Dembele, D. (2016). Status of Agricultural Innovations, Innovation Platforms, and Innovations Investment. 2015 PARI project country report: Republic of Mali. Forum for Agricultural Research in Africa (FARA), Accra Ghana.

Kidron, G. J., Karnieli, A., & Benenson, I. (2010). Degradation of soil fertility following cycles of cotton-cereal cultivation in Mali, West Africa: A first approximation to the problem. *Soil & Tillage Research, 106*, 254-262. https://doi.org/10.1016/j.still.2009.11.004

Kitzinger, J. (1994). The methodology of Focus Groups: the importance of interaction between research participants. *Sociology of Health & Illness, 16*, 103-121. https://doi.org/10.1111/1467-9566.ep11347023

Knaepen, H., Torres, C., & Rampa, F. (2015). Making agriculture in Africa climate-smart: From continental policies to local practices. European Centre for Development Policy Management, Briefing Note N°80/ November 2015.

Koch, I. C., Vogel, C., & Patel, Z. (2006). Institutional dynamics and climate change adaptation in South Africa. *Springer Science, Business Media B.V, Heidelberg, 12*, 1323-1339.

Leeuwis, C. (2004). Innovation as a process of network building, social learning and negotiation-implication for transdisciplinary research collaboration, Communication presented at International Transdisciplanary Conference on Development and Conservation of Karst-Region, Hanoi.

Leeuwis, C., & Hall, A. (2013). Facing the challenges of climate change and food security: the role of research, extension and communication for development. Occasional papers on Innovation in Family Farming, Food and Agriculture Organization of the United Nations.

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Torquebiau, E. F. (2014). *Climate-Smart Agriculture for Food Security*. *In: Nature Climate Change, 4*(12), 1068-1072.

Macauley, H., & Ramadjita, T. (2015). Cereal Crops: Rice, Maize, Millet, Sorghum, Wheat. Feeding Africa, an action plan for African agricultural transformation.

Matsaert, H., Ahmed, Z., Islam, N., & Hussain, F. (2005). Using actor-oriented tools to analyse innovation systems in Bangladesh. *Participatory learning and action*, 51 April 2005.

Ministère de l'Agriculture. (2016). Annuaire Statistique 2015 du Secteur Développement Rural. Cellule de planification et de statistique/ secteur développement rural, Ministère de l'Agriculture (MA), République du Mali.

Mundy, P., & Sultan, J. (2001). Information revolutions: how information and communication management is changing the lives of rural people. Wageningen, The Netherlands: Technical Centre for Agricultural and Rural Cooperation (CTA).

Natcher, D., Bachmann, E., Pittman, J., Kulshreshtha, S., Baco, M. N., Akponikpe, P. B. I., & Peak., D. (2016). Knowledge Diffusion and the Adoption of Fertilizer Microdosing in Northwest Benin. *Sustainable Agriculture Research, 5*(3), 2016. https://doi.org/10.5539/sar.v5n3p1

Nkwake, A., Magistro, J., & Horjus, P. (2014) Adapting to the Sahel's changing climate: local approaches an economic and technical feasibility analysis of adaptation techniques in Niger, Burkina Faso and Mali. Catholic Relief Services report.

Pedercini, M., Kanamaru, H., & Derwisch, S. (2012). Potential impacts of climate change on food security in Mali. Natural Resources Management and Environment Department, FAO, Rome.

Speranza, C. I. (2010). *Resilient Adaptation to Climate Change in African Agriculture,* German Development Institute Study in Bonn, Germany.

Stabinsky, D. (2014). *Climate Smart Agriculture: myths and problems*. Heinrich-Böll-Stiffung, The Green Political Foundation.

Trenberth, K. E. (2007). *Observations, surface and atmospheric change, in: S. Solomon et al. (eds.), Climate change 2007. The physical science basis*, Working group I contribution to the fourth assessment report of the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press;

UNDP. (2012). Food Production and Consumption Trends in Sub-Saharan Africa: Prospects for the Transformation of the Agricultural Sector. UNDP, working paper, Regional Bureau for Africa.

Van Mele, P. (2006). Zooming-in, zooming-out: a novel method to scale up local innovations and sustainable technologies. *International Journal of Agricultural Sustainability, 4*(2), 131-142.

Van Mele, P., Bentley, J.W. & Guéi, R. 2011 *African Seed Enterprises: Sowing the Seeds of Food Security*. Wallingford, UK: CABI. 236 pp.

Van Mele, P., Bentley, J., Harun-ar-Rashid, Md. Okry, F., & van Mourik, T. (2016). Letting Information Flow: Distributing Farmer Training Videos through Existing Networks. *Indian Journal of Ecology, 43*(1), 545-551.

World Bank, & CIAT. (2015). Climate-Smart Agriculture in Kenya. CSA Country Profiles for Africa, Asia, and Latin America and the Caribbean Series. Washington D.C.: The World Bank Group.

World Bank. (2007). Population Issues in the 21st Century: The Role of the World Bank. Health, Nutrition and Population (HNP) Discussion Paper. The World Bank, Washington D.C.,

Zoundji, C. G., Okry, F, Vodouhê, D. S., & Bentley, J. (2016). The distribution of farmer learning videos: Lessons from non-conventional dissemination networks in Benin. *Cogent Food & Agriculture, 2*, 1277838. https://doi.org/10.1080/23311932.2016.1277838

Zoundji, C. G., Witteveen, L., S. D. Vodouhê, & Lie, R. (2017). When baobab flowers and rainmakers define the season: farmers' perceptions and adaptation strategies to climate change in West Africa. *International Journal of Plant, Animal and Environmental Sciences,* 7(2), https://doi.org/10.21276/Ijpaes

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# Tracking the Release of Soil Nitrate and Labile C in A Legume-Maize Rotation in Zimbabwe

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**Abstract**

This study compared the effect of a weedy fallow (5.2 t/ha biomass), a velvet bean (*Mucuna pruriens*) cut for hay (7.2 t/ha biomass) and a green-manured *M. pruriens* (6.49 t/ha biomass) on the dynamics of soil N and C in a maize crop. An on-farm, farmer participatory experiment was established on a farmer's field in Wedza District, Zimbabwe. Soil mineral N and labile carbon were determined at intervals upto 120 cm depth, at maize planting and at 1 and 2 weeks after planting. Before planting, the soil mineral N content ranged from 28 kg N/ha after weed fallow to 107 kgN/ha following *M. pruriens*. Total nitrate concentration was highest in the 0-15 cm depth of the *M. pruriens* treatments in the pre-planting sampling, but following rainfall and maize planting, nitrate concentration declined rapidly. By 2 weeks after planting, 7.5 and 13.5 kg N/ha remained in the 0-120 cm soil depth of the weedy fallow and green-manured *M. pruriens*, respectively. Improving synchrony of nutrient release and uptake is critical when applying high quality residues which breakdown relatively slowly. This could result in significant inputs of C, release nutrients more slowly and reduce soil nutrient losses.

**Keywords:** forage legumes, green manures, leaching, nitrogen, carbon

## 1. Introduction

Soil organic matter (SOM) is considered to be a key factor in maintaining soil quality and is therefore crucial in determining long-term soil fertility (Bationo, 2007). Much evidence indicates that the decline in crop yield with continued production in many temperate and tropical areas is correlated with declines in organic matter levels (Sanchez & Leakey, 2004). Therefore maintaining soil organic matter must be considered as one of the goals of sustainable land management systems.

In many cropping systems, soil management to increase SOM and supply nitrogen for crop production has generally been approached via the use of green manuring and crop residue retention. The application of green manures often results in increases in crop yield. However, there is no evidence of long-term improvement of SOM and soil fertility (Rurinda et al., 2014). Green manuring produces short-term pulses of nutrients into the soil, resulting from extremely rapid oxidation of C and nutrients due to the rapid decomposition of the added material (Waddington, 2003). Conversely, lower quality crop residue (e.g. cereal straw) releases nutrients too slowly, and in insufficient quantities to meet microbial and crop requirements. As an alternative, the application of high quality residues, which breakdown relatively rapidly due to their chemical and/or physical attributes and improved mineralisation of nutrients, could result in significant increases in soil C, provide plant nutrients for longer periods and reduce soil nutrient losses.

This experiment was established to compare the effect of a weedy fallow, a grazed *M. pruriens* pasture and a ploughed in/green manured *M. pruriens* system on the dynamics of soil N and C prior to planting and up to 2 weeks after planting of a maize crop in the season following the weedy fallow/ *M. pruriens* treatments.

## 2. Method

### 2.1 Site Description

The experiment was carried out in Hwedza District, Zimbabwe, in Zana resettlement area. The resettled farming community of Zana (longitude of 18$^o$54'S, latitude of 31$^o$59'E) lies in Natural Region IIb (Surveyor-General, 1984), 80 km south of Marondera and 150 km south east of Harare in Zimbabwe. Farming in these areas is based on infertile deep brown sands to sandy loam soils that are derived predominantly from granite and supporting a range of farming and livestock systems. Mean annual rainfall ranges from 600-900 mm per annum with most of it falling between November and March. Major limitations to maize production are soil nitrogen and phosphorus deficiencies. The limited cash reserves of the predominantly subsistence farmers result in the application of very little, or no, inorganic fertilizers to their crops. Farming systems that can supply nitrogen through biological N fixation are being investigated. An on-farm, farmer participatory experiment was established on a sandy soil site at Zana communal area. The aim of the main experiment was to determine the residual effects of forage legumes V*igna unguiculata,* (cowpea), *M. pruriens* (velvet bean), *Macrotyloma axillare/Chloris gayana* cv. Katambora, weed fallows or sole maize grown in the 1999/2000 wet season on a subsequent maize crop grown in 2000/2001 season.

### 2.2 Treatment Details and Soil Sampling

Three treatments (established on 8 × 9 m plots), namely weed fallow, *M. pruriens* that was removed for hay, and *M. pruriens* that was ploughed into the soil, were soil sampled at the start of the wet season in 2000/2001 to investigate the dynamics of C and N in these systems. Soil characteristics of the site are shown in Table 1.

Weeds were not controlled on the weed fallow, and legume grain was harvested from the *M. pruriens* plots. Plant dry matter biomass was determined on all three treatments. Total above ground biomass was measured at fallow clearing by separating the biomass components into foliage (leaves and twigs), branches and stems. These components were then weighed as fresh biomass after which samples of each component were collected on plot basis and oven dried at 70$^o$C to equilibrium moisture content. This data was used to estimate dry weight on plot basis and extrapolated to a hectare basis. The plant material from the hay *M. pruriens* treatments was removed at maturity to simulate a hay system while the *M. pruriens* biomass was ploughed-in in May 2000 for the green manure treatments. Grazing livestock were allowed access to these areas during the dry season as it is situated in the community cropping areas. Maize stover, as is usual practice in communal areas, would have been removed from the fields at harvesting.

Soil samples (taken at 0-15, 15-30, 30-60, 60-90 and 90-120 cm depths) were collected following the opening wet season rains (24/25 October 2000), at maize planting (28/29 November 2000), 1 week after planting (WAP) (6 December 2000) and 2 WAP (13/14 December 2000). Soil nitrate-N, total N ($N_T$), total and labile carbon ($C_L$ 333mM $KMnO_4$ oxidisable C) were determined on these samples.

The soils were analysed for total organic carbon ($C_T$) by combustion (Leco), and labile organic carbon ($C_L$) (UNE method, Blair *et al.* 1995). Non labile carbon ($C_{NL}$) is calculated as the difference between the $C_T$ and $C_L$(333mM) pools. Lability (L), an index of the 'quality' of $C_T$, is calculated by dividing $C_L$ by $C_{NL}$. $C_L$ fractions oxidized by 33 and 333 mM $KmnO_4$ will reflect 2 pools of carbon compounds based on their lability (Loginow, *et al.* 1987). The weakest concentration, (33mM $KMnO_4$) will oxidize the most labile compounds, while the stronger concentration (333 mM $KMnO_4$) will oxidize more carbon compounds.

### 2.3 Statistical Analysis

Genstat version 14.0 statistical package was used for data analysis. Treatment differences were tested in an Analysis of Variance and least significant difference was used to calculate mean separation. Statistical significance was declared at $P \leq 0.05$.

## 3. Results

### 3.1 Plant Biomass Yield

Total biomass measured at the end of the 1999/2000 wet season (reported in detail in the thesis of Jiri (2003)) was 5.22t/ha on the weed fallow, 7.15 t/ha on the *M. pruriens* treatment cut for hay and 6.49 t/ha on the green manured *M. pruriens* treatment. The Mucuna treatemnts produced significantly higher amounts of biomass compared to the weedy fallow ($P \leq 0.05$).

### 3.2 Soil Properties

The sandy soil was highly acidic, with the pH ($CaCl_2$) below 4.5 and very low in the cations $K^+$, $Ca^{++}$ and $Mg^{++}$ (Table 1) reflecting very low soil organic matter ($C_T$<0.9% Table 2) and associated low cation exchange capacity.

Available P was marginal in the 0-15 cm depth and low in the 15-30 cm depth ($P \leq 0.05$).

Table 1. Soil characteristics at the experimental site

| | Texture | Depth | pH | K | Mg | Ca | P (Bicarb) |
|---|---|---|---|---|---|---|---|
| | | (cm) | ($CaCl_2$) | cmol+/kg | | | (mg/kg) |
| Mbavha | Sandy soil (65% sand) | 0-15 | 4.28 | 0.12 | 0.12 | 0.64 | 17 |
| | | 15-30 | 4.02 | 0.06 | 0.07 | 0.25 | 6 |

### 3.3 Organic Carbon

Soil organic carbon was determined on samples collected from the weed fallow and *M. pruriens* cut for hay treatments (so as to manage cost of analysis) at pre-planting (Table 2) and at 2 WAP (data not shown). Total C, $C_L$ and Lability declined down the profile. There were generally minor differences between the treatments in $C_L$, Lability and $N_T$ between the treatments and the two sampling times.

Table 2. Total, non-labile and labile C pools and total N of the weed fallow and *M. pruriens* cut for hay treatments at pre-planting.

| Depth (cm) | $C_T$ | $C_{NL}$ [A] | $C_L$ (33mM $KmNO_4$) | $C_L$(333mM $KmNO_4$) | Lability[B] | $N_T$ | C:N |
|---|---|---|---|---|---|---|---|
| | mg/g | | | | | mg/g | |
| Weed Fallow | | | | | | | |
| (0-15) | 5.13 | 4.22 | 0.45 | 0.91 | 0.22 | 0.41 | 12.51 |
| (15-30) | 3.11 | 2.76 | 0.20 | 0.35 | 0.13 | 0.26 | 11.96 |
| (30-60) | 4.72 | 3.97 | 0.39 | 0.75 | 0.19 | 0.48 | 9.83 |
| (60-90) | 1.85 | 1.72 | 0.08 | 0.13 | 0.08 | 0.22 | 8.41 |
| (90-120) | 1.54 | 1.50 | 0.06 | 0.04 | 0.03 | 0.29 | 5.31 |
| *M. pruriens* (Hay) | | | | | | | |
| (0-15) | 4.28 | 3.67 | 0.30 | 0.61 | 0.17 | 0.46 | 9.30 |
| (15-30) | 4.66 | 4.26 | 0.30 | 0.40 | 0.09 | 0.39 | 11.95 |
| (30-60) | 2.89 | 2.63 | 0.20 | 0.26 | 0.10 | 0.3 | 9.63 |
| (60-90) | 2.65 | 2.40 | 0.10 | 0.25 | 0.10 | 0.18 | 14.72 |
| (90-120) | 4.10 | 3.87 | 0.20 | 0.23 | 0.06 | 0.38 | 10.79 |
| SED(Standard Error of the Difference) (depth) | | | | 0.09 | | | |
| LSD (Least Significant Difference)(depth) | | | | 0.03 | | | |
| P (Probability) (depth) | | | | 0.001 | | | |

$$^{A}C_{NL} = C_T - C_L\ (333\ mM)\quad ^{B}L = \frac{C_{L\,(333mM)}}{C_{NL}}$$

### 3.4 Nitrate

The concentrations of nitrate at the site throughout the soil profile across the 4 sampling times are presented in a time series format in Figure 1a, b, c and d. The highest concentrations of nitrate were found at the pre-planting sampling in the 0-15 layers of all three treatments. Nitrate concentration was highest following the *M. pruriens* cut for hay and the green manured treatments, 21 and 30 mg/kg respectively, compared with only 7 mg/kg in the weedy treatment ($P \leq 0.05$). Total nitrate content of the profiles, calculated from the nitrate concentration and bulk density to 120 cm (Figure 2), were highest at the pre-planting sampling and showed that the *M. pruriens* cut for hay treatment contained 107 kg N/ha compared to 68 and 28 kg N/ha on the green manure and weedy fallow treatments, respectively.

By planting and after 32 mm of rain, nitrate in the 0-15 cm layer of the *M. pruriens* cut for hay treatment remained stable. However, the green manure *M. pruriens* treatment had declined by almost two thirds to 11 mg/kg with a corresponding increase in the 15-30 cm layer. The total nitrate content declined between these two samplings (Figure 2).

The samplings at 1WAP (rainfall total 78 mm) and 2 WAP (rainfall total 111 mm) indicated very little nitrate in the 0-15 cm depth (2 mg/kg) in all the treatments. A bulge of nitrate at the 15-30 cm depth of both *M. pruriens* treatments can be seen in Figure 1c and may indicate leaching of N from the surface layers that were initially higher in nitrate.

By 2WAP the 3 treatments contained less than 4 mg/kg at all sampling depths. Total N content was still highest in the *M. pruriens* cut for hay treatment (26 kg N/ha) but the green manure *M. pruriens* and weedy treatments contained only 7.5 and 13.5 kg N/ha, respectively (Figure 2) ($P \leq 0.05$).

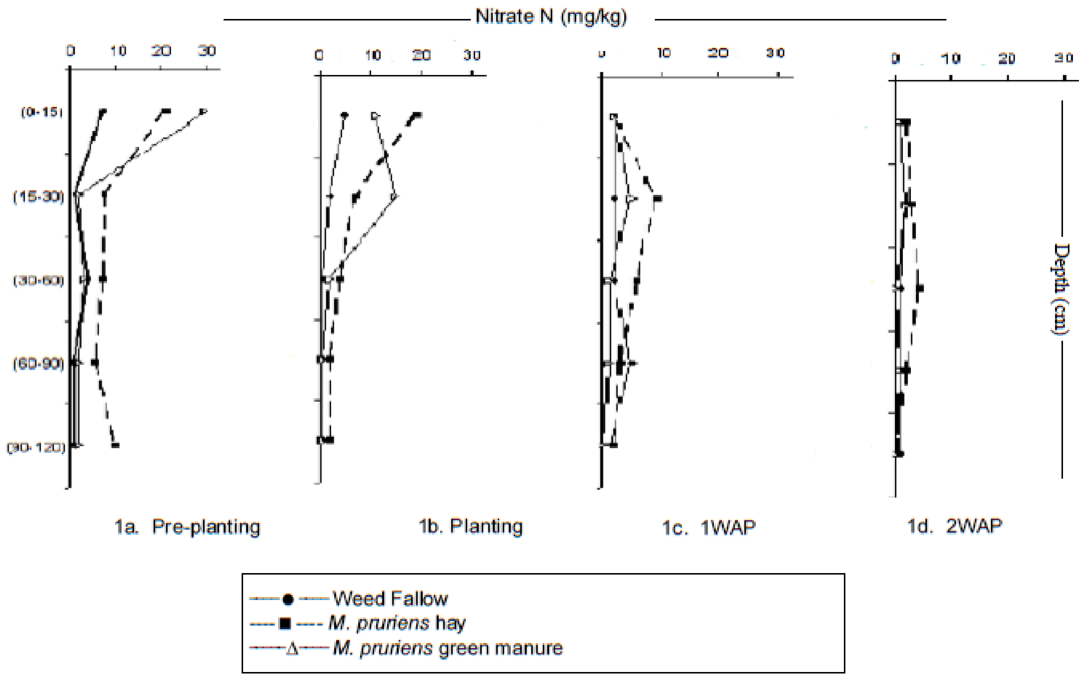
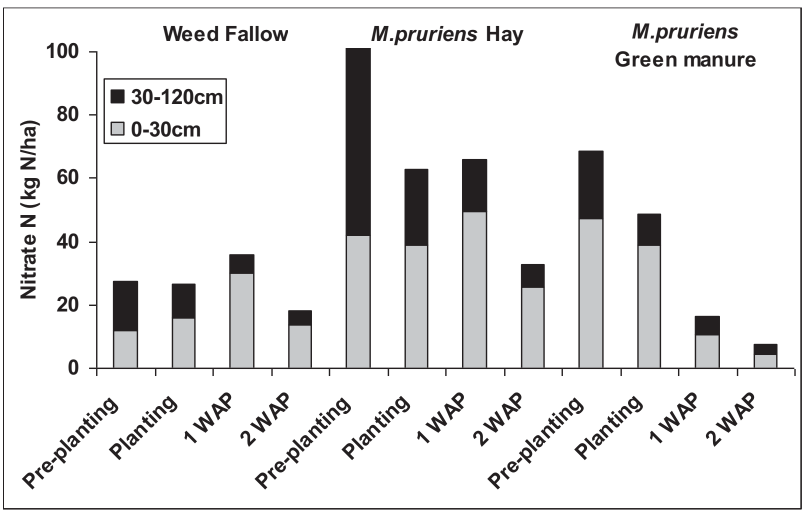



Figure 1. Nitrate N concentration of the Mbavha sandy soil site




SED = 4.15 kgNha$^{-1}$, P≤0.05.

Figure 2. Total soil nitrate in the 0-30 and 30-120 cm soil depth at the four sampling times

## 4. Discussion

The initially high nitrate concentrations at the pre-planting sampling were confined to the 0-15 cm layer of the *M. pruriens* treatments. These higher concentrations reflect the addition of N in the legume residues grown during the previous season. The production of 7.15 and 6.49 t/ha of *M. pruriens* biomass in the cut for hay and green manured plots during the 1999/2000 wet season results in approximately 178 and 162 kg N/ha, respectively, contained in the plant material (a large proportion of this would be from biological N fixation). Ploughing in the *M. pruriens* prior to the dry season ensured that plant residues were unavailable to the animals. This is reflected in the highest pre-planting nitrate concentration of this treatment (Figure 1 a). According to the local farmers, and Mr Mbavha who owned the land on which these experiments were conducted, it is unlikely that they would plough in high quality plant materials given the shortage of feed during the dry season. Harvesting, storing and feeding the plant material to penned animals is a much more likely scenario. Unfortunately much of the manure ends up staying in the kraals (penned areas) or spread around the homestead fields, with the large associated N losses (Zingore, 2006). Chikowo et al. (2004) also measured a rapid decline in mineral nitrogen between 1 and 3 WAP of a maize crop following *M. pruriens*, cattle manure, soyabean and fertiliser additions. They showed there were very few maize crop roots below 20 cm before 4 WAP, leaving nitrate susceptible to leaching. No increases in labile C at depth (33mM or 333mM $KMnO_4$ labile C) were detected as evidence of soluble C compounds leaching.

The higher nitrate content of the treatments cut for hay at all sampling times (Figure 2) throughout the trial may reflect a combination of the slightly higher *M. pruriens* biomass achieved in the previous season, and inputs of manure while the animals were grazing the residues. Even though the residues were removed from this simulated grazing treatment prior to the dry season, N inputs from the roots and leaf-fall throughout the growth of crop have become significant. This is supported by results obtained by Mafongoya and Jiri (2016) working on similar soils in central Zambia.

It is likely that more intensive sampling at the start of the rain season and throughout the growth of a maize crop would help explain disappearance of soil mineral N in the soil profile and the generally low recoveries on legume N (Ambrosano et al. 2013). While no labile C was measured at depth in this study, it is likely that the labile C and N compounds were leached with the rainfall events between the sampling times. This is supported by findings by Bationo et al (2007) in work carried out in West Africa on sandy soils.

The distinct dry season in the experimental area means there is little or no rainfall between harvest of the *M. pruriens* and land preparation for a maize crop for the subsequent season. This dry season stops most mineralisation of the plant litter and the potential for leaching of the nitrate N. The opening wet season rains are at a time of warm soil temperatures and the conditions for rapid mineralisation of leguminous material are optimum. It is under these conditions that synchronising nutrient release from high quality leguminous residues with nutrient uptake of a cereal crop is impossible. Mineralisation and leaching of N and C from high quality leguminous residues occur rapidly and changes can be measured days after the wetting event (Nguyen et al. 2014).

The nitrogen benefit to maize in rotation with legumes is mostly derived from nitrogen left in crop residue. These results show that, although N supply processes are important, they seldom provide abundance of N for long enough to sustain production on the same land (Khosla et al., 2002). Decomposition of high quality materials, such as legume residues, release mineral N. During decomposition there is a partitioning of N first between mineral N and microbial N, then with turnover of microbial N, into mineral N, humic N and microbial N (CGIAR, 2012). The availability of the N accumulated in soil organic matter to subsequent crops following the various legume-based treatments is a critical issue.

## 5. Conclusions and Recommendations

This dataset raises the difficulty of synchronizing nutrient release from leguminous plants with the demand of a growing crop such as maize. It is clear that although significant amounts of nitrate can be supplied by legumes, much of the becomes available early in the wet season and can move below 30 cm prior to crop roots growing to this depth. Since nitrogen demands of most crops are maximised during floral initiation and flowering, the use of N from the *M. pruriens* may be inefficient. Significant gains in the efficiency of N recovery can be made when plant material of slower decomposition rates is added to highly decomposable green manure materials. Wijnhoud et al (2003) found that adding rice straw to the green manure *Aeschynomene afraspera,* which is used as a green manure crop for flooded paddy rice, increased the N recovery efficiency in a subsequent rice crop from 29 to 50 %. If smallholder farmers intend to use *M. pruriens* on maize as an N source, removing and storing the green manure plant residues during the wet season and adding them to the germinating maize mixed with maize stover or other low quality organic residues is likely to improve N recovery and increase soil organic matter contents over the longer term. This is, however, a highly labour intensive job.

## References

Ambrosano, E. J., Cantarella, H., Bovi Ambrosano, G. M., Ferreira Dias, F. L., Rossi, F., Ocheuze Trivelin, P. C., & Muraoka, T. (2013). The role of green manure nitrogen use by corn and sugarcane crops in Brazil. *Agricultural Sciences*, *04*(12), 89-108. https://doi.org/10.4236/as.2013.412A008

Bationo, A. (2007). Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities: Challenges and Opportunities. Springer Science & Business Media. https://doi.org/10.1007/978-1-4020-5760-1

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B., & Kimetu, J. (2007). Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural Systems*, *94*(1), 13-25. https://doi.org/10.1016/j.agsy.2005.08.011

CGIAR. (2012). Leveraging legumes to combat poverty, hunger, malnutrition and environmental degradation. Retrieved December 20, 2015, from http://www.icrisat.org/crp/CRP3.5_Grain_Legumes_15Aug12.pdf

Chikowo, R., Mapfumo, P., Nyamugafata, P., & Giller, K. E. (2004). Mineral N dynamics, leaching and nitrous oxide losses under maize following two-year improved fallows on a sandy loam soil in Zimbabwe. *Plant and Soil*, *259*(1-2), 315-330. https://doi.org/10.1023/B:PLSO.0000020977.28048.fd

Jiri, O. (2003). Mineral nutrition and integration of forage legumes into smallholder farming systems , with emphasis on velvet bean [ Mucuna pruriens ( L ) DC. *University of Zimbabwe, MPhil Thesis*, (December).

Khosla, R., Fleming, K., Delgado, J. a, Shaver, T. M., & Westfall, D. G. (2002). Use of site-specific management zones to improve nitrogen management for precision agriculture. *Journal of Soil and Water Conservation*, *57*(6), 513-518. Retrieved from http://www.jswconline.org/content/57/6/513.abstract

Nguyen, D. H., Biala, J., Grace, P. R., Scheer, C., & Rowlings, D. W. (2014). Greenhouse gas emissions from sub-tropical agricultural soils after addition of organic by-products. *SpringerPlus*, *3*(1), 491. https://doi.org/10.1186/2193-1801-3-491

Paramu L Mafongoya; Obert Jiri. (2016). Nutrient Availability Following Planted Tree Fallows and Benefits to Subsequent Maize Crops. *International Journal of Agriculture Innovations and Research*, *4*(5), 818-823. Retrieved from http://www.ijair.org/index.php/issues

Rurinda, J., Mapfumo, P., Van Wijk, M. T., Mtambanengwe, F., Rufino, M. C., Chikowo, R., & Giller, K. E. (2014). Sources of vulnerability to a variable and changing climate among smallholder households in Zimbabwe: A participatory analysis. *Climate Risk Management*, *3*, 65-78. https://doi.org/10.1016/j.crm.2014.05.004

Sanchez, P. A., Buresh, R. J., & Leakey, R. R. B. (2004). Trees, soils, and food security. *Philosophical Considerations of the Royal B: Biological Sciences, 352*(1356).

Surveyor General. (1984). Zimbabwe. Natural Regions and Farming Areas. Government of Zimbabwe. Harare, Zimbabwe.

Waddington, S. R. (2003). *Grain Legumes and Green Manures for Soil Fertility in Southern Africa: Taking Stock of Progress. Proceedings of a Conference Held 8-11 October 2002 at the Leopard Rock Hotel, Vumba, Zimbabwe. Soil Fert. Net and CIMMYT-Zimbabwe, Harare, Zimbabwe.* Retrieved from https://books.google.com/books?id=x0bNhhtdUicC&pgis=1

Wijnhoud, J. D., Konboon, Y., & Lefroy, R. D. B. (2003). Nutrient budgets: Sustainability assessment of rainfed lowland rice-based systems in northeast Thailand. *Agriculture, Ecosystems and Environment*, *100*(2-3), 119-127. https://doi.org/10.1016/S0167-8809(03)00180-4

Zingore, S. (2006). *Exploring diversity within smallholder farming systems in Zimbabwe*. Nutrient use efficiencies and resource management strategies for crop production. PhD Thesis. Wageningen University. The Netherlands.

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# Transformation of Traditional Silvo-Pastoral Home-Gardens: A Case Study in Southern Sri Lanka

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**Abstract**

The Pasture Development Program on silvo-pastoral system in traditional home-gardens in Matara district was commenced with the aim of increasing milk production and income of the small-scale cattle farmers. The objectives of the study were to analyze ecosystem changes, economic trade-offs and social breakthroughs taken place in home-gardens after the program, with the aim of expanding the program coverage. The study was conducted through a field survey interviewing 34 farmers randomly selected from the participants. Tthe farmers have changed the composition of eco-systems in their home-gardens, replaced traditional grasses with CO3 fodder, and removed number of trees disturbing fodder cultivation. They have significantly lost some traditionally cultivated crops and trees due to competition with fodder during dry seasons. The farmers have significantly increased the milk yield per cow, market surplus and income, increased the amount of fodder sufficient to feed their cattle and little market surplus, and gradually adapted to cow-done as organic fertilizer. The social breakthroughs are identified as: reduced risk of conflicts with neighbors and theft of cattle, controlled damages caused by cattle to agricultural crops, reduced time spent on feeding cattle during dry seasons, increased domestic milk consumption, and increased the number of milk collecting centers induced by increased milk production. Although the Pasture Development Program have transformed the traditional home-gardens to improved silvo-pastoral system, community governance yet to be developed in order attract externalities particularly land use planning, technology development and policy support.

**Keywords:** silvo-pastoral system, traditional home-gardens, ecosystem changes, economic trade-offs, social breakthroughs

## 1. Introduction

According to the livestock statistics, the contribution milk production for national requirement is estimated at 33% in Sri Lanka in 2009 (Nanayakkara, 2013). The per capita consumption of milk and milk product in Sri Lanka is 3.5 kg /year, which is low compared to other South Asian countries (Perera & Jayasooriya, 2008). Sri Lanka import milk powder spending around US$ 400 million annually (Mendis and Edirisinghe, 2014). The present policy framework of Sri Lanka therefore aims at increase the national milk production and self-sufficient in milk in the medium term. The target of the government was to achieve 50 percent self-sufficiency in milk products by 2015. Smallholders dominate the local milk production systems in Sri Lanka operating by about 400,000 dairy farmers, at near-subsistence levels. About 73 % of variable costs consist of feeds alone in dairy farming (Navaratne & Buchenrieder, 2003). Limited access to good quality fodder year round is a major constraint to profitable smallholder dairy production. The main sources of concentrates used in dairy production in Sri Lanka are rice brand, coconut poonac and molasses, the by-products to supplement poor quality fodder basal diets (Department of Census and Statistics Sri Lanka, 2015). Cattles in Sri Lanka are primarily dependent on pasture and fodder found on neighbors' lands, roadsides and common areas (Ibrahim, et al., 1999). Creating conducive policy environment, the government has recognized the smallholder dairy farmers as the most important stakeholder in the domestic dairy industry and changed the land used policies particularly for pasture cultivation in favor of dairy development.

The Pasture Development Program in Matara district in Southern Sri Lanka commenced in 2012 with the aim of increasing milk production as well as income of the small-scale cattle farmers in short-term through continuous supply of sufficient quality feed. The average dairy farm has around 2-3 head of stock in Matara district are reared in small-scale operations based on proximity to markets and feed resources. Cattle are usually stall-fed, allowed to graze freely or tethered with mainly native pastures and crop residues. Presence of feed deficits is a major constraint to the dairy production systems in Matara district. The cattle depending on natural forages are facing severe shortage of green fodder availability particularly during the dry season. The pasture development program selected 10 small-scale cattle farmers who were rearing more than 2 cattle and can grow more than 200 bushes of fodder covering more than 10 perches (1 perch = 25.3m$^2$) land in their home-gardens, from each 37 Veterinary Surgeons Ranges. Each year from 2012, around 100 farmers were given opportunities to join the program with the aim of completing in 4 years period. The traditional home-garden in Matara district is an intimate association of multipurpose trees and shrubs with annual and perennial crops and livestock. Rearing livestock in home-gardens in Sri Lanka is comparatively low but important for achieving long-term food and nutrition security (Marambe & Silva, 2012). Home-gardens in Sri Lanka has a some form of cultivation in addition to the dwelling house on a total area of between 0.05 and 2.5 ha (mean 0.4 ha) (Pushpakumara et al., 2010). Home-gardens are mainly privately owned and have more secure rights and benefits from lands to land owners (De Zoysa & Inoue, 2008). Home-gardens have been practiced for centuries as traditional life supporting systems (De Costa et al., 2006).

The home-garden provides ecosystem services, household needs and part of the household livelihood strategy (Weerahewa et al.., 2012). Forest Sector Master Plan of Sri Lanka in 1995 has identified the high potential of home-gardens for the promotion and sustain its multiple uses (MFE, 1995). The structure and management of a home garden varies from place to place, depending upon ecological, socio-economic and cultural factors. Rearing livestock in home-gardens in Sri Lanka is comparatively low and important for achieving long-term food and nutrition security (Marambe & Silva, 2012).

The Provincial Council of the Southern Province invested Rs. 2.3 million in 2012 for the pasture development program. Each participant was given Rs. 5,000 as a grant in addition to the information leaflets, training, and CO3 fodder as planting materials. The Livestock Breeding Project in 1999 introduced Hybrid Napier var. CO-3 a high yielding perennial fodder as an efficient and economical solution to low productivity of national dairy herd in Sri Lanka (Premaratne & Premalal, 2006). CO-3 grass prefers a deep fertile soil and grows well in high rainfall areas with optimum temperature ranging 25 –40 C$^0$ in full sunlight as in Matara district. Hybrid Napier (Var. CO-3) fresh yields 5-8 kg / plant at 45 day cutting interval and 1 x 1 m spacing under good management. In view of the importance of feed resources as a major constraint to milk production, the analysis of impacts of the strategies of Pasture Development Program on silvo-pastoral system of home-gardens in Matara district to cope with feed constraints has become an urgent research need.

The objectives of the study were to examine the ecosystem changes, analyze the economic trade-offs and ascertain the social breakthroughs as impacts of the pasture development program on silvo-pastoral system of traditional home-gardens in Matara district. The study further made attempts to make policy implications in order to popularize and replicate in other districts as well.

## 2. Method

The study was conducted through a questionnaire survey interviewing 34 farmers randomly selected from 100 participants of the pasture development program in Matara district who had joined the program in 2012. The structural questionnaire was used in depth interviews of the survey was the primary source of data for the study. Further, discussion with key resource personnel of the program as well as field observation also facilitated for the collection of relevant primary data.

Descriptive statistics were calculated such as percent and frequency for categorical variables and mean with standard deviation, and median with range for continuous variables. Pearson's correlation was used to investigate the correlation between the variables. Wilcoxon Sign rank Test was used to identify the association between before and after the program situation of quantitative measurement. The Marginal Homogeneity Test was done to identify the association between before and after the program situation of qualitative measurements. The Kruskal-Wallis H test was used to determine if there are statistically significant differences between more groups of an independent variable on an ordinal dependent variable.

## 3. Results and Discussion

### *3.1 The Milk Farmers Participating in Pasture Development Program*

The milk farmers participating in Pasture Development Program are mainly middle age (mean 47 and median 43 years) and having upper secondary education (mean 13$^{th}$ and median 10$^{th}$ Grade) (Table -1). They are having mostly the small size families (mean 3 and median 3) and possessing wide range in sizes from 40 to 320 perches (mean 128.7 and median 95 perches) of their home-gardens. The size and land ownership of home-gardens by all the farmers have favorable environment for their ability to grow CO3 quality fodder to feed their dairy cattle. Only 29% of them are full time farmers in occupation while others (71%) are part-time farmers occupied in non-farm occupation. They are involving in the program for almost 4 years since 2012.

Table 1. General information of the milk farmers

| | Minimum | Maximum | Mean | Std. Deviation | Median |
|---|---|---|---|---|---|
| Age (Year) | 33 | 64 | 47 | 8.806 | 43 |
| Education (Grade) | 8 | 13 | 11 | 1.714 | 10 |
| Family Size (Number) | 2 | 5 | 3 | 0.913 | 3 |
| Home-garden Size (Perches) | 40.0 | 320.0 | 123.7 | 72.7 | 95 |
| Occupation | Farming-10 (29); Government-5(15); Private-7(21); Self-Employ-12(35) | | | | |

* Percentage in parentheses

### *3.2 Ecosystem Changes in Silvopastoral System of the Home-Gardens*

Traditional composition of cattle has not been changed even after the implementation of pasture development program. The farmers are usually rearing Jersey, Persian, Syhivahal-cross and Syhivahal and Batu (indigenous) breeds in their home-gardens for generations. The number of cattle rearing under home-garden silvopastoral system has been changed in 39% significantly (Z=4.073; and P=0.000) (Table -2) after the program. The average number of cattle in a home-garden has been increased from 3 (Min-2; Max-5; SD-0.937) to 4 (Min-2; Max-8; SD-1.472). With the introduction of the pasture development program and increase of number of cattle, the farmers are experiencing in changed composition of eco-systems in their traditional home-gardens. Among the large number of different woody species, the majority of tree species found in home-gardens in Sri Lanka are indigenous or endemic with multi-purpose uses (Ariyadasa, 2002). The average total vegetation of the eco-system from the average total land in home-gardens has reduced by 07% with significantly change (Z=-4.369; P=0.000) reducing from 82% (average 101 perches) to 76% (average 94 perches) after the implementation of the pasture development program. There are significant reductions of the coverage of all, Traditional grass/fodder in 66% (Z=-4.815; and P=0.000); Annual Crops in 18% (Z=-2.415; and P=0.016); Perennial Crops in 24% (Z=-4.617; and P=0.000); Forest Trees in 05% (Z=-3.207; and P=0.001); and Other Vegetation in 28% (Z=-3.066; and P=0.002) in the home-garden ecosystems. Households prefer to replace high canopy trees in their home-gardens with medium canopy cash crops and multipurpose trees to fulfill their basic needs (Pushpakumara et al., 2012).

The farmers have replaced traditional grasses and established the plots with CO3 fodder (Hybrid Napier Var.CO-3) using the planting materials distributed by the pasture development program. Technology adapted in home-gardens in Sri Lanka have changed over 55% during the past twenty years (Daulagala, et al.., 2013). The farmers have reduced the average total land of their home-gardens under traditional grass/fodder from average 26 perches (21%) to 9 perches (7%). Instead, they have cultivated average 18 perches (16%) in wide range of land extent (minimum – 10; maximum – 40) with introduced CO3 fodder, a high yielding fodder, based on the size of the home-gardens and their intention for the devotion in the program. There is a significant positive correlation ($\gamma$=0.545; P=0.001) between the size of the land used for CO3 fodder cultivation and the size of their home-gardens. The lands under coconut trees and forest tress particularly Teak in the home-gardens are commonly used for CO3 fodder as an under-cultivation. Those under-cultivations also provide grazing and cut and-carry CO3 forage for the dairy production. It could be observed that, with the development of silvopastoral system, only very few farmers have grown better quality trees mainly leguminous trees and bushes as complementary plants to make continuous access to feed the cattle and also benefit forest trees.

It could be observed that the farmers have removed number of trees disturbing fodder due to continuity of canopy cover, largely by the farmers having small-extent home-gardens. The vegetation of home-gardens of the milk farmers has lost average 9.88 perches (10%) after the implementation of the pasture program. According to analysis, there is no significant correlation ($\gamma$=0.184; P=0.296) between the average size of home-gardens and the average size of lost vegetation. However, it could be observed that the farmers having small-extent home-gardens particularly have removed some individual trees, both perennial crops and forest trees which are shading their fodder plots. Moreover, according to the farmers, small-extent home-gardens have significantly lost some traditionally cultivated annual crops and perennial crops also due to competition with fodder during dry seasons, but remaining trees are growing vigorously. Higher organic matter incorporation in home-gardens enhance soil chemical and physical properties (Egodawatta et al., 2011).

Table 2. Changes in the eco-systems of the home gardens after the pasture program

| | Before the project | After the Project | Remarks |
|---|---|---|---|
| 1. Average number of cattle | 3 (Min-2; Max-5; SD-0.937) | 4 (Min-2; Max-8; SD-1.472) | (Changed 39) Z=4.073[a;] P=0.000**** |
| 2. Average extent and % from total land under traditional grass/fodder (Perches and %) | 26 (21) (Min-0; Max-70; SD-17.910) | 9 (7) (Min-0; Max-35; SD-9.216) | (Changed -66) Z= -4.815 [a;] P=0.000*** |
| 3. Average size and % from total land under CO3 fodder (Perches): | | 18 (16) (Min-10; Max-40; SD-4.828) | |
| 4. Correlation: Size of Home-gardens vs. size of land under CO3 fodder (Perches) | Average Size of Home-gardens 123.68(Min-40; Max-320; SD-72.731) | Average Size of land under CO3 fodder 18 (16)(Min-10; Max-40; SD-4.828) | γ=0.545[c] P=0.001 |
| 5. Average extent (Perches) and % from total land covered by: | | | |
| Annual crops | 11 (9) (Min-0; Max-30; SD-7.830) | 9 (7) (Min-0; Max-30; SD-7.566) | (Changed -18) Z= -2.415 [a;] P=0.016*** |
| Perennial crops | 22 (18) (Min-5; Max-50; SD-16.602) | 17 (14) (Min-5; Max-40; SD-10.077) | (Changed -24) Z= -4.617 [a;] P=0.000*** |
| Forest trees | 35 (28) (Min-0; Max-150; SD-35.621) | 33 (27) (Min-0; Max-150; SD-36.140) | (Changed -05) Z= 3.207 [a;] P=0.001*** |
| Others vegetation | 6 (05)(Min-0; Max-20; SD-6.219) | 5 (04) (Min-0; Max-15; SD-7.459) | (Changed -28) Z= -3.066 [a;] P=0.002*** |
| 6. Average total vegetation | 101 (82) (Min-25; Max-300; SD-65.398) | 94 (76) (Min-20; Max-280; SD-63.551) | (Changed -07) Z= -4.369 [a;] P=0.000*** |
| 7. Correlation: Size of Home-gardens vs. Lost vegetation (Perches) | Average Size of Home-gardens 123.68 (Min-40; Max-320; SD-72.731) | Average Size of Lost Vegetation 9.88 (Min-(35); Max-10; SD-9.700) | γ=0.184[c] P=0.296 |
| 8. Knowledge on ecosystem management | | | |
| Knowledge on land use planning (mean and median) | Mean – 2.2**; (SD-0.592) Median – 2 | Mean – 2.8** (SD-0.717) Median – 3 | MH St.=4.379[b] P = 0.000*** |
| Knowledge on cropping systems | Mean – 1.6**; (SD-0.812) Median – 1 | Mean – 2.4**; (SD-0.657) Median – 2 | MH St.=4.747[b] P = 0.000*** |

* Percentage in parentheses
**Very High – 5; High – 4; Moderate – 3; Low – 2; Very Low – 1; No – 0
a. Z- Wilcoxon Signed Ranks Test
b. MH St.-Marginal Homogeneity Test
c. γ- Pearson Correlation
***Significant at P<0.05

The knowledge of the farmers on ecosystem management in their home-gardens has not yet be improved even after the 4 years of implementing the pasture development program. The knowledge of the farmers on ecosystem management was measured in terms of knowledge on land use planning; and the knowledge on selecting cropping systems. At the inception of the program, the farmers have been trained by the officers on CO3 fodder cultivation in home-gardens in the view of improving their dairy farming. According to the farmers, their knowledge on land use planning of the home garden has been significantly changed (MH St. = 4.379; and P = 0.000) only from the level of “Low” (mean – 2.2; minimum-1; maximum-3; SD-0.592 and median – 2) to “Moderate” (mean – 2.8; minimum-2; maximum-4; SD-0.717 and median – 3). Even the knowledge of majority of the farmers on selecting cropping systems for the home garden has been significantly changed (MH St. = 4.747; and P = 0.000), but only from the level of just “Very Low” (median – 1) to “Low” (median – 2) after 4 years of the implementation of the program.

### *3.3 Improvement of Economic Trade-Offs After the Pasture Development Program*

The pasture development program has significantly increased the milk yield per cow, market surplus and income as very important improvement of the economic trade-offs. The house-holds decisions on home-garden activities tends to be quite dynamic and management practices are mostly driven by their consumption and income generation needs (Galhena et al., 2012). The average production of milk per cow per day has increased by 90% significantly (Z=5.169 and P=0.000) from 3.1 to 5.9 liters after the implementation of the pasture program (Table – 3). Similarly, the average amount of milk production per day per farmer has increased by 164% significantly (Z=5.169 and P=0.000) from 9.6 to 25.2 liters (Table – 3). Households requires at least three upgraded cows to produce minimum of 15 liters of milk per day to earn a reasonable income from dairy farming (Ranaweera, 2007). They have increased the average amount of milk they sold in 177% significantly (Z=5.090 and P=0.000) from 8.7 to 24.1 liters even after increasing the household consumption by 28% significantly (Z=2.342 and P=0.020) from 0.9 to 1.1 liters. The average income of a farmer has increased by 291% significantly (Z=5.086 and P=0.000) from Rs. 417.41 to 1629.79 per day also increasing the selling price of milk by 42% significantly (Z=5.093 and P=0.000) from average Rs. 46.97 to 66.82 per liter. The average daily income of a farmer after the participating in the program has wide range from minimum Rs. 469 to maximum Rs. 4,340 (SD-913.910). Since most of the farmers (71%) are part-time farmers, they consider this income as an extra earning for the household. Even the full-time farmers (29%) do milk farming in their home-gardens as an additional domestic activity with the help of wife and the other family members.

Table 3. Change of economic trade-offs of the milk farmers after the pasture program

| 1. Method and duration of feeding cattle by households | Before the project | After the Project | Remarks |
|---|---|---|---|
| Home gardens<br>Average Hours / Day | 2.4 (Min-1; Max-6; SD-0.985) | 2.6 (07) (Min-1; Max-6; SD-1.021) | 7% increase<br>Z= -1.732 [a;]<br>P=0.083 |
| Private lands<br>Average Hours / Day | 4.3 (Min-2; Max-6; SD-1.142) | 2.0 (-226) (Min-0; Max-4; SD-0.937) | 226% decrease<br>Z= -5.068 [a;]<br>P=0.000*** |
| Village common lands<br>Average Hours / Day | 2.1 (Min-0; Max-4; SD-1.324) | 0.7 (-66)(Min-0; Max-2; SD-0.629) | 66% decrease<br>Z= -4.565 [a;]<br>P=0.000*** |
| Cut & Fed<br>Average Hours / Day | 0.8 (Min-0; Max-3; SD-0.758) | 3.2 (286) (Min-2; Max-5; SD-0.869) | 286% increase<br>Z= -5.179 [a;]<br>P=0.000*** |
| Average total feeding<br>Average Hours / Day | 9.6 (Min-7; Max-11; SD-0.927) | 1.5 (-11) (Min-6; Max-10; SD-1.187) | 11% decrease<br>Z= -4.647 [a;]<br>P=0.000*** |
| Cut and fed<br>Kg / Cow/Day | 2.7 (Min-0; Max-6; SD-2.067) | 5.9 (117) (Min-4; Max-8; SD-1.274) | 117% increase<br>Z= -4.991 [a;]<br>P=0.000*** |
| Other feed<br>Kg/Cow /Day | 1.9 (Min-1; Max-3; SD-0.715) | 0.9 (-52) (Min-0; Max-2; SD-0.600) | 52% decrease<br>Z= -4.757 [a;]<br>P=0.000*** |
| 2. Production of CO3 in Home-garden | | | |
| Average production of CO3<br>Kg /Home-garden/ Day | 0 | 22.35(Min-10; Max-50; SD-9.94) | |
| Average production of CO3<br>Kg / Perch/ Day | 0 | 1.3 (Min-0.5; Max-2.5; SD-0.414) | (Average size of CO3 land 18 (16) (Min-10; Max-40; SD-4.828) |
| Average production of CO3<br>Kg / Perch/ 45 days | 0 | 58.07 (Min-22.50; Max-112.5; SD-14.747) | CO3 is harvested at 45 days interval |
| Average production of CO3<br>Kg / Cattle/ Day | | 5.73 (Min-2; Max-12.5; SD-2.443) | |
| Average amount of selling CO3 by selling farmers Kg / day | | 8 (Min-5; Max-10) | Only 5 respondents (15%) sell total 40kg per day |
| Average Price per Kg (Rs) | | 7.02 (Min-5; Max-8) | |
| Average application of fertilizer<br>Kg of Urea /perch/ 45 days<br>Kg of Organic/perch/45 days | | Cannot be quantified | Fertilizer application in 45 days interval just after harvesting. Not in specific amount. |
| Storing CO3 Kg per day | | 0 | Daily harvesting |

| 3. Production, consumption, selling of and income from milk for farmers from home-gardens | Before the project | After the Project | Remarks |
|---|---|---|---|
| Average production of milk Liters / Cow / Day | 3.1 (Min-2; Max-5; SD-0.830) | 5.9 (90) (Min-4; Max-8; SD-1.200) | 90% increase Z= 5.169 [a;] P=0.000*** |
| Average amount of milk production Lit /Day / Farmer | 9.6 (Min-4; Max-25; SD-5.052) | 25.2 (164) (Min-8; Max-64; SD-12.966) | 164% increase Z= 5.090 [a;] P=0.000*** |
| Average amount of milk consumption Lit / Day / Farmer family | 0.9 (Min-0; Max-2; SD-0.610) | 1.1 (28) (Min-0; Max-3; SD-0.537) | 28% increase Z=2.324 [a;] P=0.020*** |
| Average amount of milk sold Lit / Day /Farmer | 8.7 (Min-3; Max-25; SD-5.132) | 24.1 (177) (Min-7; Max-62; SD-12.869) | 177% increase Z= 5.090 [a;] P=0.000*** |
| Average amount of milk sold to neighbors Lit / Day /Farmer | 0.7(Min-0; Max-3; SD-0.836) | 1.8 (150) (Min-0; Max-6; SD-1.499) | 150% increase Z= 4.406 [a;] P=0.000*** |
| Average Price of milk received Rs /Lit | 46.97 (Min-40; Max-52; SD-3.167) | 66.82 (42) (Min-60; Max-70; SD-2.724) | 42% increase Z= 5.093 [a;] P=0.000*** |
| Average Income from milk Rs/day/ Farmer | 417.41 (Min-120; Max-1300; SD-262.908) | 1629.79 (291)(Min-469; Max-4340; SD-913.910) | 291% increase Z= 5.086 [a;] P=0.000*** |
| 4. Correlation: Amount of milk production (Lit/Day/Farmer) vs. Production of CO3 (Kg /Home-garden/ Day) after the program | Average amount of milk production (Lit/Day/Farmer) 9.6 (Min-4; Max-25; SD-5.052) | Average production of CO3 (Kg /Home-garden/Day) 22.35 (Min-10; Max-50; SD-9.94) | $\gamma$=0.580[c] P=0.000 |
| 5. Correlation: Amount of milk production (Lit/Day/Farmer) vs. Production of CO3 (Kg /Home-garden/ Day) after the program | Average amount of milk production (Lit/Day/ Farmer) 9.6 (Min-4; Max-25; SD-5.052) | Average size of home-garden (Perches) 123.68 (Min-40; Max-320; SD-72.731) | $\gamma$=0.663[c] P=0.000 |
| 6. Contribution of vegetable, fruit, fire-wood and wood from home-gardens | | | |
| Average % of vegetable contribution from home-garden for farmer household consumption | 20.1 (Min 0; Max-40; SD-13.285) | 12.1 (- 40) (Min-0; Max-30; SD-10.381) | 40%decrease Z= -4.231 [a;] P=0.000*** |
| Average % of fruits contribution from home-garden for farmer household consumption | 57.4 (Min-10; Max-90; SD-17.111) | 35.4 (- 38) (Min-0; Max-80; SD-17.511) | 38%decrease Z= -5.098 [a;] P=0.000*** |
| Average % of fire wood contribution from home-garden for farmer household consumption | 100 | 100 | |
| Average % of wood contribution from home-garden for farmer household consumption | 63.5 (Min-0; Max-95; SD-19.288) | 62.8 (-01) (Min-0; Max-95; SD-19.196) | 01%decrease Z= -1.890 [a;] P=0.059 |

* Percentage in parentheses

a. Z- Wilcoxon Signed Ranks Test

b. MH St.-Marginal Homogeneity Test

c. $\gamma$- Pearson Correlation

***Significant at P<0.05

The farmers have increased the production of fodder at in their home-gardens sufficient to feed their cattle and little market surplus after the implementation of pasture development program. Further to grazing at home-gardens, private lands and village common lands, the average amount of fodder used for cut and fed the cattle has been increased by 117% significantly (Z=4.991 and P=0.000) from 2.7 to 5.9 kg per cow per day after the implementation of the pasture program. The pasture program has taken enough effort to produce average 5.73 kg of CO3 per cow per day with minimum 2 kg to maximum 12.5 kg (SD-2.443). They harvest CO3 daily based on the requirement of their cattle to keep the palatability of the cattle with fresh fodder. The farmers produce average 58.07 kg (minimum 22.50; maximum 112.5; SD-14.747) of CO3 per perch in 45 days production / harvesting cycle. The increase of fodder production due to the pasture development program has influenced the farmers to reduce the amount of feeding cattle with other feeds mainly rice straw and rice brand by 52% significantly (Z=-4.757 and P=0.000) from 1.9 to 0.9 kg per cow per day. More than 50% of the rice straw, a major crop residue in Sri Lanka is used as animal feed (Perera, 1992). There are 70-90,000 tons of rice bran produced annually in Sri Lanka is one of the main sources of concentrates used in dairy production to supplement the poor quality fodder basal diets (Ibrahim, et. al, 1999). The farmers purchase Rice Brand at the rate of Rs 25 / kg, and Cattle Feed (Gawa Ahaara) at Rs. 950 / 25 kg (Bag) and some Minerals to feed their cattle. The Rice Straw is available in the village paddy fields of their fellow farmers and collect free of charge to feed the cattle.

Although there is an increase of pasture production in home-gardens, the average duration of feeding the cattle per day at home-garden has not increased significantly (7%, Z=1.732 and P=0.083). However, the average feeding duration of cattle at private lands has decreased in 226% significantly (Z=-5.068 and P=0.000) from 4.3 to 2.0 hours per day after the pasture program. The average duration of feeding at the village common land also has reduced in 66% significantly (Z=-4.565 and P=0.000) from 2.1 to 0.7 hours per day after the pasture program. The average total duration of feeding the cattle also has reduced in 11% significantly (Z=-4.647 and P=0.000) from 9.6 to 8.6 hours per day after the pasture program. Moreover, the amount of milk production per day per farmer after the pasture program, has a significant positive correlation ($\gamma$=0.580; P=0.000) with the amount of the production of CO3 fodder per day per farmers. Similarly, the amount of milk production per day per farmer also has a significant positive correlation ($\gamma$=0.663; P=0.000) with the production of CO3 per home-garden per day after the program. It could be revealed that only very few (15%; 5 respondents) farmers sell average 8 kg (minimum 5; maximum 10) of CO3 per day at the average price of Rs. 7.02 per kg. As the formal milk buyers, MILCO purchase milk at the fixed rate of Rs. 70 /liter and Lucky Yogurt Rs. 65 /liter from the farmers. The purchasing price is vary by the local milk collectors.

The increased volume of cow done with the increased volume of feeding fodder has replaced the inorganic fertilizer application in CO3 plots. Hybrid Napier grass produced higher yield with adequate organic manure than applied with inorganic fertilizer (Jayanthi, 2003). According to the farmers, they have gradually adapted to cow-done as organic manure replacing urea used for fodder, crops and trees. With the implementation of the pasture program, each farmer was given Rs. 5,000 as an incentive without considering their extent of CO3 fodder cultivation or the size of their home-garden. Some of them have applied Urea to their CO3 plots without any standard amount but depend on availability after applying the fertilizer to their paddy fields. However, it could be observed that almost all the farmers are usually collecting and applying cow don as organic manure not only to their agricultural crops but also to the CO3 fodder plots in their home gardens.

Contribution of vegetables and fruits from home-gardens in daily diet has been reduced but negligible compared to the increased income from milk production. Most of the farmers (79%) have produced average 20.1% (minimum 0; maximum 40; SD-13.285) of their daily house hold requirements of vegetables in their home gardens before the pasture program. After the implementation of the pasture, 68% of the farmers have reduced the daily household vegetable contribution in 40% significantly (Z=-4.231 and P=0.000) to 12.1% (minimum 0; maximum 30; SD-10.381). Similarly, all the farmers (100%) have produced average 57.4% (minimum1 0; maximum 90; SD-17.111) of daily household fruits requirement before the implementation of the program. Home-gardens in Sri Lanka constitute the most significant fruits production system (Weerakkody, 2004). The contribution of the average daily household fruit requirement of 97% of the farmers, from the home-garden has reduced by 38% significantly (Z=-5.098 and P=0.000) to average 35.4% (minimum0; maximum 80; SD-17.511) after the pasture development program. However, all the farmers (100) fulfill the 100% of their fire-wood requirement totally from their home-gardens even after the implementation of the pasture program. The very little (01%) reduction of average home-garden contribution of household wood requirement of 97% farmers from 63.5% with wide range (minimum 0; maximum 95; SD-19.288) to 62.8% (minimum 0; maximum 95; SD-19.196) after the implementation of the program is not statistically significant. Home-gardens supply more than 70 % of the timber and more than 80 % of the fuel-wood requirement in the country (Chokkalingam & Vanniarachchy, 2011).

*3.4 Development of Social Breakthroughs by the Pasture Development Program*

The pasture program has facilitated the control of damages caused by cattle to the agricultural crops in farmers own home-gardens to some extent but the home-gardens of their neighboring households at considerable level. The reduction of average damage (from Mean 1.9 to 1.7) done by the grazing of cattle in home garden is not significant (MH St. = 0.870; P = 0.384) and still the majority is remaining at "Low" level (Median – 2) (Table – 4). However, the damage done in neighbors' home-gardens has reduced (from Mean 1.1 to 0.3) to the level of almost "No" (Median – 0) significantly (MH St. = 4.439; P = 0.000) after the pasture program. The pasture development program has reduced the conflicts with neighbors and risk of theft of cattle by increasing cutting and feeding cattle without allowing long duration grazing in private (from 4.3 to 2.0 hours per day) and common lands (from 2.1 to 0.7 hours per day). The average conflicts with neighbors due to gracing of cattle also have reduced (from Mean 0.7 to 0.1) significantly (MH St. = 4.146; P = 0.000) to the level of "No". The risk of the theft of cattle has also reduced from "Low" to "Very Low" (from Mean 1.9 to 0.8) significantly (MH St. = 4.503; P = 0.000) after the pasture development program.

Table 4. Social breakthroughs of the milk farmers after the pasture development program

| 1. Average cattle damage to agricultural crops (Mean and Median) | Before the project | After the Project | Remarks |
|---|---|---|---|
| Own | Mean-1.9**; (SD-0.702)<br>Median-2 | Mean-1.7**<br>(SD-0.760)<br>Median-2 | MH St. = 0.870[b]<br>P = 0.384 |
| Neighbor | Mean-1.1**; (SD-0.712)<br>Median-1 | Mean-0.3**; (SD-0.524)<br>Median-0 | MH St. = 4.439[b]<br>P = 0.000*** |
| 1. Average conflict with neighbor on gracing (Mean and Median) | Mean-0.7**; (SD-0.589)<br>Median-1 | Mean-0.1**; (SD-0.327)<br>Median-0 | MH St. = 4.146[b]<br>P = 0.000*** |
| 2. Average risk of theft of the cow | Mean-1.9**;<br>(SD-1.525702)<br>Median-2 | Mean-0.8**; (SD-0.855)<br>Median-1 | MH St. = 4.503[b]<br>P = 0.000*** |
| 3. Average Family members involving in feeding | 1 | 1 | Mainly husband involving in feeding. Wife also support |
| 4. Average time spend on feed collecting and stall feeding Hours (Mean and Median) | Mean-4.1**; (SD-1.647)<br>Median-4 | Mean-2.3**; (SD-0.963)<br>Median-2 | MH St. = 5.127[b]<br>P = 0.000*** |
| 5. Average time spend on moving cattle for grazing Hours (Mean and Median) | Mean-2.2**; (SD-0.819)<br>Median-2 | Mean-2.0**; (SD-0.758)<br>Median-2 | MH St. = 2.111[b]<br>P = 0.035*** |
| 6. No. of milk collectors / centers | 2 | 5 | Milco, Lucky Yogurt, 3 informal collectors |
| 7. Average convenience of milk selling (Mean and Median) | Mean-2.0**; (SD-0.603)<br>Median-2 | Mean-4.0**; (SD-1.058)<br>Median-4 | MH St. = 5.417[b]<br>P = 0.000*** |
| 8. Average amount of domestic milk consumption Lit / Day / Farmer family | 0.9<br>(Min-0; Max-2; SD-0.610) | 1.1 (28)<br>(Min-0; Max-3; SD-0.537) | 28% increase<br>Z=2.324 [a;]<br>P=0.020*** |
| 9. Average amount of milk sold to neighbors Lit / Day /Farmer | 0.7<br>(Min-0; Max-3; SD-0.836) | 1.8 (150)<br>(Min-0; Max-6; SD-1.499) | 150% increase<br>Z= 4.406 [a;]<br>P=0.000*** |
| 10. Organizing milk farmers (Mean and Median) | Mean-0.6**; (SD-0.597)<br>Median-1 | Mean-1.5**; (SD-0.896)<br>Median-2 | MH St. = 4.427[b]<br>P = 0.000*** |
| 11. Interest of farmers in further promotion of dairy farming | | Mean-4.2**; (SD-0.834)<br>Median-4 | |
| 12. Requirements for promotion | | | Kruskal Wallis Test: Grouping Variable: Interest (Range 3~5) |
| More funds | | Mean-4.1**; (SD-0.821)<br>Median-4 | KW = 8.462[d]<br>P = 0.015*** |
| Shade tolerance fodder | | Mean-3.9**; (SD-0.729)<br>Median-4 | KW = 8.337[d]<br>P = 0.015*** |
| Low priced fodder cutter | | Mean-2.1**; (SD-1.013)<br>Median-2 | KW = 0.416[d]<br>P = 0.812 |
| Improved cattle breed | | Mean-3.4**; (SD-0.981)<br>Median-3 | KW = 0.045[d]<br>P = 0.978 |
| Better Price for milk | | Mean-4.4**; (SD-0.652)<br>Median-4 | KW = 8.174[d]<br>P = 0.017*** |
| Subsidy for cattle shed | | Mean-2.6**; (SD-1.252)<br>Median-2 | KW = 0.473[d]<br>P = 0.789 |

* Percentage in parentheses

**Very High-5; High-4; Moderate-3; Low-2; Very Low-1; No-0

a. Z- Wilcoxon Signed Ranks Test
b. MH St.-Marginal Homogeneity Test
c. γ- Pearson Correlation
d. KW-Kruskal Wallis Test

***Significant at $P<0.05$

The farmers have reduced the time they spent on feeding cattle by collecting grasses and fodder from different sources available in the village, particularly during dry seasons. The dairy farmers in wet zone including Matara district spend average 3.7 hours daily on dairy activities mainly feeding the animals; either collecting fodder or taking animals to and from tethered grazing (Ibrahim, et. al, 1999). In all the households, farmers are directly involving in feed collecting and feeding their cattle with the support of their elderly sons. House wives of the farmers do milking as a traditional practice in additional to their household activities. All the farmers have to cut the fodder in the morning and feed the cattle. The part-time farmers (71%) who are engaging in non-farm occupations have to cut the fodder in the afternoon and request a family member mainly the wife to feed the cattle. Lack of labor availability is the main reason for the low level of management in home-gardens, because family members are involved in other jobs (Jayawardena & Jayatilaka, 1998). They feel that the average time they spend on feed collecting and stall feeding has significantly reduced (MH St. = -5.127; P = 0.000) from "High" to "Low" (from Mean 4.1 to 2.3) after the production of CO3 fodder in their home-gardens.

Increased domestic milk consumption by farmers' as well as their neighboring families is also an important social breakthrough of the pasture development program leading to eradication of rural malnutrition. Home-gardens in Sri Lanka are user-driven and produce multiple benefits of direct relevance for local livelihoods (Mattsson et al., 2013). The consumers perceive milk powder as an inferior good thus the demand is likely to shift increasingly to liquid milk is the current trend in Sri Lanka. The government also is making effort organizing awareness programs to popularize the liquid milk consumption. The average amount of domestic milk consumption of the farmers has increased in 28% significantly (Z=2.324; P=0.020) from 0.9 to 1.1 liter per family per day after the pasture development program. Their neighboring families also have increased their milk consumption in 150% significantly (Z= 4.406; P=0.000) from average 0.7 to 1.8 liter per family per day.

The farmers have understood that the increased number of government and private milk collecting centers have been induced by the increased milk production after the pasture development program. According to the farmers, the average number of milk collectors has been increased from 2 to 5 joining 3 trustworthy informal collectors in addition to the government own MILCO and the private own Lucky Yogurt. The informal market is critical to profitability for the small holding producers for their liquid milk and making the dairying an economically viable enterprise. The informal market consists of sales directly to individual consumers, and private milk collectors who then sell milk either to collection centers, restaurants, local manufacturers of milk products or to consumers. Presently, however, the farmers are experiencing the increase of convenience of milk selling from "Low" to "High" (from Mean 2.0 to 4.0). Increased price paid for milk along with an improved collection network encouraged dairy farmers to produce more milk (Ranaweera, 2009).

The farmers have not yet promoted community governance in order attract externalities to promote their dairy farming in home-gardens even after the successfully implementing the pasture development program. The number and total area of home-gardens in Sri Lanka have been increasing annually over the years with little policy support (Pushpakumara et al., 2012). Although the organizing of milk farmers has been significantly increased (MH St. = 4.427; P = 0.000) from Mean 0.6 to 1.5, the majority of them feel that are still remaining at "Low" (Median-2) level. Their knowledge on ecosystem management particularly the knowledge on land use planning (Mean-2.8) and knowledge on cropping system (Mean-2.4) are at "Low" and "Moderate" levels respectively even more than 4 years after the implementation of the pasture program (Table -2). It could be revealed that the farmers are "Highly" (Mean-4.2; Median-4) interested in further promotion of their dairy farming. Village households utilize home-gardens as a local strategy addressing the issue of dairy farming even with limited resources and institutional support (Galhena, et al., 2013). Considering the interest "Range from 3 to 5" (Moderate to Very High) of the farmers for the promotion of their dairy farming, the farmers have "High" and significant requirement of: more funds (Mean-4.1 and Median-4; KW = 8.462; P = 0.015), shade tolerance fodder variety (Mean-3.9 and Median-4; KW = 8.337; P = 0.015) and better price for their milk (Mean-4.4 and Median-4; KW = 8.174; P = 0.017). The officials of the pasture development program have already started adaptive research programs with shade tolerant fodder varieties with the view of replacing CO3 fodder for home-gardens. The farmers have "Low" (Mean-2.1 and Median- 2) requirement of low priced fodder cutter but not significant (KW = 0.416; P = 0.812) with interest as the grouping variable. Higher average production of milk is obtained due to better nutrition provided under cut and fed system (Ranaweera, 2007). The farmers have a "Moderate" (Mean-3.4 and Median-3) requirement of improved cow breeds which is not significant (KW = 0.045; P = 0.978) with their interest. According to Mendis & Edirisinghe (2014), the technology mainly new breeds, breeding techniques and training programs on animal husbandry significantly aid for the growth of domestic fresh milk supply. Similarly, they have almost "Moderate" (Mean-2.6 and Median-2) requirement of subsidy for a cattle shed, but not significant (KW = 0.473; P = 0.789) with their interest in further improvement of dairy farming in their home-gardens.

## 4. Conclusions and Policy Implications

The pasture development program in Matara district has created some considerable changes in ecosystem in home-gardens, and has contributed very important economic trade-offs and social breakthroughs. It is recommended to design sustainable silvo-pasture system with appropriate land use system based on the size and composition of their home-gardens. Developing and popularizing fodder resources among small cattle farmers requires strengthen institutional support particularly for the research and extension. The farmers have not yet promoted community governance in order attract externalities particularly land use planning, selection of cropping systems, technology development to introduce high yielding shade tolerance food and policy support even after the successfully implementing the pasture development program. There is not only the nutrition but also the quality of animals need for the improvement of productive efficiency in the medium term. Establish of farmer organization will empower the farmers and encourage them for collective efforts to improve standards of their dairy farming. Further improvement and expansion of the pasture development program may promote domestic liquid milk consumption particularly in rural households and will have strong positive effects on opportunities for domestic milk production thus increasing fodder production in home-gardens for feeding the cattle.

## References

Ariyadasa, K. P. (2002). *Assessment of tree resources in the home-gardens of Sri Lanka*. Bangkok, ECFAO Partnership Program on Information and Analysis for Sustainable Forest Management (FAO, 2005).

Chokkalingam, U., & Vanniarachchy. S. A. (2011). *Sri Lanka's REDD potential: Myth or reality?* Forest carbon Asia country Profile Report No. 1: Sri Lanka. Forest Carbon Asia. Retrieved November 10, 2017, from http://www.forestcarbonasia.org/wp-content/uploads/2010/10/Sri-Lanka-Country-Report-final-23.05.2011.pdf.

Daulagala, C., Weerahewa, J., Marambe, B., Pushpakumara, G., Silva, P., Punyawardena, R., Premalal, S., Miah, G., Roy, J., & Jana, S. (2013) .Socio - Economic Characteristics of Farmers Influencing Adaptation to Climate Change: Empirical Results from Selected Homegardens in South Asia with Emphasis on Commercial Orientation. *Sri Lanka Journal of Advanced Social Studies, 2*(2), 71-90. https://doi.org/10.4038/sljass.v2i2.6208

De Costa, W. A. J. M., Amaratunga, K. S. P., & Udumullage, R. S. (2006). *Transpiration characteristics of some home-garden tree species in central Sri Lanka*. In: Tropical home-gardens: a time tested example of sustainable agroforestry, ed. Kumar, E.D and P.K.R. Nair, 377 pp. Dordrecht: Springer.

De Zoysa, M., & Inoue, M. (2008). Forest governance and community based forest management in Sri Lanka: Past, present and future perspectives. *International Journal of Social Forestry, 1*, 27-49.

Department of Census and Statistics Sri Lanka (2015), *Department of census and statistics Sri Lanka. paddy statistics*. http://www.statistics.gov.lk/agriculture/Paddy%20Statistics/PaddyStats.htm

Egodawatta, W. C. P., Sangakkara, U. R., Wijesinghe, D. B., & Stamp, P. (2011). Impact of green manure on productivity patterns of home-gardens and fields in a tropical dry climate. *Tropical Agricultural Research, 22*(2), 172-182. https://doi.org/10.4038/tar.v22i2.2826

Galhena, D. H., Freed, R., & Maredia, K. M. (2013). Home gardens: A promising approach to enhance household food security and wellbeing. *Agriculture and Food Security*, *2*(1), 8. https://doi.org/10.1186/2048-7010-2-8

Ibrahim, M. N. M., Staal, S. J., Daniel, S. L. A. & Thorpe, W. (1999). *Appraisal of the Sri Lanka dairy sector*. Volume 1: Synthesis Report. Ministry of Livestock Development and Estate Infrastructure, Colombo, Sri Lanka.

Jayanthi, C. (2003) *Productivity of Bajra-Napier hybrid grass under different planting methods and time of fertilizer applications*. htpp://www.tnau.ac.in/scms/agronomy/jayanthi.htm.

Jayawardena, L. N. A. C., & Jayatilaka, M. W. A. P. (1998). *Role of gender in the optimum use of Kandyan forest gardens as a source to food to meet food security requirements*. In: Multipurpose Tree Species in Sri Lanka-Fuelwood Energy and Gender Issues. Eds. H. P. M. Gunasena, D. K. N. G. Pushpakumara, B. Marambe, S.P. Nissanka and I.P. Wickramasinghe. pp. 47-60. *Proceedings of the Ninth National Workshop on Multipurpose Trees,* December 3-5, 1998. Kandy, Sri Lanka.

Marambe, B., & Silva, P. (2012). *Sustainability management in agriculture - a systems approach*. In: Handbook of Sustainability Management. Chapter 33. Eds. C. N. Madu & Kuei, C. H. pp. 687-712. World Scientific

Publishers Company, Singapore. https://doi.org/10.1142/9789814354820_0033

Mattsson, E., Ostwald, M., Nissanka, S. P., & Marambe, B. (2013). Homegardens as a Multi-functional Land-Use Strategy in Sri Lanka with Focus on Carbon Sequestration; *AMBIO, 42*, 892-902. https://doi.org/10.1007/s13280-013-0390-x

Mendis, S. S., & Edirisinghe, J. C. (2014). Milk Powder Imports and Government Policy: The Case of Sri Lanka. *Journal of Agriculture Economics and Rural Development, 2*(3), 86-91. https://doi.org/10.12966/jaerd.08.03.2014

Ministry of Forestry and Environment (1995). *Sri Lanka forestry sector master plan*. Forestry Planning Unit, Ministry of Forestry and Environment, Battaramulla, Sri Lanka, 512 pp.

Nanayakkara, P. (2013). *'Liquid milk: on the path to self-sufficiency', business today*, 2013.05, Retrieved April 28, 2017, from http://www.businesstoday.lk/cover_page.php?issue=262

Navaratne, M. A. J. S., & Buchenrieder, G. (2003). Economics of Small-Scale Dairy Farming in Sri Lanka — A Case Study from Coconut Cattle Silvo Pastoral System. *Proceedings, "Technological and Institutional Innovations for Sustainable Rural Development",* Deutscher Tropentag, October 8-10, 2003, G¨ottingen, Germany

Perera, A. N. F. (1992). Agricultural by-products as a feed source for ruminants. In: *Poceedings of workshop on eco-friendly commercial activities*. MOF and NORAD, 8 December, 1992, BMICH, Colombo, Sri Lanka, 8-15.

Perera, B., & Jayasuriya, M., (2008). The dairy industry in Sri Lanka: current status and future directions for a greater role in national development. *Journal of the National Science Foundation of Sri Lanka, 36*, 115-126. https://doi.org/10.4038/jnsfsr.v36i0.8050

Premaratne, S., & Premalal, G. G. C. (2006). Hybrid Napier (Pennisetum perpureum X Pennisetum americarnum) var. CO-3: a resourceful fodder grass for dairy development in Sri Lanka; *The Journal of Agricultural Sciences, 2*(1). https://doi.org/10.4038/jas.v2i1.8110

Pushpakumara, D. K. N. G., Marambe, B., Silva G. L. L. P., Weerahewa, J., & Punyawardena, B. V. R. (2012). *Tropical Agriculturist, 160*, 55-125

Pushpakumara, D. K. N. G., Wijesekara, A., & Hunter, D. G. (2010). *Kandyan home-gardens: A promising land management system in Sri Lanka.* In Sustainable use of biological diversity in socio-ecological production landscapes, ed. C. Belair, Ichikawa, K., Wong, B. Y. L. & Mulongoy, K. J. 102–108. *Background to the 'Satoyama Initiative for the benefit of biodiversity and human well-being*. Secretariat of the Convention on Biological Diversity, Montreal, Canada.

Ranaweera N. F. C., (2009). 'Sri Lanka: Opportunities for dairy sector growth', *Smallholder dairy development: Lessons learned in Asia,* http://www.fao.org/docrep/011/i0588e/I0588E08.htm

Ranaweera, N. F. C. (2007) Improved Market Access and Smallholder Dairy Farmer Participation for Sustainable Dairy Development. Lessons Learned Sri Lanka. FAO Report. 5-21. http://www.s3.amazonaws.com/zanran_storage/www.aphca.org/ContentPages/45037639.pdf

Weerahewa, J., Pushpakumara, G. Silva, P., Daulagala, C., Punyawardena, R., Premalal, S., Miah, G., Roy, J., Jana, S., & Marambe, B. (2012). Are home garden ecosystems resilient to climate change? An analysis of the adaptation strategies of home gardeners in Sri Lanka. *APN Science Bulletin, 2*, 22-27.

Weerakkody, W. A. P. (2004). Horticulture in Sri Lanka. *Chronica Horticulturae, 44*, 23-27.

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# Food Budget Shares and Elasticities in Malawi's Prisons

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**Abstract**

While Malawi's per capita cereal production may be higher than her per capita cereal consumption, Malawi is a net cereal importer and thus food insecure. The food situation is much worse in Malawi's prisons because inmates generally eat one meal per day.

The general objective of this study was to determine food budget shares and elasticities for the food stuffs commonly eaten in Malawi's prisons. Using structured questionnaires in face to face interviews, the study collected data from 1000 prisoners and 30 officers-in-charge from all prisons in the country. The data was analysed using Stata 12 and employed the quadratic almost ideal demand system (QUAIDS) model as an analytical tool.

Results from the analysis showed that budget shares for maize and beans were high as reflected by the fact that 86.5 per cent of the prison food budget was spent on these two food items while 6.8 per cent was spent on meat and vegetables. Maize was inelastic while meat, beans and salt were elastic with the own-price elasticity for meat being the highest. Expenditure elasticities for maize, meat and beans, at above unity, showed that these food items were luxuries in Malawi's prisons.

**Keywords:** Malawi's prisons, budget shares, own-price elasticity, cross-price elasticity, expenditure elasticity

## 1. Introduction

The introduction gives a brief narrative about Malawi's prisons, states the problem and makes a justification for the study. Study objectives are then given and finally, study limitations are presented.

Politically, Malawi is divided into four regions, these being the Northern, the Central, the Eastern and the Southern regions. There are six prisons with a prisoner population of 1,717 in the Northern region. In the Central region, there are eight prisons with a prisoner population of 3,784. The Eastern region has eight prisons with 4,072 prisoners, while the Southern region has 3,025 prisoners in eight prisons. There were thus 12,598 prisoners in Malawi's 30 prisons in 2016 when this study was conducted.

**Statement of the Problem:** Although Malawi is generally food insecure, it is common in Malawi that most people consume three meals per day. What differs is mainly the quality, quantity and variety of the food that they eat. Inmates in Malawi's prisons, however, generally eat one meal per day (African Commission on Human and Peoples' Rights, 2002; Penal Reform International 2005). These reports mention food issues as observations made in relation to health and human rights. None of these reports is specifically about prison food budget shares or price elasticities or expenditure elasticities of foods commonly eaten in Malawi's prisons. The fact that no report nor study delineated these economic aspects of food items commonly eaten in Malawi's prisons became a problem that this study intended to address.

**Justification of the Study:** The Malawi Government's overall objective of the Food and Nutrition Security Policy is to significantly improve the food and nutrition security of the Malawi population (Malawi Government, 2005) while the specific objective of the Food Security Policy, is to guarantee that all men, women and youth in Malawi have, at all times, physical and economic access to sufficient nutritious food required to lead a healthy and active life (Malawi Government, 2006). Since prisons accommodate about 0.08 percent of the Malawi population, it is important that prisons are food secure and that every prisoner has access to not less than the minimum meal requirement. It was important that this study be carried out so that prison food budget shares, price elasticities and expenditure elasticities of foods commonly eaten in Malawi's prisons could be delineated in order to lay the foundation upon which efforts to improve and re-engineer the food situation in Malawi's prisons could be based. This would enable policy makers and prison management to take appropriate policy and budgetary measures regarding prison subvention, strategic resource allocation, and food production or procurement to accurately address the problem and improve prison food security. Also, since no study had been conducted in this area, it was important to conduct this study so that the existing knowledge gap could be filled.

**Objectives of the Study:** The general objective of this study was to determine the food budget shares and elasticities for the food stuffs commonly eaten in Malawi's prisons. The specific objectives were:

i. To determine the food budget shares for the foods commonly eaten in Malawi's prisons, and
ii. To determine the price and expenditure elasticities for the foods commonly eaten in Malawi's prisons.

**Limitations of the Study:** There were two major limitations to the study. The first was that all interviewees were male. This was because, for security reasons, the research team was only allowed access to prisoners that committed less serious offenses. Such prisoners were allowed to go out for farming activities because they were considered a lower security risk. The research team was advised to interview the sampled ones as they carried out their farming chores. No female prisoners were in this category, not necessarily because they committed serious crimes, but because female prisoners were not allowed to go out for farming duties and the research team was not allowed to enter into the female side of the prison.

The second limitation was that only 1000 prisoners, instead of the required 1418 prisoners were interviewed. This was because some of the prisoners that were selected for interviewing, according to the random sampling method used in the study, were males that were not allowed to go out of confinement because of the nature of their crimes or females, who the research team was not allowed to meet. The research team was not permitted to follow prisoners to their cells.

**The food situation in Malawi:** The Millennium Development Goals (MDGs) through the medium term development strategy, the Malawi Growth and Development Strategy (MGDS), identified nine key priority development goals (Malawi Government, 2010). The first of these development goals is to eradicate extreme poverty and hunger. To achieve this, the Government's target was to halve, between 1990 and 2015, the proportion of people who suffered from hunger. One of the indicators for monitoring hunger was the proportion of the population living below the minimum level of dietary energy consumption of 2,100 kilocalories per person per day (Ecker & Qaim, 2008; Malawi Government, 1999).

Malawi is an aggregate net exporter of food. The bulk of the food exports, however, are non-cereals such as tea and sugar and so although the country is a net food exporter, it remains a net importer of cereals and thus food insecure. Maize is the staple food in Malawi (Kidane, et al., 2006; FAO, 2010; World Bank, 2008; FAO, 2015; De Graaff, 1985; IFPRI, 2012).

**The food situation in Malawi's prisons:** It is a requirement of the United Nations that every prisoner should be provided, by the administration at the usual hours, with food of nutritional value adequate for health and strength, of wholesome quality and well prepared and served (Medecins Sans Frontieres, 2009). The Malawi Prison Act Cap. 9:02, (1983) provides a dietary schedule for prisoners belonging to various categories of prisons. Despite these legally binding dietary guidelines, the practice on the ground is different. The African Commission on Human and Peoples' Rights ( 2002) observed that Malawian prisoners receive only one meal per day and that meals are not balanced as prisoners eat the same food every day. The report also observed that the meals comprise of maize (*nsima*) and boiled beans and sometimes pigeon peas or vegetables. It further observed that almost no meat nor fish is provided, but that salt is available in all prisons. This is a typical case of food insecurity.

## 2. Materials and Methods

**Data Collection Techniques:** Both primary and secondary data were collected using questionnaires, one administered to prisoners, and the other to prison officers-in-charge. These questionnaires were administered by interviewers on face to face basis. Secondary data were collected from official records obtained from the Malawi Prison Service Headquarters and the various prisons that were visited.

**Data Analysis:** Data were entered in Excel and analysed using Stata 12. The output from the analysis was reported using descriptive statistics such as means, proportions and percentages.

**Sampling Methods:** All prisons in Malawi formed the field of study and every inmate, except those that had been in prison for less than four weeks, was an eligible interviewee. The four week requirement is a normal procedure followed by the USAID-funded Food and Nutrition Technical Assistance (FANTA) project which developed a questionnaire (Swindale & Bilinsky, 2006; Maxwel & Frankenberger, 1992) upon which the questionnaires used in this study were based. In order to select respondents from the population of inmates, the stratified random sampling and simple random sampling methods were used. The stratified random sampling method was applied to select *n* units out of *N* sub-populations called strata. In this case, each prison was a strata and from each strata *n* number of inmates were selected using simple random sampling in order to give each prisoner an equal chance of being selected (Agresti, 1996; Zikmund, 1997; McGill *et al*., 2000; Bryars, 1983). In order to select participating inmates, tables of random numbers (Magnani, 1997) were used. In selecting prison officers for the interview, the purposive sampling method was used.

**Sample Size:** For more precision on sample size calculation, when population size and population proportions are known, the formula given below is used (Kothari, 2004).

$$n = \frac{z^2}{e^2}\frac{p.q.N}{(N-1)+z^2.p.q} \quad (1)$$

where $n$ = sample size, $z$ = 1.96 = z-value yielding 95% confidence level, $p$ = proportion of the population of interest, $q = 1 - p$, $N$ = 12,598 = the population of interest, $e$ = 5% = absolute error in estimating $p$.

The population proportion for each prison was calculated as in Equation **(2).**

Prison proportion,

$$p = \frac{\text{Number of prisoners at a given prison}}{\text{Total prisoner population in Malawi}} \quad \mathbf{(2)}$$

In 2016, the total number of, both convicted and un-convicted, inmates in Malawi's prisons was 12,598 (Malawi Government, 2016), while the population of Malawi as given by the UNDP in its 2011 Human Development Report was 15,380,900 (UNDP, 2011). Following the reasoning articulated above and applying Equation **(1)**, the value of *n,* the sample size, was found to be 1418. However, when conducting the survey, only 1,000 inmates were interviewed because of the study limitations.

Data were collected by three trained interviewers using a questionnaire that had been reviewed by a group of key informants, refined by eight prisoners that were representative of the survey population but who were not part of the survey sample, and pretested on fifteen prisoners through a preliminary survey. Data collected were subjected to regression and correlation analysis and results summarized.

**Model Specification.** The quadratic almost ideal demand system (QUAIDS) model was used to address the objective of the study.

**The Quadratic Almost Ideal Demand System model**

To compute food budget shares in the past, use had been made of the almost ideal demand system (AIDS) of Deaton and Muellbauer which had been a popular functional form to model demand behaviour during the past two decades. The AIDS model had budget shares that were linear functions of log total expenditure. AIDS is a member of the Price-Independent Generalized Logarithmic (PIGLOG) class of demand models (Sola, 2013) which are derived from indirect utility functions that are themselves linear in log total expenditure. However, there was a growing body of literature providing evidence on the importance of allowing for nonlinearity in the budget share equations (Pangaribowo & Tsegai, 2011).

The quadratic almost ideal demand system (QUAIDS) model, which has budget shares that are quadratic in log total expenditure, is an example of the empirical demand systems that have been developed to allow for this expenditure nonlinearity (Banks, et al., 1997). The model is also quadratic in expenditure if we assume that there is a non-linear relationship between income and expenditure.

Many studies confirm the appropriateness of QUAIDS in modeling preferences. For example, Abdulai (2002) used the QUAIDS model to analyze food expenditure data from Switzerland. Moro and Sckokai (2000) used it on Italian food expenditure data, and Blundell and Robin (1999) applied it on UK expenditure data for consumption goods. Furthermore, Fisher et al. (2001) applied the QUAIDS model to study the US consumption data, Abdulai and Aubert (2004) used it on Tanzanian food expenditure data, Meenkashi and Ray (1999) on Indian food expenditure data, Gould and Villarreal (2006) on Chinese food expenditure data, and Molina and Gil (2005) applied it on consumption data from Peru.

The QUAIDS model is a generalization of PIGLOG preferences based on the following indirect utility (V) function:

$$lnV = \left\{[\frac{\ln m - \ln a(p)}{b(p)}]^{-1} + \lambda(p)\right\}^{-1} \quad (3)$$

where m is the total food or food group expenditure, and p is a vector of food prices. The term $\frac{\ln m - \ln a(p)}{b(p)}$ is the indirect utility function of a demand system of the (PIGLOG) preference class. The functions ln $a(p)$ and $b(p)$ are the translog and the Cobb-Douglas price aggregator functions defined by:

$$\ln a(p) = \alpha_0 + \sum_{i=1}^{n} \alpha_i \ln p_i + \frac{1}{2} \sum_{i=1}^{n} \sum_{i=1}^{n} \gamma_{ij} \ln p_i \, ln\, p_j \quad (4)$$

And

$$\mathrm{b(p)} = \prod_{i=1}^{n} p_i^{\beta_i} \quad (5)$$

The price aggregator function $\lambda(p)$ is given by

$$\lambda(p) = \sum_{i=0}^{n} \lambda_i \ln p_i \quad (6)$$

Applying Roy's identity, after appropriate substitutions to equation **(3),** food budget shares for each food group can be expressed as:

$$w_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} \, ln\, p_j + \beta_i ln\left(\frac{m}{a(p)}\right) + \frac{\lambda_i}{b(p)}\left(ln\left(\frac{m}{a(p)}\right)\right)^2, \forall_i = 1, \dots, n \quad (7)$$

The theoretical restrictions of adding-up, homogeneity, and Slutsky symmetry are imposed in the basic QUAIDS by setting

$$\sum_{i=1}^{n} \alpha_i = 1, \ \sum_{i=1}^{n} \beta_i = 0, \ \sum_{i=1}^{n} \lambda_i = 0, \ \sum_{j=1}^{n} \gamma_{ij} = 0, \ \forall_i = 1, \dots \dots n,$$

$$\sum_{i=1}^{n} \gamma_{ij} = 0, \ \forall_j = 1, \dots\dots, n, \ \text{and} \ \gamma_{ij} = \gamma_{ji}, \ \forall_i \neq j \quad (8)$$

From equation **(7),** it can be seen that the QUAIDS collapses to the AIDS when all λi equal zero. In conformity with the first budgeting stage, linear socioeconomic translation was allowed for through the intercept in equation **(7).**

This study applied a two-stage budgeting process on prison food following Blundell *et al*. (1993), who used the two-stage budgeting process in demand elasticity estimations in the fish industry, while Dey (2000) and Kumar (2004) used it for Bangladesh and India respectively. The approach worked on the premise that in the first stage, the prison made decisions on how much of its subvention was to be allocated to food given that some of the subvention needed to cater for other non-food goods. The model further assumed that in the second stage, the prison allocated the total food expenditure among the different food items that prisoners ate (Kumar et al, 2011; Tafere & Worku, 2012; Torero & Robles, 2008; Mittal, 2010). Below are the specific functional forms used in the two stages:

**Stage 1: The food expenditure function**

$$L_n(M) = \alpha + y_1 L_n(P_f) + y_2 L_n(P_{nf}) + \beta_0 L_n(Y) + \beta_1 (L_n Y)^2 \quad (9)$$

where $M$ is individual prison food expenditure; $Y$ is individual prison total expenditure (subvention); $P_f$ is individual prison specific price index for food; $P_{nf}$ is the non-food price index. Equation **(9)** was estimated by the OLS method, and homogeneity of degree zero in prices and income was imposed by restricting

$$Y_1 + Y_2 + \beta_0 + 2\beta_1 L_n(Y) = 0 \text{ at the sample mean of } L_n(Y) \quad (10)$$

Mittal (2010) and, Deaton and Muellbauer (1980) suggested approximating the price index P by the Stone geometric price index.

$$l_n P^* = \sum_i w_i l_n p_i \quad (11)$$

**Stage 2: The QUAIDS model**

In stage 2, the QUAIDS model was used. The specific functional form for the $i^{th}$ food item was:

$$S_i = a_i + \sum_j b_{ij} L_n(FP_i) + c_{1i}(L_n \frac{M}{I})^2 + \sum_k e_{ik} I\, MR_k \quad (12)$$

Where $FP_i$ is price of the $i^{th}$ food item; $I$ is Stone geometric price index. The parameters $a_i$, $b_{ij}$, $c_i$, and $e_{ik}$ are estimated by imposing the homogeneity (degree zero in prices), symmetry (cross price effects are same across the foods) restrictions. The following restrictions are econometrically imposed.

Homogeneity: $\sum_{j=1}^{n} b_{ij} = 0$; Symmetry: $b_{ij} = b_{ji}$, $\frac{c_{11}}{c_{10}} = \frac{c_{21}}{c_{20}} = \cdots = \frac{c_{n1}}{c_{n0}}$ (13)

The homogeneity and symmetry restrictions are imposed at sample mean. Because of the quadratic specification of the demand system **(**Equations **9** and **12)**, Mittal (2010) citing Blundell *et al.* 1993 said that a test of symmetry, in addition to the normal requirements, required that the ratio of the coefficients on the food expenditure and the square terms in food expenditure be the same for all food items. The predicted value of food expenditure obtained from stage 1 was used as the explanatory variable in stage 2. The expenditure and price elasticities became:

Food expenditure elasticity: $$\eta_i = \left[c_{i0} + \frac{2c_{i1}L_n(F)}{w_i}\right] + 1 \quad (14)$$

Uncompensated price elasticity:

$$\xi_{ij} = \left\{\frac{b_{ij}}{w_i}\right\} - [c_{i0} + 2c_{i0}L_n(F)]\left\{\frac{w_j}{w_i}\right\} - k_{ij} \quad (15)$$

where $k_{ij}$ is Kronecker delta, which takes the value of one for own-price elasticity and zero for cross-price elasticity; and $w_i$ is the budget share of the $i^{th}$ food item used as a weight in constructing Stone's price index.

After the expenditure and uncompensated price elasticities are estimated, the compensated own and cross-price elasticities are calculated, using Slutsky equation in elasticity form, as:

$$\xi_{ij}^H = \xi_{ij} + w_j \eta_i \quad (16)$$

where $\xi_{ij}^H$ is the compensated (Hicksian) price elasticity.

Income elasticity of demand for an individual food item,$\eta_i^y$, is estimated as the product of expenditure elasticity of the individual food item, $\eta_i$, and food expenditure elasticity with respect to total income, $\eta^y$, where $\eta_i^y = \eta_i * \eta^y$.

The own price elasticity of demand is a measure of the proportionate change in quantity demanded in response to a proportionate change in a good's own price and, normally, carries a negative sign except in the case of a giffen good when it carries a positive sign. A giffen good is an inferior good whose demand, paradoxically, moves in the same direction as its price; for example, its demand increases as its price increases (Huang & David, 1993). The income or expenditure elasticity of demand is a measure of the proportionate change in quantity demanded in response to a proportionate change in income. The cross-price elasticity of demand is a measure of the proportionate change in quantity demanded of some good, *x*, in response to a proportionate change in the price of some other good, *y* (Tefera, Demeke, & Rashid, 2012). Positive cross-price elasticities show substitutability while negative cross-price elasticities indicate complementarity effects (Snyder and Nicholson, 2008).

## 3. Results and Discussion

**Prison Food Budget Shares.** Foods that were rarely consumed, such as, cooking oil, fruits and sugar, were not included in the analysis as their consumption was negligible and were eaten in only a few prisons on isolated occasions. Maize, in the form of *nsima* (a thick porridge made from maize flour), was eaten with beans almost every day in all prisons in the country. Consequently, maize took 52.2 percent of the prison food budget while beans took 34.3 percent. Thus, 86.5 percent of the prison food budget was spent on maize and beans. Using household data, Ecker and Qaim (2008) studying the income and price elasticities of food demand and nutrient consumption in Malawi found that the weighted mean budget share for starchy foods was 45.9 percent and that maize took 72.1 percent of the starchy foods budget. They also found that the weighted mean budget share for pulses was 9.6 percent and that 37.0 percent of the budget for pulses was taken by beans. Their results, especially those for beans, compare well with those found in this study as shown in Table 1.

Table 1. Prison food budget shares in percentages

| Variable | N | Mean Share (%) | Std. Dev. |
|---|---|---|---|
| **Wmaize** | 30 | 52.2 | 0.120 |
| **Wmeat** | 30 | 2.0 | 0.035 |
| **Wbean** | 30 | 34.3 | 0.094 |
| **Wvege** | 30 | 4.8 | 0.127 |
| **Wsalt** | 30 | 6.7 | 0.069 |

Vegetables, which took 4.8 percent of the budget, were eaten occasionally while meat, on which two percent of the budget was spent, was consumed very rarely. Salt was also consumed every day and the prisons spent 6.7 percent of their food budget on it. Ecker and Qaim (2008) found that Malawian households spent 39.4 per cent of their food budget on green-leaf vegetables and 15.4 per cent on animal-source foods. Prisons, therefore, spent much less on these food items than did households. This was possibly a pointer to inadequate funding to prisons.

**Marshallian (Uncompensated) Price Elasticities of Demand for Food**

Marshallian own-price, cross-price and expenditure elasticities were presented as below.

**Own-price elasticities.** Table 2 presents Marshallian or uncompensated price elasticities of demand and expenditure or income elasticities of the five foods that were often consumed in Malawi's prisons. The figures in the diagonal of the table are Marshallian own-price elasticities of demand while those on the off-diagonal are Marshallian cross-price elasticities of demand. The figures in the diagonal indicated that the own-price elasticities for the foods usually consumed by prisoners were negative except for vegetables. The own-price elasticity for maize at -0.72 was inelastic. This showed that the demand for maize in prisons was not very sensitive to maize-price changes. Prisons in Malawi strove to acquire the same quantity of maize in-spite of maize-price changes. This was probably a reflection of the fact that maize was a staple food in Malawi.

Table 2. Marshallian (uncompensated) price elasticities of demand for food

| Commodity | Maize | Meat | Beans | Vegetables | Salt | Expenditure Elasticities |
|---|---|---|---|---|---|---|
| **Maize** | -0.72 | -0.02 | -0.11 | -0.35 | 0.20 | 1.01 |
| **Meat** | -0.79 | -25.92 | 7.97 | -0.12 | 17.60 | 1.25 |
| **Beans** | -0.21 | 0.46 | -2.10 | 0.98 | -0.21 | 1.08 |
| **Vegetables** | -3.61 | -0.04 | 7.12 | 0.58 | -4.72 | 0.67 |
| **Salt** | 1.77 | 5.19 | -0.94 | -3.41 | -3.27 | 0.65 |

The own-price elasticities for meat, beans and salt were elastic, with meat being the most elastic at -25.92. The value of elasticity for meat is clearly an outlier, possibly showing that meat is consumed so rarely and it takes up so much money per unit that it is actually an outlier food item in the prisons. These higher values of uncompensated own-price elasticities reflected the greater income effects of a price change in these foods. This meant that a small increase, for example, in the price of meat would force the prisons to drastically reduce meat consumption, practically to zero. This could be the reason why meat was rarely consumed in the prisons. The elasticities of beans and salt at -2.1 and -3.27 respectively, showed that the prisons readily adjusted downwards the quantities of these two foods each time their prices were raised. This would explain the observation that some prisoners made to the effect that they ate watery beans, meaning that there would be just a small number of beans in a plate filled with thin gravy. The high own-price elasticity for salt probably showed that prisons were willing to reduce salt quantities, when faced with an increase in salt prices, in order to channel the money into foods which were more filling, such as, maize. The own-price elasticity for vegetables was positive 0.58. This showed that, in prisons, vegetables were considered a giffen good. Among less educated people in the Malawi context, vegetables are considered an inferior food. This perception of vegetables may have been applicable in prisons.

**Cross-price elasticities**. Cross-price elasticities show substitutability and complementarity effects. Positive cross-price elasticities show substitutability while negative cross-price elasticities indicate complementarity. Meat, beans and vegetables were found to be complements to maize. This finding was ordinary and the normal practice in Malawi. Beans were substitutes to meat and vegetables, meaning that prisoners did not eat these foods at the same time. Vegetables, however, complemented meat, although weakly. This was surprising because eating meat together with vegetables would suggest luxurious living, of which the prisoners did not have. The possibility here could be that whenever there was meat, there was so little of it that it could ordinarily not be enough for everyone. As a result, vegetables were also prepared so that each prisoner could get a tiny piece of meat, a lot of thin gravy from the meat and some vegetables as fillers.

Salt complemented beans and vegetables, which was ordinary and normal. But salt had a positive relationship with maize and meat, meaning that salt was a substitute to maize as well as meat. This was a strange relationship. But it was earlier deduced that the high own-price elasticity for salt probably showed that prisons were willing to reduce salt quantities, when faced with an increase in salt prices, in order to channel the money into foods which were more filling, such as, maize. In essence, this was a substitution relationship where, in practice, at least in terms of the budget, money for salt was used to procure maize and/or meat because maize was considered a paramount commodity and the maize budget insufficient for the needed maize quantities, while meat was possibly used as a treat to give the prisoners a break from the usual unpalatable food and lift up their spirits.

The prison management may have found it a better evil to sacrifice the salt budget for maize and/or meat, hence the observed substitution effect. But salt substituted meat so strongly that the value of the cross-price elasticity for salt here is clearly an outlier. This relationship possibly indicates two things: firstly, that this substitution relationship occurs so rarely that it is indeed an outlier event. Secondly, that when need arises that the salt budget should be used to procure meat, given the extremely high unit price of meat by prison standards, a substantial portion of the salt budget which is much more than is the case under normal salt usage, is directed towards meat procurement, making such expenditure from the salt budget a real outlier occurrence.

**Expenditure elasticities.** Expenditure elasticities for maize, meat and beans at 1.01, 1.25 and 1.08 respectively, were just above unity, meaning that these foods were tending towards being luxurious goods. This was a typical reflection of food insecurity. This, however, closely resembled the results obtained by Ecker and Qaim (2008) where they found that expenditure elasticities for maize, animal-source foods and beans among Malawian households were 0.856, 1.138 and 1.026 respectively.

### Hicksian (Compensated) Price Elasticities of Demand for Food

The compensated own-price, cross-price and expenditure elasticities took the same trend and compared well with the Marshallian elasticities given earlier on. Similar to the observation made about uncompensated price elasticities, here too, the negativity property of own-price elasticities held for all foods except vegetables. Therefore, the discussion made earlier on about uncompensated elasticities also applied here. Table 3 shows Hicksian (compensated) price and expenditure elasticities of demand.

Table 3. Hicksian (compensated) price elasticities of demand for food

| | Maize | Meat | Beans | Vegetables | salt | Expenditure elasticities |
|---|---|---|---|---|---|---|
| **Maize** | -0.20 | -0.01 | 0.23 | -0.30 | 0.27 | 1.01 |
| **Meat** | -0.13 | -25.89 | 8.40 | -0.06 | 17.69 | 1.25 |
| **Beans** | 0.36 | 0.48 | -1.73 | 1.03 | -0.14 | 1.08 |
| **Vegetables** | -3.26 | -0.03 | 7.35 | 0.62 | -4.68 | 0.67 |
| **Salt** | 2.11 | 5.21 | -0.71 | -3.38 | -3.23 | 0.65 |

## 4. Conclusion

The objective of this study was to determine prison food budget shares and, price and expenditure elasticities of foods commonly eaten in Malawi's prisons. Budget shares for maize and beans were high as reflected by the fact that 86.5 per cent of the prison food budget was spent on these two food items while 6.8 per cent was spent on meat and vegetables. By comparison, it was found that prisons spent much less on meat and vegetables than did households.

Maize was inelastic while meat, beans and salt were elastic with the own-price elasticity for meat being the highest, possibly explaining why meat was rarely eaten in prison. Expenditure elasticities for maize, meat and beans at above unity, meant that these foods were luxuries, which was a typical reflection of a situation of food insecurity. Hicksian own-price, cross-price and expenditure elasticities compared well to Marshallian elasticities. In difficult times, the salt budget was readily sacrificed for maize and meat.

## References

Abdulai, & Aubert. (2004). A cross-sectional analysis of household demand for food and nutrients in Tanzania. *Agricultural Economics, 3*(1), 67-79.

Abdulai, A. (2002). Household demand for food in Switzerland: A quadratic almost ideal demand system. *Swiss Journal of Economic Statistics, 138*, 1-18.

African Commission on Human and Peoples' Rights. (2002). Prisons in Malawi-Report on a Visit 17 to 28 June 2001 by Dr. V.M. Chirwa Special Rapporteur on Prisons and Conditions of Detention in Africa. Paris, France.

Agresti, A. (1996). *An introduction to categorical data analysis.* New York: Wiley and Sons Inc. .

Banks, J., Blundell, R., & Lewbel, A. (1997). Quadratic Engel curves and consumer demand. *Review of Economics and Statistics, 124*(4), 527-539. https://doi.org/10.1162/003465397557015

Blundell, R. W., & Robin, J. M. (1999). Estimation in large and disaggregated demand systems: An estimator for conditionally linear systems. *Journal of Applied Econometrics, 14*, 209-232. https://doi.org/10.1002/(SICI)1099-1255(199905/06)14:3<209::AID-JAE532>3.0.CO;2-X

Blundell, R., Pashardes, P., & Weber, G. (1993). What do we learn about consumerdemand pattern from micro data? *American Economic Review, 83*, 570-597.

Bryars, D. (1983). *Advanced Level Statistics .* Slough : University Tutorial Press.

Deaton, A. S., & Muellbauer, J. (1980). An Almost Idael Demand System. *American Economic Review, 70*(3), 359-368.

De Graaff, J. (1985). *Introduction to the economics of maize. (Unpublished manuscript).*

Dey, M. M. (2000). Analysis of demand for fish in Bangladesh. *Aquaculture, Economics and Management*, 4, 63-81. https://doi.org/10.1080/13657300009380261

Ecker, O., & Qaim, M. (2008). *Income and price elasticities of food demand and nutrient consumption in Malawi.* Orlando: American Agricultural Economics Association.

FAO. (2010). *Food Security Information for Decision Making.* www.fao.org/docrep/013/am187e/am187e00.pdf.

FAO. (2015). *Food Balance Sheets 2015.* http://Knoema.com/FAOFBS2015R/food-balance-sheets-2015.

Fisher, D., Fleissig, A. R., & Serletis, A. (2001). An empirical comparison of flexible demand system functional forms. *Journal of Applied Econometrics, 16*(1), 59-80. https://doi.org/10.1002/jae.585

Gould, W., & Villarreal, H. J. (2006). An assessment of the current structure of food demand in Urban China. *Agricultural Economics, 34*, 1-16. https://doi.org/10.1111/j.1574-0862.2006.00098.x

Government, M. (2006). Malawi Growth and Development Strategy from poverty to prosperity 2006-2011.

Government, M. (2010). Malawi Millenium Development Goals Report.

Huang, J., & David, C. (1993). Demand for cereal grains in Asia: The effect of urbanization. *Agricultural Economics, 8*, 107-124. https://doi.org/10.1016/0169-5150(92)90025-T

IFPRI. (2012). *Malawi Strategy Support Program, Policy Note 11.* Lilongwe: IFPRI.

Kidane, W., Maetz, M., & Dardel, P. (2006). *Food security and agricultural development in Sub-Saharan Africa; building a case for more public support.* Rome: FAO.

Kothari, C. (2004). *Research Methodology: methods and techniques, 2nd edition* . New Delhi: New Age International.

Kumar. (2004). *Fish demand and supply projections in India, ICAR-ICLARM Project.* New Delhi: Indian Agricultural Research Institute.

Kumar, P., Kumar, A., Parappurathu, S., & Raju, S. (2011). Estimation of demand elasticity for food commodities in India. *Agricultural Economics Research Review, 24*, 1-14.

Magnani, R. (1997). *Sampling Guide. IMPACT Monitoring Project.* Va: Arlington.

Malawi Government. (1983). *Laws of Malawi, The Prison Act (Cap. 9:02).* Zomba: Malawi Government.

Malawi Government. (1999). *Food Security and Nutrition Bulletin.* Lilongwe: Ministry of Economic Planning and Development.

Malawi Government. (2005). *Food and Nutrition Security Policy.* Lilongwe.: Ministry of Agriculture and Food Security.

Malawi Government. (2006). *Food Security Policy.* Lilongwe: Ministry of Agriculture and Food Security.

Malawi Government. (2006). *Agricultural and livestock development strategy and action plan.* Lilongwe: Ministry of Agriculture and Food Security.

Malawi Government. (2006). Malawi Growth and Development Strategy-frompoverty to prosperity 2006-2011.

Malawi Government. (2008). *Malawi Population and Housing Census 2008.* Zomba: National Statistical Office.

Maxwel, S., & Frankenberger, T. (1992). *Household Food Security: concepts, indicators and measurements; a tecchnical review.* New York: UNICEF and IFAD.

McGill, F., McLennan, S., & Migliorini, J. (2000). *Complete Advanced Level Mathematics – Statistics* . Cheltenham : Stanley Thornes.

Medecins Sans Frontieres. (2009). *No food or medicine here until you die.* Retrieved from http://www.doctorswithoutborders.org/publications/article.cfm?id=3433&cat=special-report.

Meenakshi, J. V., & Ray, R. (1999). Regional differences in India's food expenditure pattern: A completed demand systems approach . *Journal of International Development, 11*, 47-74. https://doi.org/10.1002/(SICI)1099-1328(199901/02)11:1<47::AID-JID549>3.0.CO;2-Y

Ministry of Finance, Economic Planning and Development. (2014). *Annual Economic Report.* Lilongwe: Malawi Government.

Mittal, S. (2010). Application of the QUAIDS model to the food sector in India. *Journal of Quantitative Economics, 8*(1), 42-54.

Molina, J. S., & Gil, A. I. (2005). The demand behaviour of consumers in Peru: A demographic analysis using the QUAIDS. *Journal of Developing Areas, 39*(1), 191-206. https://doi.org/10.1353/jda.2005.0038

Moro, D., & Sckokai, P. (2000). Heterogenous preferences in household food consumption in Italy. *European Review of Agricultural Economics*, 27(3), 305-323. https://doi.org/10.1093/erae/27.3.305

Pangaribowo, E., & Tsegai, D. (2011). *Food demand analysis of Indonesian household with particular attention to the poorest.* Bonn: Centre for Development Research.

Penal Reform International. (2005). *A model for good prison farm management in Africa. Penal Reform in Africa 2000.* Retrieved from http://www.panelreform.org/download/prison_farms_eng.pdf

Snyder, C., & Nicholson, W. (2008). *Mcroeconomic Theory- Basic Principles and Extensions.* Mason: South-Western Cengage Learning.

Swindale, A., & Bilinsky, P. (2006). Development of a universally applicable household food insecurity measurement tool: Process, current status and outstanding issues . *Journal of Nutrition 136*, 1449s-1452s.

Tafere, K., & Worku, J. (2012). Consumption patterns of livestock products in Ethiopia: Elasticity estimates using HICES (2004/05) Data. *IFPRI ESSP II Working Paper 38*.

Tefera, N., Demeke, M., & Rashid, S. (2012). *Welfare Impacts of Rising Food Prices in Rural Ethiopia: A Quadratic Almost I deal Demand System Approach.* Brazil: IFPRI.

Torero, M., & Robles, M. (2008). A perfect storm or an opportunity for Latina America: High world commodity prices. *IFPRI*.

UNDP. (2011). *Human Development Report.* UNDP.

World Bank. (2008). *World Development Report.* Washington D.C: World Bank.

Zikmund, W. G. (1997). *Business Research Methods, fifth edition.* Fort Worth: The Dryden Press.

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# Organic Farming Suffices to Feed a Country: a Large-Scale Linear Programming Model to Develop an Organic Agriculture Plan for Turkey

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**Abstract**

A frequently voiced critique is that due to lower yields on organically managed farmlands, one cannot feed a country using organic agriculture. In this paper, we aim to mathematically disprove this claim by developing a linear programming model and produce a detailed agriculture plan for Turkey sufficient to feed her population with a 2400 kcal daily menu on average, solely comprising of organic foods. The model uses information about population sizes and food needs of 81 cities in Turkey, and yields of 120 food, feed, forage crops, and four animal products. Intensive and extensive livestock production methods as well as food transportation between cities has been incorporated into the model. The resulting problem with 950 thousand variables and 40 thousand constraints can be solved with an optimization package in under a minute. Results, prescribing how many acres of each crop should be grown in each city, indicate that to feed the country fully on organic produce, 63% of the arable land suffices, yielding 8.9 million hectares of unused land where further organic foods could be grown for export or aid. We also run the model under different scenarios: fully vegetarian diet, omnivore model, different transportation structures, drought conditions and a limit on fruit trees. With this work, we have shown that it is possible to feed the whole population of Turkey with an agricultural practice that is not harmful to human health, soil, water and air; respects biological cycles and reduces food miles and fossil fuel consumption, thus contributing to sustainability and fighting climate change. We tested preliminary scenarios to understand the robustness of organic agriculture in the face of extreme weather events. The proposed model can also be applied to other countries when appropriate data are used.

**Keywords:** organic agriculture, linear programming, agricultural planning, farming, sustainability, arable land, fossil fuels, carbon emission, food miles, climate change, biodiversity, nutrition, goal programming

## 1. Introduction

A major effort goes into agricultural activities to produce food for the human population. For a long time, food production and distribution systems have been solely judged by one criterion: the economic value of food production and consumption. This fact encouraged the use of agricultural methods that make it possible to produce large quantities of food at the expense of degrading nature and society. The monoculture structure of these large-scale production systems is at the root of many economic problems for farmers throughout the world (Altieri & Rosset, 1996). The situation is not different in Turkey; Keyder and Yenal (2011) report that deregulation efforts left small farmers vulnerable to the fluctuations of world markets on inputs and outputs. This, coupled with the commodification of land and labor, led small farmers to seek employment outside farming. Besides these adverse economic consequences for farmers, conventional agriculture is known to have several harmful effects on the environment and public health. Decreased biodiversity, contamination of water, soil and air are only a few of the problems generated, (Fukuoka, 1978; Rembiałkowska, 2007; Stolze, Piorr, Häring, & Dabbert, 2007). Horrigan, Lawrence, and Walker (2002) list the human health effects of industrial agriculture as extensive use of antibiotics compromising their effective use in medicine, increased cardiovascular diseases and certain cancers from excessive consumption of animal fat, heavy use of pesticides increasing cancer risks for agricultural workers and consumers, and certain agricultural chemicals causing hormonal and reproductive problems. Taking an alternative position on food production, Cockshott and Cottrell (1993) argue that a better way to feed a population is by ensuring the sufficient intake of nutrients while showing care to the ecology. Using examples from Japan, Fukuoka (1978) proposes the use of small-scale organic farming to reverse the adverse effects of modern lifestyles on the ecology. A recent meta-analysis (Barański et al., 2014) reports that organic crops are indeed healthier with higher concentrations of antioxidants, lower concentrations of cadmium and a lower incidence of pesticide residues than their non-organic counterparts across regions and production seasons.

Based on principles of health, ecology, fairness and care (International Federation of Organic Agriculture Movements [IFOAM], 2008), organic farming is an answer to various other contemporary problems (Note 1). Organic farms' use of input energy is lower than conventional (Gündoğmuş, 2006; Delate, Cambardella, Chase, & Turnbull, 2015) and the mean labor requirement per area is more on organic farms, about twice the conventional farm value (Morison, Hine, & Pretty, 2005). Long-term organic comparison trials in the US have shown that organic practices have the potential to better store carbon and nitrogen, resulting in higher soil quality, and allowing farmers to remain competitive in the marketplace (Delate et al., 2015). These characteristics of organic agriculture provide a solution for the economic problems of farmers by reducing unemployment and the dependence on off-farm inputs and help farmers to capture a higher proportion of the value added by giving a specific position to their products (Keyder & Yenal, 2011; Aktar & Ananias, 2005).

Organic crops also perform better than their conventional counterparts during extreme weather events such as droughts and floods whose frequency has increased as a consequence of climate change, (Intergovernmental Panel on Climate Change [IPCC], 2013; Jentsch & Beierkuhnlein, 2008; Rosenzweig, Iglesius, Yang, Epstein, & Chivian, 2001). With higher levels of C and N, greater resistance to erosion and an increased ability to capture water during heavy rain and to retain water afterwards, organic farms need less irrigation and report decreased levels of plant stress during drought (Liebig & Doran, 1999). Lotter, Seidel, and Liebhardt (2003) found that water harvest, important for groundwater recharge, was significantly better in organic systems and argue that the better water holding capacity of organically managed soils is a likely reason for the better yields obtained during times of drought. Significant differences between organic and conventional farms were found in soil health indicators such as nitrogen mineralization, microbial abundance, organic carbon content and diversity, (Drinkwater, Letourneau, Workneh, van Bruggen, & Shennan, 1995). The increased soil health in organic farms also led to a considerably lower disease incidence in plants.

Comparing organic and conventional fields of tomato, Drinkwater et al. (1995) concluded that yields in both systems are comparable but that crop productivity depends more on inherent soil fertility, water availability, cultivar and the management skill. Badgley et al. (2007) compared yields of organic and conventional agriculture and found no substantial yield differences in the developed world whereas, in developing nations, yields of organic agriculture surpassed those of conventional methods. This could be attributed to the robustness of organic crops during extreme climates (Lotter et al., 2003). Seufert, Ramankutty, and Foley (2012) used a comprehensive meta-analysis and found that with good management practices organic yields could match conventional yields but on average organic yields are 25% lower than their conventional counterparts.

Globally, organic production and consumption have been growing over the past decades (Willer and Lernoud, 2014). There is an upward trend in the number of farmers applying organic farming methods, in the hectares dedicated to organic agriculture, the number and variety of companies active in marketing and selling organic foods and the number of consumers of organic products. Turkey is no exception. Certified organic farming in the country started in 1986 with the production of dried fruits to export to Europe. The Turkish Parliament passed the organic farming law in December 2004 and the land allocated to organic agriculture more than quadrupled since then: from 209,573 hectares in 2004 to 883,118 hectares in 2014 (Note 2). However, most organic production of Turkey was being exported (Demiryürek, Stopes, & Güzel, 2008) and the domestic market remained underdeveloped (Aktar & Ananias, 2005). Studying the state of the organic sector in Turkey, Kenanoğlu and Karahan (2002), Demiryürek (2004) and Özbilge (2007) listed the reasons for the undeveloped state of the domestic market as the *limited availability of organic products and of sales channels, high price premium, lack of consumer recognition and lack of government support* among the constraints impeding the development of the sector, and suggest that to expand organic production further, the domestic market for organic products needs to be developed. Lehner (2009) too underlines the importance of a lively domestic market in order to decrease the risk of export dependency. All of these works emphasize the support and the sponsorship of the ministry in all stages and some argue that universities and other "knowledge creating and distributing actors" should be given a bigger role in the development of the sector. As an attempt to develop the domestic organic market, civil society organizations are collaborating with local governments to establish marketplaces solely for organic products. These marketplaces, located primarily in Istanbul, had a mobilizing effect on the domestic organic sector (Akyüz and Demir, 2016).

One of the claims supported by the proponents of conventional agriculture is that without conventional methods there would be starvation. They also argue that without the use of harmful chemicals or GMOs, a lot more farmland will be needed and forests will be cut down. A comprehensive document on answers to the criticisms and misconceptions about organic agriculture such as starvation can be found in (IFOAM, 2009). As Reganold and Wachter (2016), we are of the opinion that the cause of hunger is not the absence of sufficient food; the cause of hunger is the unfair distribution of wealth and of food. Because of this unfair distribution, some people go hungry whereas some people have a lot more than they need and food waste is a reality, (Stenmarck, Jensen, Quested, & Moates, 2016). Indeed, the recent work of Muller et al. (2017) reports that organic agriculture is a viable option to feed the world population in the future when combined with reductions of food wastage; consumption of animal products; and food-competing-feed from arable land. While reasons behind the hunger problem in the world are political (Lappe & Collins, 1986) and not agricultural, organic agriculture still presents a solution by increasing yields in low-input areas, increasing income, reducing costs and providing employment for farm families; conserving bio-diversity and natural resources on the farm and in the surrounding area, and producing safe and varied food.

With the current paper, we want to contribute to the discussion above by showing that there is sufficient arable land in Turkey to feed the whole population solely with organic foods. The availability of other limited resources used in farming such as water and labor are not considered in our work. Water availability data for Turkey is not publicly available. Therefore, though water is a critical resource for farming, its availability in sufficient amounts is taken for granted in this study. Considering that organic and other environmentally friendly farming practices use water in a more sustainable and responsible manner (Reganold & Wachter, 2016; Liebig & Doran, 1999), we assume that the model results would not be significantly influenced by the addition of water availability data. Furthermore, the crop yield data indirectly comprise and reflect water availability as combined with climate conditions, top soil quality, etc. Another resource, not included in the model, is labor. Turkey has a relatively high proportion of young people (the first among EU and OECD countries) and a significant working-age population. Besides, throughout the history, a large portion of Turkey's population has been engaged in agriculture and the country used to be one of the few self-sufficient countries in the world until the 90s. Although the population practicing agriculture has been decreasing continually, Turkey is still considered among the top agricultural countries. Consequently, the additional labor required to convert to an all-organic Turkey is presumed to be available in this research. Finally, we assume the sufficient availability of nitrogen; a substance necessary for plant growth but whose surplus creates environmental problems. In conventional agriculture, nitrogen is provided in the form of chemical fertilizers whose use is unsurprisingly prohibited in organic agriculture due to its adverse environmental effects. In organic agriculture, nitrogen is supplied by manure, crop residues and N-fixation from increased legume cropping. Indeed, some of the organic certification firms active in Turkey require organic farmers to reserve at least 25% of the farm land to legume cropping (V. Ersöz, personal communication, December 2017). Since legumes are valuable sources of protein included in a healthy diet for humans and some, such as alfalfa, can also be consumed by animals, we assume that this condition be easily satisfied in the agricultural plans that we produce using our model..

To show that there is sufficient arable land in Turkey to feed the whole population solely with organic foods, we developed an organic agricultural plan for Turkey by using linear programming (LP), a renowned optimization technique successful in solving large real-world problems. Specifically, we find how many acres of each crop should be grown in each of the 81 cities in Turkey so that the whole population consumes organic foods only – plant-based as well as animal products–. To feed livestock and poultry, crops such as corn and barley and forages such as alfalfa are planted on arable land using organic practices. Both intensive (industrial) and extensive (grazing on meadows and pastures) methods of organic livestock production are utilized. The model incorporates transportation between cities while identifying any missing foods or excess land. Using suggestions from health experts and eating habits of Turkey's citizens, we compiled a diet providing sufficient energy and containing healthy sources of fats and carbohydrates balanced with appropriate levels of protein from organic foods. The linear programming model includes 120 crops and four animal-based products resulting in about 950 thousand variables and 40 thousand constraints. Using General Algebraic Modeling System (GAMS) as the modeling language and CBC as the LP solver, we reach an optimum solution in less than 40 seconds. Computational results indicate that there are no food shortages and that it is possible to feed a whole population with organic products using only 63% of the available arable land. By mathematically refuting the argument that it is impossible to feed the whole population with organic foods, we contribute to the removal of one obstacle on the way leading to the development of the domestic organic market and the widespread accessibility of organic agriculture products in Turkey. In addition, with the use of an embedded transportation module we obtain results that lower fossil fuel consumption in food delivery.

## 2. Linear Programming in Agricultural Planning

Linear programming is one of the most important tools used by industrial engineers and operations researchers. It is an optimization method to formulate and solve problems with a linear objective function and constraints in the form of linear (in)equalities. The solution process is incredibly fast taking advantage of linear algebra methods and the progress in the computing discipline. Developed by George Dantzig towards the end of World War II, linear programming has been successfully used for the solution of large scale problems. A nice history of linear programming, followed by its theory as well as references to various LP applications can be found in Dantzig and Thapa (1997).

Agriculture has been one of the application areas of linear programming, (Dent, Harrison, & Woodford, 1986; Moss, 2002; Williams, 1999). A good source for linear optimization models in agriculture is the model library of General Algebraic Modeling System (GAMS); see Brooke, Kendrick, Meeraus, and Raman (1998) for how to access the model library. Linear programming is becoming a frequently used technique in research conducted in organic farming as well. Several farm level studies exist, for example, Acs, Berentsen, and Huirne (2007) use dynamic programming to study the conversion process of farms from conventional to organic and apply sensitivity analysis to show the effects of organic prices, depreciation and availability of labor at peak periods. Kerselaers, De Cock, Lauwers, and Van Huylenbroeck (2007) model the economic potential of farmers for conversion to organic farming. Pacini, Wossink, Giesen, and Huirne (2004) compare the economic and environmental performances of conventional farms and organic farms in Italy under different regulations and support schemes. Annetts and Audsley (2002) propose a multi-objective linear programming model to study environmental farm planning; this is a very detailed model at the farm level including crop rotation and sequencing, machine availability, land availability, and livestock grazing and feeding constraints; objectives considered are the maximization of profit and the minimization of the negative environmental effects of farming; UK data is used. An LP problem modeling the use of organic fertilizers and crop sequences to conserve and replenish the nutrients in the soil can be found in the GAMS model library, see Brooke et al. (1998). Lansink, Pietola, & Bäckman (2002) use data envelopment analysis to compare the efficiency and productivity of conventional and organic crop and livestock farms in Finland -on average organic farms are found to be more efficient but less productive- and discuss the possible reasons behind the lower productivity of organic farms. More recently, a landscape-level model was proposed by Kennedy et al. (2016) to jointly optimize biodiversity, water quality and profit using a multi-objective model targeting sugarcane production and cattle ranching in southeastern Brazil. The work proposed by Le-Si et al. (1983) is very much related to ours in the sense that it is a linear programming model of Turkey's agricultural sector but differs from ours in many aspects. The main goal of Le-Si et al. (1983) is economic growth and so they include prices, price elasticity, (linearized) demand functions, import and export quantities; which we do not include in our model. In contrast, our main goal is to achieve a healthy human, animal and plant population as well as preserve soil fertility, water quality and clean air. Therefore, we provide an organic agriculture plan for the country prescribing which crop or animal to grow in every city, a detail which Le-Si et al. (1983) omit. The resulting plan from our work is a step towards ensuring food security and food sovereignty of the country, respecting nature, biodiversity and providing fair working conditions for farmers and farm families. At this point, the work of Jacobson et al. (2017) is worth mentioning who provide a roadmap for 139 countries of the world to convert all energy use to 100% water, wind and sun powered technologies. Ours is also a holistic model prescribing that all arable land to be converted to organic agriculture. They argue that in their case 100% conversion is possible economically and technically but that the barriers would be social and political. We show here mathematically that feeding a country with 100% organic foods is possible while expecting barriers of a similar nature.

## 3. **Developing Turkey's Organic Agriculture Plan**

Our goal is to feed the whole population of Turkey with organic products only and in this section, we present a linear programming formulation of an organic agriculture plan at the country level. This is in contrast with most of the models mentioned in the above paragraph that are at the farm level. Figure 1 is a visualization of data requirements and summary of outputs.

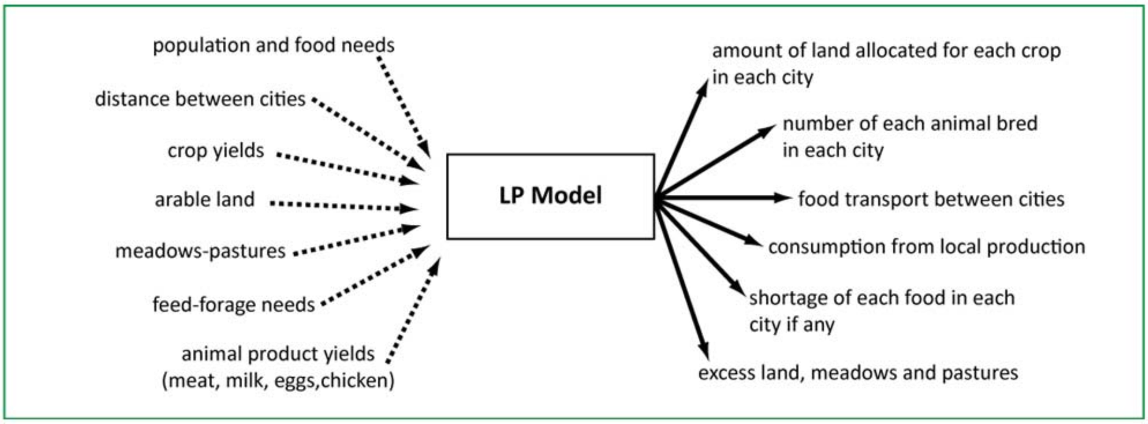


Figure 1. Inputs and Outputs of the LP Model

Main inputs of the mathematical model are:

- a menu containing a variety of foods,
- the list of crops to be grown for human consumption,
- the list of feed and forage crops to be grown,
- the crop yields under organic farming,
- the amounts of arable land, meadows and pastures in each city,
- the list and quantities of animal products to be consumed,
- the different animal species traditionally bred in the country, and
- the product (such as milk or meat) yields of these animals.

Some of the data, we easily obtained from websites of government agencies: (i) the distances between cities from the General Directorate of Highways of Turkey [KGM] (2014), (ii) the geographic distribution of the population from the Turkish Statistical Institute [TUIK] (2014a), and (iii) the amount of arable land from TUIK (2014b). The rest of the above-mentioned inputs required more effort to obtain. In the following, we discuss these in more detail while specifying sources used to extract them.

*3.1 Data Requirements: a Balanced Nutritious Diet*

After modeling the constraints and the objective function of the mathematical model that we report in Section 3.4, to run our program and obtain results, we needed the values of a variety of input parameters. One such input to the LP model is the list and quantities of products to be consumed by one individual in a year. In a balanced nutritious diet, an individual has to consume fresh fruits and vegetables, good sources of carbohydrates and fats and a certain amount of protein. Depending on the activity level, age and physical size, the daily energy requirement can be anywhere between 1000-3200 kcal (Note 3). The percentage ranges for a healthy diet, (Lichtenstein et al. 2006), recommend that calories from protein range in (10-35%), those from carbohydrates in (45-65%) and calories from fat in (20-35%) which can surpass 40% when a Mediterranean type diet is consumed with healthy sources of fat such as olive oil (Kafatos, Verhagen, Moschandreas, Apostolaki, & Van Westerop, 2000). Indeed, in the model, the fat consumed comes from four sources: olive oil (52%), nuts (11%), animal products (14%), and other plants (23%). To curb appetite and control weight gain we used a slightly larger fraction of calories from proteins than that in the standard diet, (Pesta & Samuel 2014).

Due to the rich biodiversity of the country, Turkey's citizens are used to consuming a wide variety of products. In the model, we made an effort to include the most frequently consumed plants and animal products. Appendix A contains a detailed list of 106 crops for human consumption, 4 animal products, 7 feed crops and 12 forage crops used in the model. For an average person we use a 2400 kcal diet with 90 grams of fat, 272 grams of carbohydrates and 91 grams of protein. These quantities fall into the percentage ranges recommended by health experts. The calorie level of 2400 kcal is high for a young child and low for individuals who work at physically demanding jobs and need to consume a large amount of calories, but, when averaged, there will be ample food for every citizen to remain healthy. In Table 1, we provide the list and quantities of foods consumed, grouped into main categories.

Table 1. Main food groups and consumption levels

| Food group | Legumes | Grains | Vegetables | Greens | Fruits | Olives** | Meat | Chicken | Milk*** | Eggs | Nuts |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Consumption* | 100 | 200 | 300 | 250 | 400 | 250 | 30 | 40 | 364 | 260 | 20 |

* All quantities in the table except eggs are daily figures in grams; for eggs, annual consumption is given in units.

**25 gr olives to be consumed at breakfast and 225 gr converted to olive oil, making approximately 32 gr olive oil (conversion ratio of olives to olive oil is 7:1) to be used for cooking and on salads.

***We assume that an individual consumes 25 gr cheese (conversion ratio of milk to cheese is 8:1), 100 gr yoghurt (conversion ratio of milk to yoghurt is 1.4:1) and 24 gr of milk daily, resulting in an equivalent of 364 gr milk.

### *3.2 Data Requirements: Crops and Yields*

After deciding on the plants to be included in the model, we needed to compute the yield of each crop in each city when grown under organic farming conditions. Turkish Statistical Institute (TUIK) publishes past data regarding crop production using conventional farming methods in Turkey (Note 4). Data are detailed; one can find location information ranging from country level down to municipalities. Individual crops are listed as well as food groups together with quantity produced and the amount of land cultivated. Unfortunately, such data are not available for organic products. For organics, data published only list the amount produced but not the amount of cultivated land for individual crops, vital piece of information to compute organic crop yields. Employees at the Ministry of Food, Agriculture and Livestock were very helpful and we are grateful for all their support but the information provided by them was too limited to be used in research. To obtain yield information for each crop, we used conventional farming yield data published by TUIK together with the results of research comparing organic and conventional yields. Although there exist many articles arguing that organic yields get very close to their conventional counterparts and even surpass them, (Badgley et al., 2007; Drinkwater et al., 1995; Liebig and Doran, 1999; Lotter et al., 2003), to be on the safe side, we used a certain decrement in yields when organic farming methods are used. Specifically, we used the average results reported by Seufert et al. (2012), a comprehensive meta-analysis which reported that overall, organic yields are 25% (in the 5-34% range) lower than conventional with organic performance varying widely over crop types, species and practices used. We made the necessary reductions in the yields of crops, reported in Table 2.

Table 2. Average yield reductions reported in Seufert et al. (2012)

| Food group | Fruits and nuts | Grains | Wheat | Vegetables | Legumes | Tomato | Salad greens |
|---|---|---|---|---|---|---|---|
| Reduction percentage | 10% | 25% | 40% | 30% | 10% | 20% | 25% |

To increase modeling complexity at a reasonable pace, we first formulated a vegetarian model. In this model, all citizens of the country consume only plants. In order to account for the loss of animal protein, we increased the daily intake of legumes and grains. Using the most frequently consumed 106 crops and 81 cities resulted in about 750 thousand variables and 28 thousand constraints. We found the optimal solution in less than 30 seconds. The results showed that 54% of the arable land in Turkey sufficed to provide the necessary nutrition (2330 calories, 83 gr protein, 69 gr fat, and 297 gr carbohydrates) to the whole population in the form of organic foods. In the second model, we included organic animal products to allow for a more diverse diet. We report the details of the omnivore model in Sections 3.3 and 3.4.

### *3.3 Data Requirements: Modeling Animal Products*

In this paper, our main concern is the availability of sufficient arable land to feed the population. Therefore, in what follows, we only consider the feed needs of animals as they affect the amount of arable land. Organic farming rules and regulations that are in effect in Turkey prescribe several other conditions for raising animals; these concern the amount of living space to be allotted to each individual animal, the access to outdoors, exposure to natural lighting etc. These conditions are of a more technical nature and can be satisfied without a burden on arable land.

A difficulty in modeling was the dual role of animals. Once, their products are food items for humans, then again, animals themselves are consumers of plants that were grown on the same arable land used for growing plants for human consumption. Hence by defining appropriate variables in the model, (i) we determine how many of each animal we need to raise to feed the human population, and (ii) we allot certain amount of arable land to satisfy the feed needs of these animals. Animals modeled are beef cattle, dairy cows, and two breeds of chicken, for meat and eggs. Although there are a number of different sheep and goat breeds in Turkey, we have not included them in our model to keep data processing efforts at a reasonable level (Note 5).

3.3.1 Chicken and Eggs

In the model, we included two general breeds of chicken: *broilers*, those raised for their meat and *egg-laying* chicken, each with a different lifetime and meat/egg yields. To feed both types of chicken, main feed products used are soy and corn. Lampkin (1997) suggest that corn-fed table birds may be fed a ration containing a minimum of 65% cereals and if corn is used, it should make up at least 50% of the ration. For laying hens, Zollitsch and Baumung (2004) suggest a 100% organic diet consisting of 50% corn, 35 % soybean or sunflower, 5% alfalfa and 10% minerals. In the model, we used feed rations from an organic poultry farm in the Agean part of Turkey. There, broilers consume 8.75 kilograms of total feed during their lives whereas egg-laying chicken daily consume 54 grams in the first 15 weeks of their lives and 130-140 grams in the remaining 75 weeks. Using these figures, we computed total annual soy and corn consumption of each chicken breed. The feed rations and product yields are summarized in Table 3. These quantities are in accordance with the percentages suggested in the literature.

Table 3. Yield and feed needs of chicken

| | Lifetime | Yield | Soy content | Corn content | Vitamins, minerals and stone |
|---|---|---|---|---|---|
| Broiler | ≥ 81 days | At the end of their lives: 2.5 kg live weight becomes 1.7 kg of chicken meat (68% carcass yield). | 25% | 70% | 5% |
| Egg-laying chicken | ≈ 90 weeks | With no eggs in the first 15 weeks, 260±10 eggs are produced annually (Note 6). | 29% | 56% | 15% |

Source: (E. Çetinkol, personal communication, January 10, 2015)

3.3.2 Milk and Beef Cows

There are two fundamentally different methods of cattle breeding: intensive and extensive.

Table 4. Animal breeds, regions and yields

| Type | Region | Average annual milk yield (kg) | Average life weight - adult female (kg) | Average life weight - adult male (kg) | Carcass ratio (%) |
|---|---|---|---|---|---|
| Yerli Kara | Central Anatolia | 1062 | 200 | 300 | 57 |
| Kilis Bahçe | South East Anatolia | 1875 | 414 | 610 | 60 |
| Yerli Sarı* | Eastern and northern parts of Mediterranean | 633 | 200 | 300 | 57 |
| Boz Step | East Marmara, Thrace, North Aegean and west parts of Central Anatolia | 1096 | 375 | 470 | 57 |
| Doğu Anadolu Kırmızısı | East Anatolia | 939 | 322 | 393 | 61 |
| Manda Camış | All parts of Turkey but mainly the Blacksea region. | 925 | 438 | 438 | 55 |
| Zavot | Kars (city in East Anatolia) and vicinity | 2300 | 400 | 550 | 57 |
| Intensive beef cattle and milk cows | All parts of Turkey. | 5000 | 500 | 650 | 60 |

*We used data from Yerli Kara to fill the missing data pieces of Yerli Sarı, similarly for the weight of male Manda we used the figures for female Manda.

In the extensive method, also called traditional, animals freely graze on meadows and pastures as long as climate and grass conditions allow. The farmer provides a roof under which the animals can seek shelter when the weather gets rough (either too cold and stormy or too hot and sunny). The shelter can also be in the form of a group of densely grown appropriate trees. When weather or grass conditions are ill-suited for grazing, the farmer provides grass, hay or forages that have been cut and dried for this purpose at the time of harvest (S. Beyazıt, personal communication, February 2015; Younie, 2001, Voisin, 1959). In the intensive method, animals are kept indoors apart from a small grazing area and the farmer provides all of their feed needs. Mete Hacaloğlu criticized that organic intensive animal husbandry differs from conventional animal husbandry in only a single aspect: the feeds used are organically grown. From an optimistic perspective, this means that it is relatively simple to convert from conventional intensive animal husbandry to an organic method (personal communication, February 2015). Details regarding the locality, milk and meat yields of the animals are inputs to the mathematical model in Section 3.4. This information, mainly compiled from Meat&Milk Board [MMB] (2015) and the Official Gazette of the Republic of Turkey [OGTR] (2004), is summarized in Table 4.

#### 3.3.2.1 Extensive Animal Husbandry: Feed Needs

The extensive method has long been the traditional animal husbandry technique used in Turkey with several local breeds of both beef cattle and milk cows. In feeding cattle using the extensive method, we did not distinguish between milk cows and beef cattle but acknowledged a seasonal differentiation. Cattle, when grazing in a meadow in ideal conditions (15 cm grass height), daily consume green grass that amounts to at most 10% of their body weights (Voisin, 1959) (Note 7). On meadows and pastures in average conditions, the cows graze an equivalent of at most 8.5% of their body weights, daily (Voisin, 1959 p. 77). For a Zavot of 550 kg, that means a daily consumption of 46.75 kg of forage, making a total annual consumption of 17064 kg green forage. A portion of this annual figure is obtained by grazing. Each city has a certain amount of meadows and pastures with different dry fodder yields; we have used these as inputs to the mathematical model. However, when meadows or climate conditions do not allow for grazing, the farmer provides the remaining amount in the form of dry forage. Forages common to Turkey are alfalfa (*medicago sativa*), common vetch (*vicia sativa*), sainfoin (*onobrychis sativa*), oat (*avena*), grasspea (*lathyrus*), wheat (*triticum*), sorghum, bitter vetch (*vicia ervilia*), barley (*hordeum vulgare*), rye (*secale cereale*) and crimson clover (*trifolium incarnatum*). We have observed that alfalfa is grown in almost all cities in Turkey except a few; for example in Rize only barley is grown, similarly in Mardin, grass pea, bitter vetch and common vetch are used as forages. In the model, instead of forcing a diet containing a specific forage crop such as alfalfa, we allowed traditional forages common to each city to be used for supporting animal nutrition when necessary, see Section 3.4 equation (10). Using 2014 data from United States, Kniss, Savage, and Jabbour (2016) report that as a group, organic hay crops yield similarly or better than conventional hay crops (Note 8). Since the experience of organic livestock farmers in Turkey is similar (M. Hacaloğlu, personal communication, February 2015), we used conventional yields without making any reduction when computing the yields of forage crops under organic farming.

#### 3.3.2.2 Intensive Animal Husbandry: Feed Needs

To summarize the feed needs of cattle, the term ration is used in the intensive method. Rations for beef cattle are different from those for milk cows, (Görgülü, 2002). In the model, we simplified real life and used one species of beef cattle and one species of milk cow to represent the average animal under intensive management. One can think of this average animal as a Holstein or a Simental or a crossbreed of these with one of the local cattle species. Feeds used in the intensive method are classified as roughage and concentrate feed. Roughage consists of fresh and dry hay, forages and silage whereas concentrate feed mainly consists of grains and legumes. In organic animal husbandry, additives are tightly controlled and restricted but some vitamins can be added to the feeds (Özen, Şayan, Ak, Yurtman, & Polat, 2010).

In feeding milk cows, it is suggested to have a high ratio of roughage (A. Sökmen, personal communication, 2014) and provided that it is kept very high for lactating cows, this ratio should be at least 60% (Ministry of Food, Agriculture and Livestock [MFAL], 2017). Same document also states that 3 kg of silage is equivalent to 1 kg of dry feed. In the model, we used feed rations from an organic dairy farm where roughage to concentrate ratio is on average 77%. To obtain the necessary annual feed need figures, we assumed that a milk cow's life lasts 7 years, the first two years of these are spent first as a calf then as a heifer without lactating, and in the next five years, the cow is lactating and goes through different stages in terms of milk yield and nutritional needs during lactation. We assumed that on average, a milk cow under intensive management consumes daily 1.2 kg of barley, 1.7 kg of corn, 15 kg corn silage, 1 kg soy, 3.3 kg dry alfalfa and 3 kg wheat straw (M. Hacaloğlu, personal communication, February 2015). Using these figures, we computed her annual average need of each feed crop: 426 kg barley, 606 kg corn, 5655 kg corn silage, 372 kg soy, 1207 kg dry alfalfa (*medicago sativa*) and 1095 kg wheat straw (Note 9). Noticing that wheat straw is a by-product and its need can be satisfied from wheat grown for human consumption we only added decision variables that represent the amounts of barley, corn, soy, corn silage and alfalfa to be grown in each city.

Nutrition of beef cattle raised using the intensive method differs from that of milk cows greatly, especially in terms of protein content. Organic cattle farms suggest that organic beef cattle on average consume 4 kg of barley, 2.5 kg of corn, 2.5 kg of soy, 1.22 kg of dry alfalfa and 3 kg of wheat straw daily (Mete Hacaloğlu, personal communication, April 2015). Usually beef cattle are slaughtered around 15-18 months of age so they need to gain weight quickly. Therefore, the concentrate ratio in the feed mix is higher than that of milk cows, it is at least 60% and reaches 100% at the end of their lifetimes (Uğur, 2004; Younie, 2001). In the mathematical model, we kept the concentrate ratio for intensive beef cattle at 68% on average.

### *3.4 Components of the LP Model*

Following the list of index sets and the definition of parameters and decision variables in Table 5, we present the main constraints and the objective function(s) of the problem.

Table 5. Index sets, variables and parameters

| *Index sets* | |
|---|---|
| $P$ | set of all organic crops grown for human and animal consumption |
| $F$ | subset of $P$, set of organic feed products for chicken and livestock including grass |
| $L$ | set of organic animal products for human consumption |
| $H$ | subset of $P$, set of organic forage products grown on arable land |
| $A$ | set of animal types bred using organic practices |
| $C$ | set of cities |
| *Parameters* | |
| $D_{jk}$ | distance between cities $j$ and $k$ |
| $Agrland_j$ | amount of arable land in city $j$ (decares) |
| $Pop_i$ | population of city $j$ |
| $FoodReq_i$ | annual requirement of one person of food $i$ (both plant and animal products) |
| $FeedN_{hij}$ | annual need for feed $i$ of one animal $h$ in city $j$ |
| $ForageN_{hj}$ | annual forage need of one animal $h$ in city $j$ |
| $Meadw_j$ | Amount of meadows in city $j$ (decares) |
| $GrassNeed_{hj}$ | annual grass need of one animal $h$ in city $j$ (grazing) |
| $Grassyield_j$ | fresh grass yield of meadows and pastures in city $j$ (kg/decare) |
| $Yield_{ij}$ | yield of crop $i$ in city $j$ under organic farming conditions (kg/decare) |
| $Cmeatyield_{hj}$ | average annual chicken meat production capacity of animal $h$ in city j |
| $Eggyield_{hj}$ | average annual egg production capacity of animal $h$ in city j |
| $Meatyield_{hj}$ | average annual meat production capacity of animal $h$ in city j |
| $Milkyield_{hj}$ | average annual milk production capacity of animal $h$ in city j |
| $SC$ | Shortage cost of food |
| $TC_i$ | unit transportation cost for food type $i$ per shipment |
| *Variables* | |
| $\boldsymbol{Z}$ | total distance travelled by food and costs of transportation, shortages and agriculture |
| $\boldsymbol{x_{ij}}$ | amount of arable land allocated for growing crop $i$ in city $j$ (decares) |
| $\boldsymbol{a_{hj}}$ | number of animals of type $h$ bred in city $j$ |
| $\boldsymbol{p_{ij}}$ | amount of food type $i$ (in kg) produced in city $j$ |
| $\boldsymbol{c_{ij}}$ | amount of food type $i$ (in kg) consumed in city $j$ |
| $\boldsymbol{y_{ij}}$ | amount of food type $i$ (in kg) produced in city $j$ and consumed in the same city |
| $\boldsymbol{t_{ijk}}$ | kilograms of food type $i$ transported from city $j$ to city $k$ |
| $\boldsymbol{s_{ij}}$ | kilograms of food type $i$ in shortage in city $j$ |
| $\boldsymbol{el_j}$ | excess land in city $j$ (decares) |
| $\boldsymbol{epm_j}$ | excess meadows and pastures in city $j$ (decares) |
| $\boldsymbol{pu_j}$ | percent land used in city $j$ |
| $\boldsymbol{cg_j}$ | amount of leftover pastures in city $j$ cut to be used indoors (decares) |

#### 3.4.1 The Mathematical and Logical Restrictions of the Problem

In LP terminology, the mathematical and logical restrictions of a real world problem are called constraints. The main constraints are given as:

$$\boldsymbol{p_{i,j}} = \boldsymbol{x_{i,j}} \cdot Yield_{ij} \text{ for } i \in P \backslash \{Grass\} \text{ and } j \in C \quad (1)$$

$$\boldsymbol{p_{Milk,j}} = \sum_{h \in A} Milkyield_{hj} \cdot \boldsymbol{a_{h,j}} \text{ for } j \in C \quad (2)$$

$$\boldsymbol{p_{Meat,j}} = \sum_{h \in A} Meatyield_{hj} \cdot \boldsymbol{a_{h,j}} \text{ for } j \in C \quad (3)$$

$$\boldsymbol{p_{Chicken,j}} = \sum_{h\in A} Cmeatyield_{hj} \cdot \boldsymbol{a_{h,j}} \quad \text{for } j \in C \tag{4}$$

$$\boldsymbol{p_{Eggs,j}} = \sum_{h\in A} Eggyield_{hj} \cdot \boldsymbol{a_{h,j}} \quad \text{for } j \in C \tag{5}$$

$$\boldsymbol{y_{i,j}} = \boldsymbol{p_{i,j}} - \sum_{k\neq j} \boldsymbol{t_{i,j,k}} \quad \text{for } i \in (P \cup L)\backslash\{Grass\} \text{ and } j \in C \tag{6}$$

$$\boldsymbol{c_{i,j}} = \boldsymbol{y_{i,j}} + \sum_{k\neq j} \boldsymbol{t_{i,k,j}} \quad \text{for } i \in (P \cup L)\backslash\{Grass\} \text{ and } j \in C \tag{7}$$

$$\boldsymbol{c_{i,j}} + \boldsymbol{s_{i,j}} = Pop_j \cdot FoodReq_i \quad \text{for } i \in (P \cup L)\backslash(F \cup H) \text{ and } j \in C \tag{8}$$

$$\boldsymbol{c_{Grass,j}} = \left(Meadw_j + Pastur_j - \boldsymbol{epm_j} - \boldsymbol{cg_j}\right) \cdot Grassyield_j \quad \text{for } j \in C \tag{9}$$

$$\sum_{i\in H} \left(\boldsymbol{c_{i,j}} + \boldsymbol{s_{i,j}}\right) + \boldsymbol{cg_j} \cdot Grassyield_j = \sum_{h\in A} \left(ForageN_{hj} \cdot \boldsymbol{a_{h,j}}\right) \quad \text{for } j \in C \tag{10}$$

$$\boldsymbol{c_{i,j}} + \boldsymbol{s_{i,j}} = \sum_{h\in A} \left(FeedN_{hij} \cdot \boldsymbol{a_{h,j}}\right) \quad \text{for } i \in F \text{ and } j \in C \tag{11}$$

$$\sum_{i\in P} \boldsymbol{x_{i,j}} + \boldsymbol{el_j} = Agrland_j \quad \text{for } j \in C \tag{12}$$

$$\boldsymbol{pu_j} = 1 - \boldsymbol{el_j}/Agrland_j \quad \text{for } j \in C \tag{13}$$

Constraints (1) relate the amount of land cultivated for each crop, $\boldsymbol{x_{i,j}}$, to the amount of production, $\boldsymbol{p_{i,j}}$, using organic farming yields, $Yield_{ij}$. ***Grass*** is excluded from (1) because it is not "produced" on arable land but on meadows and pastures, modeled in (9).

Constraints (2) – (5) relate the amount of animal products produced to the number of animals grown. For example, in the case of milk, the equations compute $\boldsymbol{p_{Milk,j}}$, the amount of milk produced in city *j* using $\boldsymbol{a_{h,j}}$, the number of animals of type $h$ bred in city $j$, and $Milkyield_{hj}$, the milk yield of animal $h$ in city $j$. Each type of animal, also depending on the locality it is commonly bred, produces a different amount of milk throughout their lives. This makes an annual amount of about 5000 kg of milk for intensive milk cows but only 1061 kg for the Yerli Kara milk cow when bred in Ankara or Aksaray, etc. Because Yerli Kara is not commonly bred in Adana, the annual milk yield of Yerli Kara in Adana is zero. So that with a two dimensional parameter, $Milkyield_{hj}$, we have incorporated whether or not a certain type of animal is grown in a city as well as its annual milk yield. The remainder of the animal products is modeled similarly in (3) – (5).

Constraints (6) reserve a portion of production to be consumed locally in the same city, $\boldsymbol{y_{i,j}}$, and ship the remainder to other cities in need, $\sum_{k\neq j} \boldsymbol{t_{i,j,k}}$. Constraints (7) then define the total amount of consumption of a product as the sum of the amount consumed from local production and the total amount received from other cities with excess, $\sum_{k\neq j} \boldsymbol{t_{i,k,j}}$.

Constraints (8) ensure that the food requirements of the human population in every city are met. The set $(P \cup L)\backslash(F \cup H)$ includes all crops and animal products for human consumption. Products in $(F \cup H)$ are excluded because these are either feed crops or forages that will be modeled in Constraints (10) and (11).

Grass is "produced" in the meadows and pastures and consumed by extensively bred cows via grazing. If there is any excess then that amount is either left unutilized, $\boldsymbol{epm_j}$, or is cut, $\boldsymbol{cg_j}$, as in Constraints (9). The excess grass cut in (9) is used to supplement indoor feeding needs of extensively managed traditional local cow breeds modeled in Constraints (10). These equations also utilize different forage crops such as alfalfa grown on arable land. Here we do not prescribe which specific forage crop should be consumed; the summation in equation (10) enables an animal to consume whatever forage is grown in the locality it is bred. Constraints (11) ensure that the feed needs of chicken and intensively managed milk and beef cows are satisfied and include crops such as corn, soy and barley, as well as alfalfa grown on arable land. Grazing (outdoor feeding) needs of extensively managed traditional local cow breeds are also modeled in Constraints (11) when the index $i$ equals ***Grass***. We use variables $\boldsymbol{s_{i,j}}$ in constraints (8), (10) and (11) to keep a record of shortages if there are any.

Finally, constraints (12) and (13) make sure that the amount of arable land utilized does not exceed the available amount, record the actual land use and compute the percentage of arable land left unused.

### 3.4.2 The Objective Function and Multi-Objective Programming

The objective function is an important element of an LP problem and it is frequently used as a vehicle to direct the solution towards specific targets. In this section, we construct the objective function to achieve our targets. Primarily, we want to feed the whole population using organic agriculture hence we will minimize food shortages as much as possible. At the same time, we want to minimize total distance travelled by food, transportation costs incurred by farmers and avoid unnecessary crop production. Obviously, the problem on hand has a multi-objective nature.

Standard approaches to solve multi-objective optimization problems, also called lexicographic optimization, are classified as the preemptive and non-preemptive methods (Note 10). The equivalence of these approaches for the linear case is shown in (Sherali & Sosyter, 1983). In the preemptive approach, objectives are optimized in turn according to their priorities. This approach is sometimes preferred because different objectives are measured in different units as well. At the end of each stage, a constraint is added to ensure that a higher priority objective function value is preserved in the subsequent stages (optimizations). In the non-preemptive method, a weight is assigned to each objective that represents its relative importance. The weighted objective functions are combined into a single objective function which then is minimized.

In our problem, we have the following objectives:

$$minimize\ food\ shortages: minimize\ \sum_{i,j} \boldsymbol{s_{i,j}} \tag{14}$$

$$minimize\ distance\ travelled\ by\ food: minimize\ \sum_{i,j,k} D_{jk} \cdot \boldsymbol{t_{i,j,k}} \tag{15}$$

$$minimize\ total\ actual\ transportation\ cost: minimize\ \sum_{i,j,k} TC_i \cdot \boldsymbol{t_{i,j,k}} \tag{16}$$

$$minimize\ amount\ of\ cultivated\ land:\ minimize\ \sum_{i \in P, j \in C} \boldsymbol{x_{i,j}} \tag{17}$$

In (14) we summed the shortage variable $\boldsymbol{s_{i,j}}$ and minimized total food shortage. In some cities such as Istanbul with a large population but very limited amount of arable land, food requirements cannot be met from local production; in these cases excess foods from nearby cities are transported. To prevent unnecessary transportation, distances, $D_{jk}$, are multiplied with $\boldsymbol{t_{i,j,k}}$, the variable representing the amount of food *i* transported from city *j* to *k*, and total distance travelled by food is computed and minimized in (15). To construct (16), actual transportation costs incurred by farmers are found by multiplying $TC_i$ with $\boldsymbol{t_{i,j,k}}$. Similarly to prevent unnecessary crop production, total cultivated land is found by adding variables $\boldsymbol{x_{i,j}}$ and minimized in (17).

We applied both methods of multi-objective programming. In the preemptive method, we first optimized the objective function (14) subject to constraints (1) through (13). Using the optimal OF value as a bound on total shortages together with (1) through (13), we next optimized (15). We continued in this fashion until all the objectives are optimized. In the non-preemptive method, we formed a combined objective function. Because penalizing shortages has the highest priority, we use a high weight for (14). Trying out several penalties, we found out that a weight of 1000 is sufficient to avoid food shortages in the whole country and set $\boldsymbol{SC}$ equal to 1000 (Note 11). Objectives (15), (16), and (17) are equally important with respect to each other and we used weights of 1 for each to obtain the following combined OF:

$$minimize\ \boldsymbol{z} = SC \cdot \sum_{i,j} \boldsymbol{s_{i,j}} + \sum_{i,j,k} D_{jk} \cdot \boldsymbol{t_{i,j,k}} + \sum_{i,j,k} TC_i \cdot \boldsymbol{t_{i,j,k}} + \sum_{i \in P, j \in C} \boldsymbol{x_{i,j}} \tag{18}$$

In compliance with the result of (Sherali & Sosyter, 1983), both methods produced the same solution. We discuss the results in the next section.

## 4. Discussion of Results

The LP model presented in Section 3.4 is capable of generating a large number of numerical results. In a basic run with 2013 data, we obtained insight into the problem of devising an organic agriculture plan for Turkey. Below we share the basic points.

Turkey can satisfy the nutrition requirements of its citizens solely from organic foods grown in the country and can feed her animals solely with organic feeds and forages; 63% of total arable land in the country suffices to achieve this. There is no shortage of any food item, neither crops nor animal products. In the vegetarian model, the required arable land was only 54% of the total available.

Transportation of food between cities takes place in all scenarios. In all of them, the most "needy" city is Istanbul requiring around 7 million tons of food products to be transported from 18 other cities. More than 70 % of the food transported to Istanbul are from cities such as Tekirdağ, Sakarya, Balıkesir, Çanakkale and Edirne; all of these cities are located in the Marmara Region in close proximity to Istanbul. We see the effect of the transportation module here, minimizing total transportation costs and food-kilometers led to the utilization of cities closest to Istanbul to feed this "giant" city. All cities "export" food, especially Sakarya and Tekirdağ with 2.4 and 1.7 million tons, respectively.

In the outputs of the model, we observe that meadows and pastures have completely been used up by grazing animals and extensive animal husbandry has been the preferred method to the extent that available meadows and pastures allowed. The reason for this preference is that to produce one unit of output by the extensive method, a smaller amount of input is required than the intensive method. In that sense the intensive method is a more "expensive" animal husbandry method. In LP terminology, meadows and pastures are scarce resources and that means if Turkey were to expand the amount of meadows and pastures, better and less costly agricultural plans would be found.

When we try out different transportation cost structures, we see the tremendous effect of transportation on the solution. Because animal products require certain temperatures during delivery, transporting these is costlier. If it costs 1 TRY to transport one kilogram of crops, it costs 2, 4.5, and 7.5 TRY to transport one kilogram of milk, chicken and meat, respectively, whereas figures for eggs are given as 0.1 TRY per unit. All of these figures are close estimates of actual costs incurred that we obtained by interviews with organic farmers and officials of companies processing, marketing and transporting organic food products. Due to the contacts that the farmers have with the logistics companies, the unit transportation cost is independent of distance travelled. However, this does not reflect the true cost to the environment and therefore we also considered an objective function (OF) where food-kilometers are added to the total actual transportation costs. Table 6 reports a comparison of different transportation cost structures.

Table 6. Distance travelled by food and required arable land at optimum solution for different transportation cost structures; distance is reported as unit-kilometers for eggs and ton- kilometers for all other products

| | *TC = 0* | *TC = actual* | *TC = actual with food kilometers in OF* |
|---|---|---|---|
| plants for human consumption | 29904 million | 12752 million | 4381 million |
| chicken feed | 6401 million | 682 million | 283 million |
| cow feed | 5996 million | 434 million | 128 million |
| forages | 42943 million | 0 | 0 |
| chicken | 2483 million | 194 million | 278 million |
| eggs | 54982 million | 3814 million | 0 |
| milk | 19179 million | 1563 million | 284 million |
| meat | 1141 million | 266 million | 496 million |
| used arable land percentage | 29% | 57% | 63% |

First, notice the obvious result (when TC=0) which is still worth mentioning because it points to the trade-off between required arable land and the distance travelled by food. When we allow transportation without penalizing it, we see that crops are produced almost entirely in cities where their yields are highest and transported to all the other cities in the country. This gives rise to a very high amount of distance travelled by food but a very low amount of arable land used, only 29%, to feed the whole country. Of course, we do not suggest such an approach because its high usage of fossil fuels and adverse effects on environment are obvious. Next, we considered an OF with actual unit transportation costs. This is the case in which to comply with what the farmers are experiencing, we did not take distances into account. The required arable land percentage increased to 57% and the distances traveled by food decreased in comparison to the previous case. However, this second cost structure still did not reflect the true cost to the environment and we added the total distance travelled by food to the objective function in Section 3.4 in addition to the total transportation costs incurred by farmers. Results indicate that food now travels much less and when food travels, it does so to eliminate shortages. Finally, the required arable land to feed the country increased to 63%.

Next, we made a stress test and assumed that due to drought, the topsoil in central Anatolia was lost and all the arable land has become a desert that is no longer suitable for farming. Running the model under these new conditions, we obtained results that in detail prescribe where food should be grown and transported to satisfy the food needs of Turkey including the people of central Anatolia. We observed that it is still possible to feed the whole country but this time 88 % of arable land is used with most of unused land being fallow land.

Recognizing the fact that the number of fruit trees cannot be increased at a level that we require in one instant, we investigated a restrictive scenario where we placed an upper bound on the number of fruit trees in the vegetarian model. Results indicated small shortages in kiwis, bananas and some berries; larger shortages in walnuts and almonds and major shortage in olive trees. This is caused by three mechanisms: (i) we ignored regional diets and forced everybody to consume berries and kiwis, etc. (ii) a large portion of the fat in the daily diet is obtained from nuts and (iii) the major fat requirement including cooking oil is satisfied from olive oil. From this scenario we can deduce that to arrive to a Turkey consuming healthy and organic foods we need to increase the number of olive trees considerably.

In the beginning of the chapter, we reported arable land percentages for the vegetarian and the omnivore models. In the vegetarian model, daily energy intake for an individual was set at 2330 kcal and used arable land accounted to 54% of the total available. In the omnivore model, daily energy intake was set higher at 2400 kcal and used arable land accounted to 63% of the total available. A 3% increase in the energy intake (from 2330 to 2400 kcal) of individuals caused a 17% increase in the required arable land. Here we do not impose a specific diet such as vegetarianism; however, results of our mathematical model confirm the fact that a vegetarian diet puts a lower burden on natural resources than one that includes animal products.

Finally, we made a comparison with 2013 figures reported by the Turkish Statistical Institute summarized in Table 7. In short, our model proposes to consume less meat, much less milk and chicken meat, and 20% more eggs but in a fairly distributed fashion. Professional associations of red meat producers frequently complain of the low consumption of animal products in Turkey. With the exception of eggs, our model suggests an even lower consumption. In devising the daily menu, we complied with guidelines suggested by health experts regarding the consumption of all kinds of products including animal products. Therefore, we argue that TUIK numbers for red meat, chicken meat and milk would have been more than sufficient to feed the population in a healthful manner if they were fairly distributed.

Table 7. Comparison of model results with actual consumption of animal products

| | Model output | 2013 TUIK figures |
|---|---|---|
| Red meat (ton) | 839 513 | 996 125 |
| Chicken meat (tons) | 1 119 351 | 1 758 363 |
| Milk (tons) | 10 186 092 | 18 223 712 |
| Eggs (units) | 19 933 644 540 | 16 496 751 178 |

## 5. Limitations, Further Research and Conclusions

There are some limitations of our study. Firstly, mushrooms and fish have not been included in our study. These products are healthy sources of protein and we hope to include them in the future as more data becomes available regarding their production using organic methods. Mushrooms and fish are widely consumed products in Turkey and their inclusion into the proposed diet will reduce the amount of arable land required to feed the country, making the 63% in effect an upper bound on the amount of land required. Similarly; despite the high potential in Turkey, uncultivated wild food (hunted and gathered from nature) have been out of consideration.

Secondly, breeding sheep and goat is very common in Turkey and consuming their meat is known to have a number of health benefits due the specific fatty acids in the sheep meat and the leanness of the goat meat. Still, we have not included these in our model to reduce data collection and processing time. However, if there is political will to use our model for agricultural planning, some effort must be reserved for extracting the necessary input data such as grazing habits, feed needs, meat and milk yields, for sheep and goat breeds in Turkey.

In agriculture, it is commonly encountered that the output of one part of the system to be used as input to another part. For example, manure from organic livestock production acts as valuable fertilizer for crop production. To reflect such relationships inherent in agriculture, the model needs to be extended with appropriate variables. Similarly, with additional variables, the amounts of water, labor and nitrogen in the form of any extra amount of legume cropping required in the above proposed plan should be calculated and checked against available resources.

As our goal is to feed the population of Turkey, we have only planned the organic cultivation of crops for human and animal consumption. Since only 63% of arable land is used to feed the population, there is ample space for organically cultivating commodity products such as tobacco, sugar, or cotton some of which could also be exported. In the future, the model can be extended to include these additional agricultural activities using organic farming.

Some thought needs to be given to how to reflect risk factors and effects of seasonality or include different farming practices such as permaculture in the model. It would also be useful to disaggregate the 81 cities of Turkey into its 957 municipalities and produce a more detailed agricultural plan. The conventional yield data contains a few inconsistent and incorrect records and some data cleansing is necessary. We suggest that the yield information for a product to be removed or replaced by a regional average when the total amount cultivated in a year is on less than a reasonable amount in a specific locality.

In this work, we developed a large scale mathematical model to be used in agricultural planning. Bearing in mind that historically growing crops and animal husbandry used to go hand in hand and support each other, we constructed a holistic model that includes both crops and animals. To this end, we modeled intensive and extensive methods of livestock production. Recognizing the need for a healthier method of farming for the well-being of humans, animals, plants, air, water, and soil, we used organic farming data as input and produced an organic agriculture plan for Turkey. We have shown mathematically that it is possible to feed the whole population of Turkey with organic foods using only 63% of arable land. Data that drives the model are a determinant factor and with similar data, the same model could be used for agricultural planning of other countries or of other farming techniques. The resulting program is also a tool that can be used to understand the effects of climate change on world food production. The encouraging results of our work give us reason to hope the feasibility of feeding the whole world with healthier farming methods such as organic agriculture.

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**References**

Acs, S., Berentsen, P. B. M., & Huirne, R. B. M. (2007). Conversion to organic arable farming in The Netherlands: a dynamic linear programming analysis. *Agricultural Systems, 94*(2), 405-415. https://doi.org/10.1016/j.agsy.2006.11.002

Aktar, C., & Ananias, V. (2005). Yeni bir ulusal politika: ekolojik tarım. *İktisat İşletme ve Finans, 20*(229), 26-32. http://dx.doi.org/10.3848/iif.2005.229.1324

Akyüz, A. A., & Demir, A. Y. (2016). The role of a civil society organization in the development of the domestic organic market in Turkey. İ.Ü. *Siyasal Bilgiler Fakültesi Dergisi, 54,* 43-61. Retrieved from http://dergipark.gov.tr/iusiyasal/issue/24993/263783

Altieri, M. A., & Rosset, P. (1996). Agroecology and the conversion of large-scale conventional systems to sustainable management. *International Journal of Environmental Studies, 50,* 165-185. http://dx.doi.org/10.1080/00207239608711055

Annetts, J.E., & Audsley, E. (2002). Multiple Objective Linear Programming for Environmental Farm Planning. *Journal of the Operational Research Society, 53,* 933-943. http://dx.doi.org/10.1057/palgrave.jors.2601404

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M. J., Avil´es-V´azquez, K., … Perfecto, I. (2007). Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems, 22*, 86-108. http:// dx.doi.org/10.1017/S1742170507001640

Barański, M, Średnicka-Tober, D, Volakakis, N, Seal, C., Sanderson, R., Stewart, G. B., ... Leifert, C. (2014). Higher antioxidant and lower cadmium concentrations and lower incidence of pesticide residues in organically grown crops: a systematic literature review and meta-analyses. *British Journal of Nutrition, 112,* 794-811. http://dx. doi.org/10.1017/S0007114514001366

Brooke, A., Kendrick, D., Meeraus, D., & Raman, R. (1998). *GAMS: a User's Guide*, Washington DC: GAMS Development Corporation.

Cockshott, W. P., & Cottrell, A. (1993). *Towards a new socialism*. Nothingham: Spokesman.

Dantzig, G. B., & Thapa, M. N. (1997). *Linear Programming: Introduction.* New York: Springer.

Demiryürek. K. (2004). Organic agriculture in the world and Turkey. *Journal of Agriculture Faculty HR. University, 8*(3/4), 63-71.

Demiryürek, K., Stopes, C., & Güzel, A. (2008). Organic agriculture: the case of Turkey. *Outlook on Agriculture, 37,* 261-267. http://dx.doi.org/10.5367/000000008787167754

Delate, K., Cambardella, C., Chase, C., & Turnbull, R. (2015). A review of long-term organic comparison trials in the U.S. *Sustainable Agriculture Research, 4*(3), 5-14. http://dx.doi.org/10.5539/sar.v4n3p5

Dent, J. B., Harrison, S. R., & Woodford, K. B. (1986). *Farm Planning with Linear Programming*. Sydney: Butterworths.

Drinkwater, L. E., Letourneau, D. K., Workneh, F., van Bruggen, A. H. C., & Shennan, C. (1995). Fundamental differences between conventional and organic tomato agroecosystems in California. *Ecological Applications, 5,* 1098-1112. https://doi.org/10.2307/2269357

Fukuoka, M. (1978). *The one-straw revolution.* Emmaus: Rodale Press.

General Directorate of Highways of Turkey. (2014). *Chart of the distance between the cities*. Retrieved December 11, 2014, from http://www.kgm.gov.tr/Sayfalar/KGM/SiteEng/Root/Distances.aspx

Görgülü, M. (2002). *Büyük ve Küçükbaş Hayvan Besleme*, Adana: Çukurova Üniversitesi Ziraat Fakültesi Ofset Atölyesi.

Gündoğmuş. E. (2006). Energy use on organic farming: a comparative analysis on organic versus conventional apricot production on small holdings in Turkey. *Energy Conversation and Management, 47,* 3351-3359. https://doi. org/10.1016/j.enconman.2006.01.001

Horrigan, L., Lawrence, R. S., & Walker, P. (2002). How sustainable agriculture can address the environmental and human health harms of industrial agriculture. *Environmental Health Perspectives, 110,* 445-456. https://doi. org/10.1289/ehp.02110445

Intergovernmental Panel on Climate Change. (2013). *Summary for Policymakers. In: Climate Change 2013: The Physical Science Basis*. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T. F., D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P. M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Retrieved September 1, 2016 from http://www.climatechange2013.org/ images/report/WG1AR5_Summary Volume_FINAL.pdf.

International Federation of Organic Agriculture Movements. (2008). *Definition of organic agriculture*. Retrieved, June 12, 2009, from http: //www.ifoam.org/growing_organic/definitions/doa/index.html.

International Federation of Organic Agriculture Movements. (2009). *Criticisms and frequent misconceptions about organic agriculture: the counter-arguments*. Retrieved, March 7, 2011, from http://www.ifoam.org/growing_organic/1_arguments_for_oa/criticisms_misconceptions/misconceptions_index.html.

Jacobson, M. Z., Delucchi, M. A., Bauer, Z. A. F., Goodman, S. C., Chapman, W. E., Cameron, M. C., …Yachanin, A. S. (2017). 100% clean and renewable wind, water, sunlight (WWS) all-sector energy roadmaps for 139 countries of the world. *Joule, 1,* 1-14. http://dx.doi.org/10.1016/j.joule.2017.07.005

Jentsch, A., & Beierkuhnlein, C. (2008). Research frontiers in climate change: effects of extreme meteorological events on ecosystems. C. R. *Geoscience, 340,* 621-628. https://doi.org/10.1016/j.crte.2008.07.002

Kafatos, A., Verhagen, H., Moschandreas, J., Apostolaki, I., & Van Westerop, J. J. M. (2000). Mediterranean diet of Crete: foods and nutrient content. *Journal of the American Dietetic Association, 100,* 1487-1493. https://doi. org/10.1016/S0002-8223(00)00416-8

Kenanoğlu, Z., & Karahan, Ö. (2002). Policy implementations for organic agriculture in Turkey. *British Food Journal, 104,* 300-318. https://doi.org/10.1108/00070700210425732

Kennedy, C. M., Hawthorne, P. L., Miteva, D. A., Baumgarten, L., Sochi, K., Matsumoto, M., …, Kiesecker, J. (2016). Optimizing land use decision-making to sustain Brazilian agricultural profits, biodiversity and ecosystem services. *Biological Conservation, 204,* 221-230. https://doi.org/10.1016/j.biocon.2016.10.039

Kerselaers, E., De Cock, L., Lauwers, L., & Van Huylenbroeck, G. (2007). Modelling farm-level economic potential for conversion to organic farming. *Agricultural Systems, 94,* 671-682. https://doi.org/10.1016/j.agsy.2007.02. 007

Keyder, Ç., & Yenal, Z. (2011). Agrarian change under globalization: markets and insecurity in Turkish agriculture. *Journal of Agrarian Change, 11,* 60-86. https://doi.org/10.1111/j.1471-0366.2010.00294.x

Kniss, A. R., Savage, S. D., & Jabbour, R. (2016). Commercial crop yields reveal strengths and weaknesses for organic agriculture in the United States. *PloS one, 11*(8), 1-16. https://doi.org/10.1371/journal.pone.0161673

Lampkin, N. (Ed.). (1997). *Organic Poultry Production*. Aberystwyth: University of Wales Welsh Institute of Rural Studies.

Lansink, A. O., Pietola, K., & Bäckman, S. (2002). Efficiency and productivity of conventional and organic farms in Finland. *European Review of Agricultural Economics, 29,* 51-65. https://doi.org/10.1093/erae/29.1.51

Lappe, F. M., & Collins, J. (1986). *World hunger: twelve myths.* New York: Groove Press.

Le-Si, V., Scandizzo, P. L., & Kasnakoğlu, H. (1983). Turkey agricultural sector model *(AGREP Division working paper, no:AGP0067, Washington, DC: World Bank).* Retrieved from http://documents.worldbank.org/curated/en /630071468172441778/Turkey-agricultural-sector-model

Lehner, M. (2009). *Hindrances local organic farmers are facing in the Turkish organic agricultural sector - an attempt to identify barriers and suggest ways to eliminate them* (Master's thesis, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden). Retrieved from http://stud.epsilon.slu.se/666/

Lichtenstein, A. H., Appel, L. J., Brands, M., Carnethon, M., Daniels, S., Franch, H. A., … Wylie-Rosett, J. (2006). Diet and lifestyle recommendations revision 2006: a scientific statement from the American heart association nutrition committee. *Circulation, 114,* 82-96. https://doi.org/10.1161/CIRCULATIONAHA.106.176158

Liebig, M. A., & Doran, J. W. (1999). Impact of organic production practices on soil quality indicators. *Journal of Environmental Quality, 28*, 1601-1609. https://doi.org/10.2134/jeq1999.00472425002800050026x

Lotter, D.W., Seidel, R., & Liebhardt, W. (2003). The performance of organic and conventional cropping systems in an extreme climate year. *American Journal of Alternative Agriculture, 18,* 146-154. https://doi.org/10.1079/ AJAA200345

Meat & Milk Board. (2015). *Yerli Sığır Irkları.* http://www.esk.gov.tr/tr/11004/Yerli-Sigir-Irklari Accessed 17 March 2015.

Ministry of Food, Agriculture and Livestock. (2017). *Büyükbaş Hayvancılık (Sığırcılık).* Earlier version retrieved August 21, 2015, from http://www.tarim.gov.tr/HAYGEM/Belgeler/Hayvancılık/Büyükbaş%20Hayvancılık/2017%20Yılı/Büyükbaş%20Hayvan%20Yetiştiriciliği.pdf.

Morison, J., Hine, R., & Pretty, J. (2005). Survey and analysis of labor on organic farms in the UK and Republic of Ireland. *International Journal of Agricultural Sustainability, 3,* 24-43. http://dx.doi.org/10.1080/14735903. 2005.9684742

Moss, C. B. (2002). Applied optimization in agriculture. In P. M. Pardalos & M. G. C. Resende (Eds.), *Handbook of applied optimization* (pp. 957-966), New York, NY: Oxford University Press.

Muller, A., Schader, C., El-Hage Scialabba, N., Hecht, J., Isensee, A., Erb, K.-H., … Niggli, U. (2017). Strategies for feeding the world more sustainably with organic agriculture, *Nature Communications, 8*(1290), 1-13. https://doi.org/10.1038/s41467-017-01410-w

Official Gazette of the Republic of Turkey. (2004). *Yerli Hayvan Irk ve Hatlarının Tescili Hakkında Tebliğ*. No: 004/39-25668, Date: 12.12.2004, Ankara. Retrieved March 5, 2015, from http://www.resmigazete.gov.tr/eskiler /2004/12/20041203.htm

Özbilge, Z. (2007). An analysis of organic agriculture in Turkey: the current situation and basic constraints. *Journal of Central European Agriculture, 8,* 213-222. http://dx.doi.org/10.5513/jcea.v8i2.454

Özen, N., Şayan, Y., Ak, İ., Yurtman, İ. Y., & Polat, M. (2010, January). *Hayvansal üretim-çevre ilişkileri ve organik hayvancılık.* Paper presented at the Seventh Turkey Agricultural Engineering Technical Congress, Ankara. Paper retrieved from http://www.zmo.org.tr/resimler/ekler/e98410c45ea98ad_ek.pdf

Pacini, C., Wossink, A., Giesen, G., & Huirne, R (2004). Ecological-economic modeling to support multi-objective policy making: a farming systems approach implemented for Tuscany. *Agriculture, Ecosystems and Environment, 102,* 349-364. https://doi.org/10.1016/j.agee.2003.08.010

Pesta, D. H., & Samuel, V. T. (2014). A high-protein diet for reducing body fat: mechanisms and possible caveats. *Nutrition & Metabolism, 11,* 53. https://doi.org/10.1186/1743-7075-11-53

Reganold, J. P., & Wachter, J. M. (2016). Organic agriculture in the twenty-first century*, Nature Plants, 2,* 1-8. https://doi.org/10.1038/nplants.2015.221

Rembiałkowska, E. (2007). Quality of plant products from organic agriculture. *Journal of the Science of Food and Agriculture, 87,* 2757-2762. https://doi.org/10.1002/jsfa.3000

Rosenzweig, C., Iglesius, A., Yang, X. B., Epstein, P. R., & Chivian, E. (2001). Climate change and extreme weather events - Implications for food production, plant diseases, and pests. *Global Change & Human Health, 2,* 90-104. http://dx.doi.org/10.1023/A:1015086831467

Seufert, V., Ramankutty, N., & Foley, J.A. (2012). Comparing the yields of organic and conventional agriculture. *Nature, 485,* 229-232. https://doi.org/10.1038/nature11069

Sherali, H. D., & Sosyter, A. L. (1983). Preemptive and nonpreemptive multi-objective programming: relationships and counterexamples. *Journal of Optimization Theory and Applications, 39*(2), 173-186. https://doi.org/10. 1007/bf00934527

Stenmarck, Å., Jensen, C., Quested, T., & Moates, G. (2016). *Estimates of European food waste levels* [Report]. Retrieved from https://www.eu-fusions.org/phocadownload/Publications/Estimates%20of%20European%20food%20waste%20levels.pdf

Stolze, M., Piorr, A., Häring, A. M., & Dabbert, S. (2000). *Environmental impacts of organic farming in Europe*. Karlsbad-Ittersbach: Hago Druck & Medien.

Turkish Statistical Institute (2014a) *Population of provinces by years.* Retrieved from http://www.turkstat.gov.tr

Turkish Statistical Institute (2014b) *Agricultural land by provinces.* Retrieved from http://www.turkstat.gov.tr

Uğur, F. (2004). *Sığır Yetiştirme*. Çanakkale: Çanakkale Onsekiz Mart Üniversitesi Yayınları.

Voisin, A. (1959). *Grass Productivity*. Washington DC: Island Press.

Willer, H., & Lernoud, J. (2014). *The World of Organic Agriculture - Statistics and Emerging Trends 2014.* FiBL-IFOAM Report. Rheinbreitbach: Medienhaus Plump.

Williams, H.P. (1990). *Model Building in Mathematical Programming.* Chichester: John Wiley & Sons.

Younie, D. (2001). *Organic and Conventional Beef Production - a European Perspective*, Paper presented at 22nd Western Nutrition Conference, University of Saskatchewan, Saskatoon, Canada.

Zollitsch, W., & Baumung, R. (2004). Protein supply for organic poultry: options and shortcomings. In M. Hovi, A. Sundrum and S. Padel (Eds.), *Organic livestock farming: potential and limitations of husbandry practice to secure animal health and welfare and food quality*: Proceedings of the 2nd SAFO Workshop (pp.153-159). Witzenhausen, Germany: The University of Reading.

## Notes

Note 1. In 2008, IFOAM adopted the following definition: "Organic Agriculture is a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved."

Note 2. Report of the General Directorate of Plant Production - Ministry of Food, Agriculture and Livestock available at: http://www.tarim.gov.tr/sgb/Belgeler/SagMenuVeriler/BUGEM.pdf

Note 3. National Heart Lung and Blood Institute: http://www.nhlbi.nih.gov/health/educational/wecan/healthy-weight-basics/balance.htm

Note 4. https://biruni.tuik.gov.tr/bitkiselapp/bitkisel.zul

Note 5. There are 24 domestic sheep and five domestic goat breeds in Turkey, for more information, see http://www.tarim.gov.tr/Konular/Hayvancilik/Kucukbas-Hayvancilik/Koyun-Yetistiriciligi and http://www.tarim.gov .tr/Konular/Hayvancilik/Kucukbas-Hayvancilik/Keci-Yetistiriciligi

Note 6. In conventional agriculture, annual egg yield of a chicken is 315±10.

Note 7. Whatever the meadow conditions, the cow was observed to graze no more than 8 hours a day.

Note 8. Hay crops are forages used for hay making.

Note 9. 1207 kg dry alfalfa is equivalent to 6036 kg fresh alfalfa because when fresh forage is dried it loses about 80% of its weight.

Note 10. In the case of multiple goals, the approach adopted is goal programming. Goals are expressed as constraints; the deviations from the goals are then minimized. In our problem, we have objectives rather than goals and for that reason we use multi-objective programming and not goal programming.

Note 11. A shortage penalty of 100 instead of 1000 caused shortages in certain products and cities. If shortage occurs with the first penalty used, we advise the researcher to persist trying out several penalties until an appropriate one is found. Sometimes, the reason we have shortage is not because shortage is inevitable but because the optimization program found it cheaper to have shortages instead of transporting food between cities. Trying a larger shortage penalty will solve this problem.

**Appendix: List of Products and their Classifications used in the Model**

A lot of data went into the model. Population sizes of cities; distances between cities; the amount that an individual consumes of each food item; crop yields in every city under organic farming; amount of arable land, meadows and pastures in every city; the list of different animal species traditionally bred in the country; and the product yields of these animals together with their localities. To give an idea of data requirements, we provide the lists of crops for human consumption and the list of feed and forage crops, below in table format.

Tables are according to a specific classification of crops into grains, legumes, vegetables, greens and salad ingredients, fruits, nuts and olives that we used in devising a healthy menu for humans. Because only cow milk, beef, eggs and chicken meat are used as animal products in the model we did not make a separate table for those.

Table A1. Grains

| | | | | | | |
|---|---|---|---|---|---|---|
| Barley | Corn | Oat | Rice | Rye | Wheat | Wheat-durum |

Table A2. Legumes

| | | | | | | |
|---|---|---|---|---|---|---|
| Beans-Dried | Chickpea | Cowpea | Fava beans-dried | Lentil - green | Lentil - red | Soy |

Table A3. Olives

| | |
|---|---|
| Olive-for oil | Olive-to eat |

Table A4. Nuts

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Almond | Chestnut | Hazelnut | Peanut | Pistachio | Pumpkin-kernel | Sesame | Sunflower seeds | Walnut |

Table A5. Vegetables

| | | | | |
|---|---|---|---|---|
| Artichoke | Carrot | Garlic | Okra | Potato |
| Beans-Fresh | Cauliflower | Green beans | Onion | Pumpkin |
| Beet | Celery | Kidney bean | Pea-Fresh | Spinach |
| Broccoli | Chard | Leaf cabbage | Pepper-for paste | Tomato-for paste |
| Brussel sprouts | Cowpea-Fresh | Leek | Pepper-to stuff | Zucchini |
| Cabbage | Eggplant | | | |

Table A6. Greens and salad ingredients

| | | | | | |
|---|---|---|---|---|---|
| Arugula | Cucumber-for pickling | Green onion | Mint | Purslane | Romaine lettuce |
| Cress | Dill | Horseradish | parsley | Radish-red | Thyme |
| Cucumber | Garlic-fresh | Lettuce | Pepper-thin | Red cabbage | Tomato |

Table A7. Fruits

| | | | | | |
|---|---|---|---|---|---|
| Apple-Amasya | Banana | Grape-no seed | Kiwi | Nectarine | Pomegranate |
| Apple-Golden | Blackberry | Grape-no seed to dry | Lemon | Orange-Other | Quince |
| Apple-Grannysmith | Cherry | Grape-wine | Loquat | Orange-Washington | Raspberry |
| Apple-other | Cherry | Grape-with seed | Mandarin-Satsuma | Peach | Strawberry |
| Apple-Starking | Fig | Grape-with seed to dry | Melon | Pear | Tangerine-other |
| Apricot | Grapefruit | Japanese Persimmon | Mulberry | Plum | Watermelon |

Table A8. Feed crops and forages

| | | | |
|---|---|---|---|
| Barley-CowFeed | Corn-Silage | Common vetch-forage | Trifolium-forage |
| Beans-CowFeed | Soy-CowFeed | Lathyrus-forage | Triticale-forage |
| Common vetch-grain | Soy-feed eggchicken | Oat-forage | Vetch-forage |
| Corn-CowFeed | Soy-feed meatchicken | Rye-forage | Wheat-forage |
| Corn-feed eggchicken | Alfalfa-forage | Sainfoin-forage | |
| Corn-feed meatchicken | Barley-forage | Sorghum-forage | |

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# Effect of Pot Volume on the Growth of Sweetpotato Cultivated in the New Hydroponic System

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**Abstract**

Hydroponics is an effective means for promoting plant growth as it facilitates water and nutrient uptake by plant roots. For increasing the production of sweetpotato (*Ipomoea batatas*), we developed the new hydroponic cultivation system in which tuberous roots were grown in solid media in the pots whereas fibrous roots were grown in the nutrient solution. Using this method, the effect of pot volume (1.6, 3.0, and 4.5 L) on the growth of sweetpotato was investigated. When plants were grown in small-sized pots (1.6 L), the fresh weight of the top and that of tuberous roots were decreased compared with plants grown in 3.0 L and 4.5 L pots. No clear difference was observed between the top and the tuberous roots in terms of the dry weight ratio, regardless of the pot size. The number of tuberous roots per plant and the maximum tuberous root weight were not influenced by the pot size either. However, the number of tuberous roots weighing more than 100 g was decreased in plants grown in small pots. Some of the tuberous roots grown in this hydroponic system contained a non-hypertrophic parts with severely lignified metaxylems. These results suggest that the environment surrounding the tuberous root influenced by the pot volume may be important for root enlargement in this hydroponic system.

**Keywords:** sweetpotato, hydroponics, pot size, tuberous roots, pencil roots

## 1. Introduction

Sweetpotato (*Ipomoea batatas*) is cultivated in temperate and tropical climates and has the ability to fix a relatively large amount of solar energy even when grown in poor nutrient condition (Pimentel et al., 2002). In recent years, sweetpotato has become a potential resource for the production of cost-effective biofuels because of its ability to efficiently convert solar energy into sugar (Koçar & Civaş, 2013). Root crops, such as sweetpotato and cassava have been proposed as substitutes for corn-based ethanol production considering their high ratio of output (bioethanol produced from such crops) to input (estimates of fertilizer, water, and pesticide) (Ziska et al., 2009). Several studies have been reported to have developed efficient biofuel extraction methods from sweetpotatoes and their residues in the form of hydrogen, ethanol, and methane (Chu et al., 2012; Lay et al., 2012; Kobayashi et al., 2014; Wang F. et al., 2016).

In temperate areas of Japan, edible and industrial sweetpotatoes are widely cultivated. In addition, demand for sweetpotato as a biofuel resource may be increased in the future for the production of substitute energy sources, such as nuclear power. However, the number of workers in the agriculture sector is steadily declining in Japan because of their increasing age. Therefore, it is necessary to develop the cost-effective methods for efficient cultivation of sweetpotato.

Hydroponics is a cultivation method that uses mineral nutrient solutions in a water solvent, instead of solid medium (soil) and fertilizer. In this method, plant roots are either directly exposed to the mineral nutrient solution or indirectly supported by highly absorbent material, such as vermiculite, perlite, and rock wool that easily absorb the nutrient solution. Hydroponic cultivation systems often provide rapid growth of plants by efficiently feeding nutrients to the roots, as the rhizospheres are constantly surrounded by nutrient-dense water essential for plant growth. Although the practical use of hydroponics is restricted mainly to leafy vegetables and some fruit crops, studies have been conducted to establish the use of hydroponic systems for root vegetables. Previous studies have demonstrated that the degree of immersion of carrots (*Daucus carota*) roots in nutrient solutions affects the tap root development regardless of the hydroponic systems used (Terabayashi et al., 2008; Kusakawa & Inoue, 2010; Eguchi et al., 2011). Experiments have also been conducted to investigate the tuberous root characteristics of sweetpotato when grown in a hydroponic systems (Eguchi et al., 1996; Kitaya et al., 2008). The hydroponic method that cultivates tuberous roots in air and fibrous roots in nutrient solution revealed that humidity is an important factor for the development of tuberous roots (Eguchi et al., 1998). Although this study enabled the sequential observations of tuberous root growth, its practical application might be obscure as it only used plants in which the tuberous roots had already differentiated, and these plants were cultivated only for 4 days in the hydroponic system (Eguchi et al., 1998). Sweetpotato has also been cultivated from stem cuttings using rock wool slab-based hydroponic method (Kitaya et al., 2008). However, this system was complex and expensive that designed to utilize for space farming. These results recommended the development of new cost-effective hydroponic systems. Here, we constructed a cost-effective hydroponics system for sweetpotato cultivation. Using this hydroponic system, we investigated the effect of pot volume on the growth of sweetpotato.

## 2. Method

### *2.1 Plant Materials and Cultivation Methods*

Sweetpotato (*Ipomoea batatas*) cultivar “Narutokintoki” was used in our study. The experimental hydroponics system was constructed based on passive hydroponics (Figure 1). Black vinyl pots filled with vermiculite were placed on corrugated plastic boards. To bring the vermiculite in direct contact with the water absorption sheet placed on the plastic boards, holes were made in the bottom of the pots. The ends of the water absorption sheet were soaked in nutrient solution, which enabled the transport of nutrients to the vermiculite by capillary action. Vermiculite was kept saturated with nutrient solution throughout the cultivation period. Culture containers (59 × 39 × 18 cm) were set under the plastic boards and filled with nutrient solution with a half-strength culture solution of OAT House recipe A (Sakamoto & Suzuki, 2015a, 2015b; Sakamoto et al., 2016). Reduction in the level of nutrient solution due to plant uptake or water evaporation was compensated for by the addition of water. Nutrient solution was exchanged every 2 weeks. Pot surface was sealed with silver insulation sheets to avoid excess water evaporation and pest contamination. Plastic boards and culture containers were also covered with these insulation sheets to enable maximum utility of sunlight for photosynthesis by reflection. Two separate experiments were conducted over two years (2015 and 2016) using different sized pots. Experiment 1 used 3.0 L pots (14.0 cm lower diameter × 15.5 cm height), whereas experiment 2 used three different sized pots: 1.6 L (10.3 cm × 12.5 cm), 3.0 L (14.0 cm × 15.5 cm), and 4.5 L (15.0 cm × 21.0 cm).

In experiment 1, stem cuttings of sweetpotato were planted in vermiculite-filled vinyl pots and grown for 14 days. Pots were then transferred to the hydroponic system (1 pot per cultivation container) and cultured for 76 days from June 16 to August 31 in 2015 on the experimental field of Kindai University (Faculty of Biology-Oriented Science Technology, Wakayama, Japan). In experiment 2, the stem cuttings planted in vermiculite-filled vinyl pots and were grown for 10 days using the same growth conditions as those used for experiment 1. Pots were then transferred to the hydroponic system (4 pots per cultivation container) and cultured for 159 days from May 7 to October 13 in 2016 in the experimental field of Kindai University.

The top, tuberous roots, and fibrous roots of each plant were dried in an oven for more than 7 days at 80°C, and the dry weight were measured. In experiment 2, the average dry weight of 8 plants was calculated, except for those of fibrous roots. Because fibrous roots were intertwined with the absorption sheet and the cultivation container, total weight of the roots was measured and weight per plant was calculated.

### *2.2 Lignin Staining*

Microscopic analysis of lignin was conducted as previously described (Zhong et al., 2000). Enlarged tuberous roots and pencil-type roots were sectioned free hand using a razor blade or a cutter knife. Sections were stained with 1% phloroglucinol-HCl solution for 5 min and observed under stereo- and light microscope.

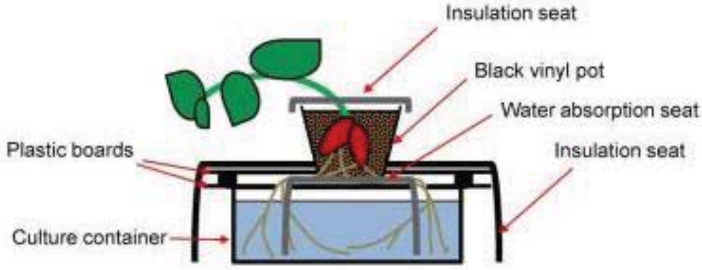


Figure 1. Hydroponic system used for the cultivation of sweetpotato in experiments 1 and 2

### 3. Results and Discussion

We developed the new hydroponic system for the cultivation of sweetpotato (Figure 1). The first experiment (experiment 1) was conducted for preliminary examination to check whether this hydroponic system ensures the formation of tuberous roots of sweetpotato. After 90 days from the plantation of sweetpotato cuttings in this system, fibrous roots extended through the water absorption sheet into the cultivation container (Figure 2A). Enlarged tuberous roots of sweetpotato developed in the pots filled with vermiculite; tuberous roots were never observed in the water absorption sheets or the cultivation container. These data coincides with the previous report wherein complete immersion of the root system in the nutrient solution restricted the formation of tuberous roots in sweetpotato (Eguchi & Yoshida, 2004). Tuberous roots were formed in all four plants cultivated in this system (Figure 2B). Fresh weights of top and tuberous roots per plant were 143.0 ± 18.0 g (mean ± SE) and 294.5 ± 46.1 g, respectively, whereas the corresponding dry weights were 23.7 ± 3.7 g and 74.8 ± 0.9 g, respectively. The average number of tuberous roots per plant was 3.75 ± 0.48. Although the duration of the hydroponic cultivation in this experiment (90 days post plantation of sweetpotato cuttings) was shorter than that of field cultivation in Japan (120–160 days post plantation), several thickened tuberous roots were obtained in all plants. To harvest larger tuberous roots, we extended the cultivation period to 159 days in the second experiment.


Figure 2. Sweetpotato fibrous and tuberous roots 90 days after plantation in experiment 1. (A) Fibrous roots extended in the cultivation container. (B) Tuberous roots harvested from four plants

In experiment 2, we examined the effect of pot size (1.6, 3.0, and 4.5 L) on the growth of sweetpotato in order to determine the minimum amount of vermiculite required for tuberous root enlargement. After 159 days, all plants in each pot formed some tuberous roots (Figure 3). The average biomass of tuberous roots was lower in plants grown in 1.6 L pots compared with plants grown in 3.0 L and 4.5 L pots (Figures 4A and 5A). Average fresh weights of plants grown in 1.6 L, 3.0 L, and 4.5 L pots were 668.2 g, 923.9 g, and 892.2 g, respectively. Top fresh weight was also reduced in plants grown in 1.6 L pot (Figure 4B). In contrast, the fresh weight of fibrous roots was decreased with an increase in pot size (Figure 4C). Total plant biomass, represented by the sum of dry weights of top, tuberous roots, and fibrous roots, was lower in plants grown in 1.6 L pots than in those grown in 3.0 and 4.5 L pots (Figure 5A). The ratio between the dry weights of the top and the tuberous roots did not differ between plants grown in pots of different size (Figure 5B). These data suggest that pots with a volume of 3.0 L or higher are necessary to obtain sufficient tuberous root yield using this hydroponic system under similar experimental conditions. In a previous report, the tuberous roots of sweetpotato became smaller when young seedlings were cultivated in a small plastic case. (Adachi et al., 2016). This suggests that tuberous roots of plants grown in small pots in our study may undergo greater physical pressure than those of plants grown in larger pots, thus resulting in limited enlargement of tuberous roots in small pots.

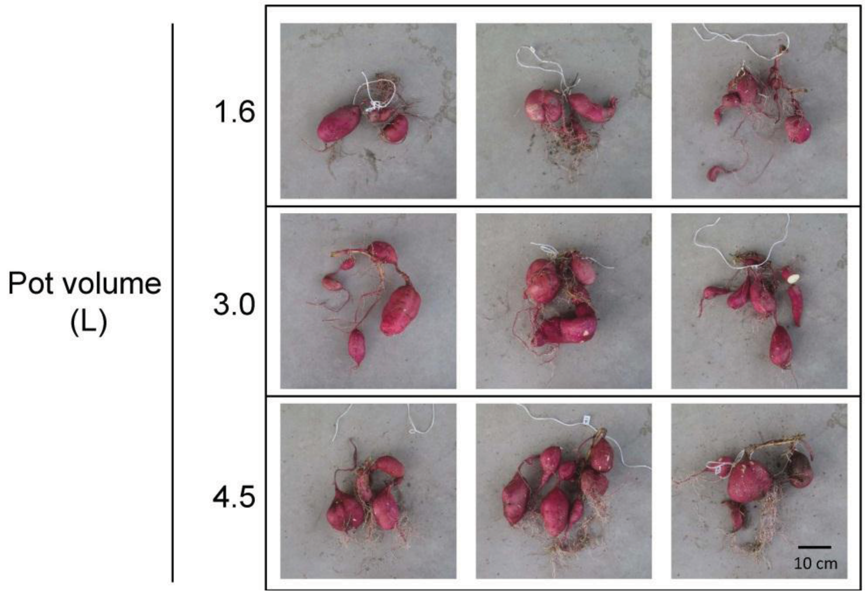


Figure 3. The effect of pot volume on tuberous root growth of sweetpotato plants 159 days after plantation in experiment 2

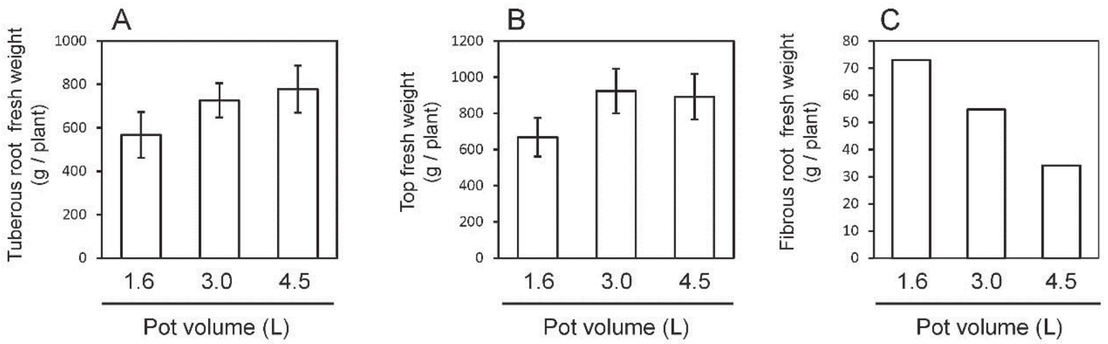


Figure 4. The effect of pot volume on the fresh weight of tuberous roots (A), top (B), and fibrous roots (C) of sweetpotato plants 159 days after plantation in experiment 2. Vertical bars represent mean ± SE ($n$ = 8)

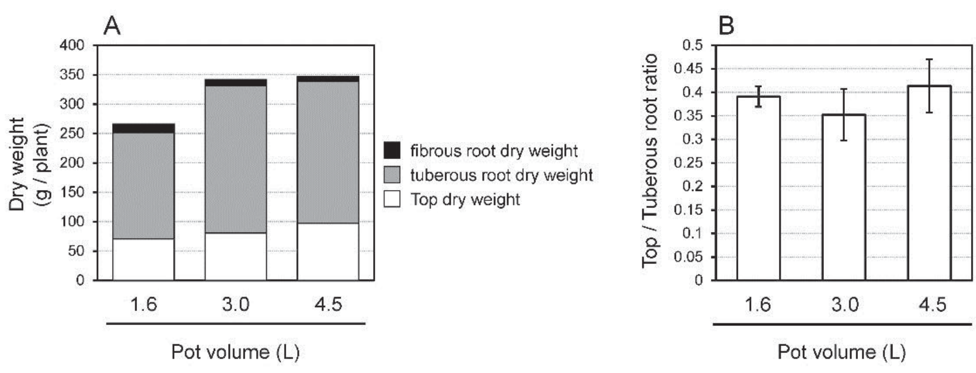


Figure 5. The effect of pot volume on dry weight (A) and top/tuberous root ratio (B) of sweetpotato plants 159 days after plantation in experiment 2. Vertical bars represent mean ± SE ($n$ = 8)

Although the number of tuberous roots per plant and the maximum tuberous root weight were not affected by the pot volume, the number of tuberous roots weighing over 100 g were lower in 1.6 L pots than in larger pots (Figure 6). These data imply that some tuberous roots may have suppressed the enlargement of other tuberous roots in 1.6 L pots. Tuberous root enlargement depends on the environment including the soil (Eguchi et al., 1998, 2003). Using a laser micrometer system, the tuber volume was observed to increase during the night, and the tuber volume was influenced by ambient humidity (Eguchi et al., 1998). In our study, deformities in vinyl pots were observed as the tuberous root volume increased at later stages of growth, even in 3.0 L pots (Figure 7B). Given that root zone temperature at day and night also influences tuberous root enlargement (Eguchi et al., 2003), extreme deformities in 1.6 L pots might have modified the soil environmental condition including temperature and humidity surrounding the tuberous roots, resulting in limited enlargement of tuberous roots.

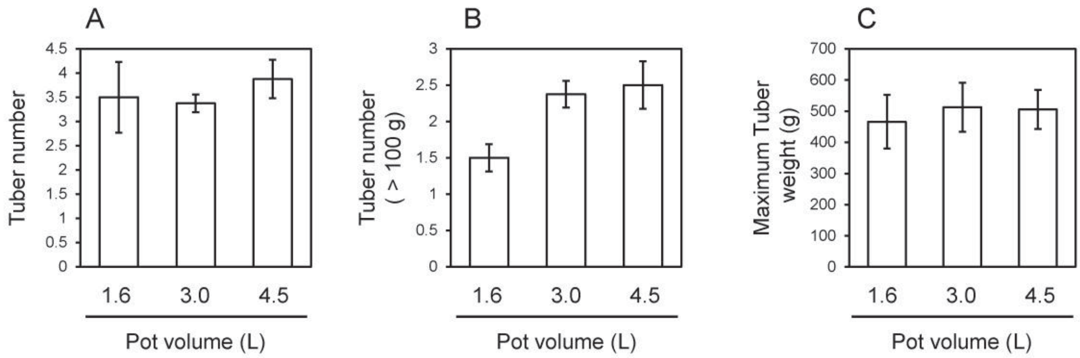


Figure 6. The effect of pot volume on the total number of tuberous roots (A), number of tuberous roots over 100 g (B), and maximum tuberous root weight (C) of sweetpotato plants 159 days after plantation in experiment 2. Vertical bars represent mean ± SE (*n* = 8).

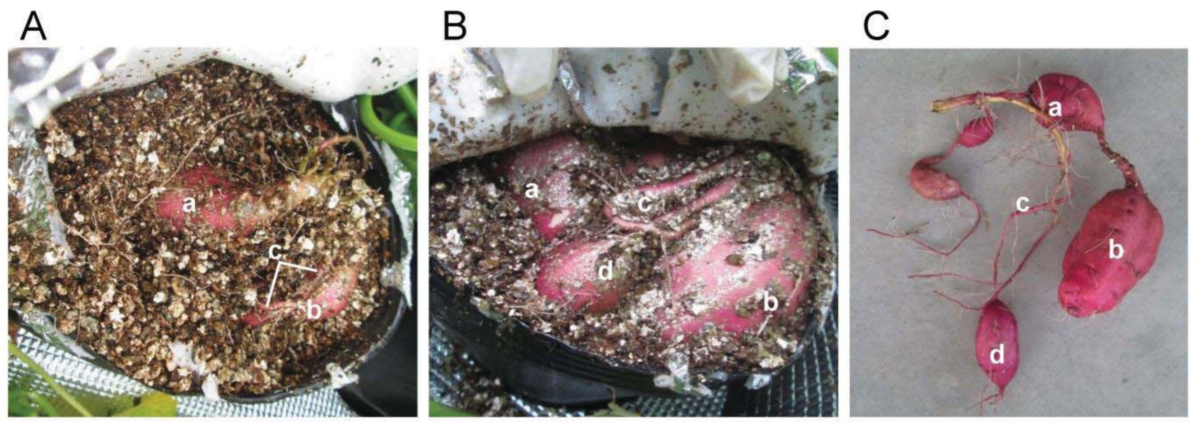


Figure 7. Temporal changes in tuberous roots of sweetpotato plants grown in 3.0 L pots in experiment 2. Tuberous roots of the same plant at 79 (A), 149 (B), and 159 days (C) after plantation are shown. Same alphabet in pictures represents identical part of tuberous roots at different growth stages.

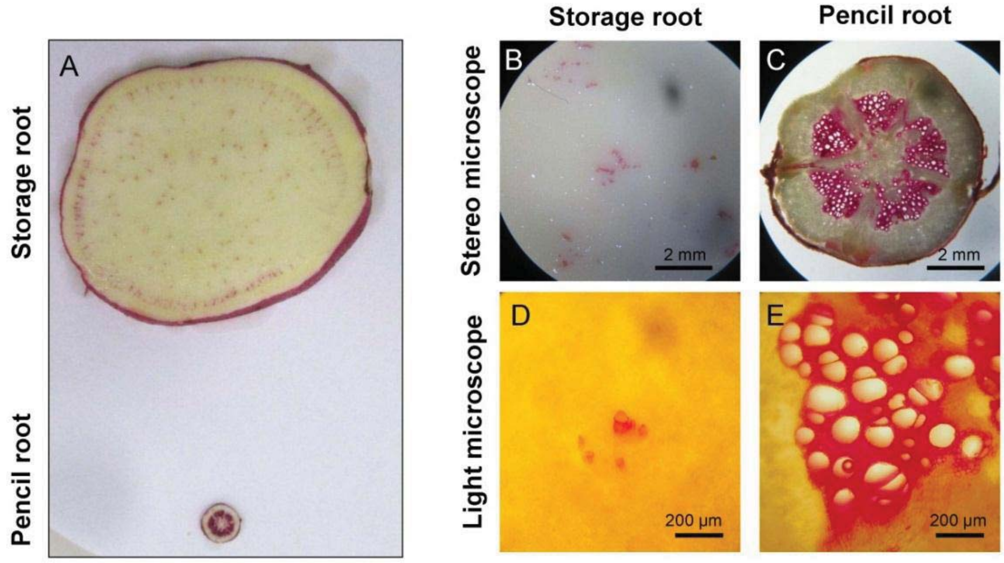


Figure 8. Lignin content in storage and pencil-type roots shown in Figure 7C. Cross-sections of storage and pencil-type roots stained with 1% phloroglucinol-HCl solution (A) observed under stereomicroscope (B, C) and light microscope (D, E).

The growth characteristics of tuberous roots were monitored during hydroponic cultivation by opening the silver insulation sheets covering vermiculite (Figure 7). Enlarged tuberous roots were observed at 79 days post plantation and their sizes were noted to have increased at 146 days post plantation (Figures 7A and 7B). Some parts of tuberous roots showed restricted enlargement known as pencil-type roots (Figure 7C). Pencil-type roots were differentiated at early period (within 26 days from transplanting) of sweetpotato cultivation, accompanied by the expansion of lignified root structures (Villordon et al., 2009). Consistent with this observation, the pencil-type root parts identifiable at 79 days post plantation (Figure 7A) and their volumes had barely increased when observed at 146 days and 159 days post plantation (Figures 7B and 7C). Lignin staining revealed the existence of lignified structures in tuberous roots of enlarged and pencil-type root parts from plants harvested at 159 days (Figure 8A). In enlarged roots, a small collection of lignified cells was observed scattered, which presumably functioned as xylems (Figures 8B and 8D). Pencil-type roots contained large lignified structures known as metaxylems (Figures 8C and 8E). Differentiation of tuberous roots from adventitious roots coincides with an increase in the activity of primary cambium and a decrease in the lignification of stele (Togari, 1950). Consistent with this observation, genes involved in lignin biosynthesis are down-regulated during the initiation of tuberous root development (Firon et al., 2013; Wang et al., 2015). In addition, overexpression of Maize *Lc* gene in transgenic sweetpotato induced the activation of the lignin biosynthetic pathway in the developing roots, leading to pencil-type root differentiation (Wang H. et al., 2016). Given that pencil-type root parts were observed in our study, it is possible that restriction of initial adventitious root elongation due to the small pot size triggered several stresses at the stage of tuberous root development, resulting in the emergence of pencil-type root parts. The vinyl pots may have caused partial contact of the initial roots to the bottom and sides of the pot, which could have made low humidity conditions unsuitable for tuberous root development. As drought stress induces stress-responsive genes and restricts tuberous root development (Ogawa et al., 2006; Gajanayake et al., 2013; Solis et al., 2014), the initial roots contacted with vinyl pots may undergo drought-like stress. Genes encoding antioxidant enzymes, which are often activated during drought stress, are upregulated in pencil-type roots compared with tuberous roots (Kim et al., 2015). As observed in previous hydroponic studies on sweetpotato (Kitaya et al., 2008), transplanting sweetpotato seedlings containing already developed tuberous roots might restrict the formation of pencil-type roots.

In root and tuber crops, hormone-signaling networks control root architecture (Villordon et al., 2014). In sweetpotato, endogenous levels of cytokinin and auxin rapidly increase in the roots during tuberous root development (Nakatani & Komeichi, 1991). Exogenous application of cytokinin also activates tuberous root formation (McDavid & Alamu, 1980; Eguchi & Yoshida, 2008). Given that *SRD1*, a gene which activates the development of storage roots, is highly induced by exogenous auxin treatment (Noh et al., 2010), manipulations of root hormonal levels using pharmacological treatments or environmental regulation may be employed to increase the tuberous root yield. Our hydroponic system may be effective to control root hormonal levels as the tuberous roots were grown in the small pots.

## 4. Conclusions

Although several studies have demonstrated hydroponic cultivation of sweetpotato with or without absorbent materials (Eguchi et al., 1996; Kitaya et al., 2008), these studies used young sweetpotato plants, which had already acquired the ability to develop tuberous roots. In contrast, in our study, stem cuttings were directly transplanted to the pots, thus saving the cost of labor required to prepare plants with differentiated tuberous roots from stems. In addition, our system saves absorbent materials (soil) and can be used at any place that is exposed to sunlight. Therefore, our hydroponic system may be capable of lowering the cost of labor and resources needed for mass production of sweetpotato.

## References

Adachi, K., Omine, M., Sugimoto, M., Ishii, T., Niimi, H., Suzuki, T., Kamebayashi, M., Takada, M., Gotoh, A., and Yokoyama, K. (2016). Yield-enhancing and tuber-downsizing effects of transplantation cultivation method of case-held tuber seedlings in the sweet potato cultivar Beniharuka. *Plant Production Science, 19*, 125-131. https://doi.org/10.1080/1343943X.2015.1128086

Chu, C. Y., Sen, B., Lay, C. H., Lin, Y. C., & Lin, C. Y. (2012). Direct fermentation of sweet potato to produce maximal hydrogen and ethanol. *Applied Energy, 100*, 10-18. https://doi.org/10.1016/j.apenergy.2012.06.023

Eguchi, T., Kitano, M., & Eguchi, H. (1996). New system of hydroponics for growth analysis of sweet potato tuber. *Biotronics, 25*, 85-88.

Eguchi, T., Kitano, M., & Eguchi, H. (1998). Growth of sweetpotato tuber as affected by the ambient humidity. *Biotronics: Reports of Biotron Institute, Kyushu University, 27*, 93-96.

Eguchi, T., Kitano, M., Yoshida, S., & Chikushi, J. (2003). Root temperature effects on tuberous root growth of sweetpotato (*Ipomoea batatas* Lam.). *Environment Control in Biology, 41*(1), 43-49. https://doi.org/10.2525/ecb1963.41.43

Eguchi, T., & Yoshida, S. (2004). A cultivation method to ensure tuberous root formation in sweetpotatoes (*Ipomoea batatas* (L.) Lam.). *Environment Control in Biology, 42*(4), 259-66. https://doi.org/10.2525/ecb1963.42.259

Eguchi, T., & Yoshida, S. (2008). Effects of application of sucrose and cytokinin to roots on the formation of tuberous roots in sweetpotato (*Ipomoea batatas* (L.) Lam.). *Plant Root, 2*, 7-13. https://doi.org/10.3117/plantroot.2.7

Eguchi, T., Suzuki, T., Yoshida, S., Miyajima, I., & Kitano, M. (2011). Time-course pattern of carrot storage root growth in a solid substrate, sub-irrigation culture system. *Environmental Control in Biology, 49*(4), 177-183. https://doi.org/10.2525/ecb.49.177

Firon, N., LaBonte, D., Villordon, A., Kfir, Y., Solis, J., Lapis, E., Perlman, T. S., Doron-Faigenboim, A., Hetzroni, A., Althan, L., & Nadir, L. A. (2013). Transcriptional profiling of sweetpotato (*Ipomoea batatas*) roots indicates down-regulation of lignin biosynthesis and up-regulation of starch biosynthesis at an early stage of storage root formation. *BMC Genomics, 14*(1), 460. https://doi.org/10.1186/1471-2164-14-460

Gajanayake, B., Reddy, K. R., Shankle, M. W., & Arancibia, R. A. (2013). Early-season soil moisture deficit reduces sweetpotato storage root initiation and development. *HortScience, 48*(12), 1457-1462.

Kim, Y. H., Park, S. C., Ji, C. Y., Lee, J. J., Jeong, J. C., Lee, H. S., & Kwak, S. S. (2015). Diverse antioxidant enzyme levels in different sweetpotato root types during storage root formation. *Plant Growth Regulation, 75*(1), 155-164. https://doi.org/10.1007/s10725-014-9940-x

Kitaya, Y., Hirai, H., Wei, X., Islam, A. F. M. S., & Yamamoto, M. (2008). Growth of sweetpotato cultured in the newly designed hydroponic system for space farming. *Advances in Space Research, 41*(5), 730-735. https://doi.org/10.1016/j.asr.2007.09.005

Kobayashi, T., Tang, Y., Urakami, T., Morimura, S., & Kida, K. (2014). Digestion performance and microbial community in full-scale methane fermentation of stillage from sweet potato-shochu production. *Journal of Environmental Sciences, 26*(2), 423-431. https://doi.org/10.1016/S1001-0742(13)60423-4

Koçar, G., & Civaş, N. (2013). An overview of biofuels from energy crops: Current status and future prospects.

*Renewable and Sustainable Energy Reviews, 28*, 900-916. https://doi.org/10.1016/j.rser.2013.08.022

Kusakawa, T., & Inoue, M. (2010). Damage to pot-cultured carrot growth due to a temporarily raised groundwater level and flooding period. *Horticultural Research (Japan), 9*(4), 495-500. https://doi.org/10.2503/hrj.9.495

Lay, C. H., Lin, H. C., Sen, B., Chu, C. Y., & Lin, C. Y. (2012). Simultaneous hydrogen and ethanol production from sweet potato via dark fermentation. *Journal of Cleaner Production, 27*, 155-164. https://doi.org/10.1016/j.jclepro.2011.12.027

McDavid, C. R., & Alamu, S. (1980). The effect of growth regulators on tuber initiation and growth in rooted leaves of two sweet potato cultivars. *Annals of Botany, 45*(3), 363-364. https://doi.org/10.1093/oxfordjournals.aob.a085833

Nakatani, M., & Komeichi, M. (1991). Changes in the endogenous level of zeatin riboside, abscisic acid and indole acetic acid during formation and thickening of tuberous roots in sweet potato. *Japanese Journal of Crop Science, 60*(1), 91-100. https://doi.org/10.1626/jcs.60.91

Noh, S. A., Lee, H. S., Huh, E. J., Huh, G. H., Paek, K. H., Shin, J. S., & Bae, J. M. (2010). SRD1 is involved in the auxin-mediated initial thickening growth of storage root by enhancing proliferation of metaxylem and cambium cells in sweetpotato (*Ipomoea batatas*). *Journal of Experimental Botany*, *61*(5), 1337-1349. https://doi.org/10.1093/jxb/erp399

Ogawa, H., Kakehashi, Y., Inoue, M., Tanabe, K., & Otani, H. (2006). Influence that transition of soil moisture exerts on amount and quality of sweet potato in a sandy field. *Tokushima Noken Hou (Japan), 3*, 13-19.

Pimentel, D., Doughty, R., Carothers, C., Lamberson, S., Bora, N., & Lee, K. (2002). Energy inputs in crop production in developing and developed countries. *Food Security and Environmental Quality in the Developing World*, 129-151. https://doi.org/10.1201/9781420032215.ch8

Sakamoto, M., & Suzuki, T. (2015a). Elevated root-zone temperature modulates growth and quality of hydroponically grown carrots. *Agricultural Sciences, 6*(8), 749-757. https://doi.org/10.4236/as.2015.68072

Sakamoto, M., & Suzuki, T. (2015b). Effect of root-zone temperature on growth and quality of hydroponically grown red leaf lettuce (*Lactuca sativa* L. cv. Red Wave). *American Journal of Plant Sciences, 6*(14), 2350-2360. https://doi.org/10.4236/ajps.2015.614238

Sakamoto, M., & Suzuki, T. (2016). Effect of root-zone temperature on the growth and fruit quality of hydroponically grown strawberry plants. *Journal of Agricultural Science, 8*(5), 122-131. https://doi.org/10.5539/jas.v8n5p122

Solis, J., Villordon, A., Baisakh, N., LaBonte, D., & Firon, N. (2014). Effect of drought on storage root development and gene expression profile of sweetpotato under greenhouse and field conditions. *Journal of the American Society for Horticultural Science, 139*(3), 317-324.

Terabayashi, S., Harada, N., & Fujime, Y. (2008). Effects of aeration and root immersion level on the development of carrot [*Daucus carota*] root in hydroponics. *Horticultural Research (Japan), 7*(3), 439-444. https://doi.org/10.2503/hrj.7.439

Togari, Y. (1950). A study on the tuberous-root formation of sweet-potatoes. *Nourinshou Noujishikenjou Houkoku (Bull. Natl. Agric. Expt. Stn. (Tokyo))*, *68*, 1-96.

Villordon A. Q., La Bonte, D. R., Firon, N., Kfir, Y., Pressman, E., & Schwartz, A. (2009). Characterization of adventitious root development in sweetpotato. *HortScinece, 44*, 651-655.

Villordon, A. Q., Ginzberg, I., & Firon, N. (2014). Root architecture and root and tuber crop productivity. *Trends in Plant Science, 19*(7), 419-425. https://doi.org/10.1016/j.tplants.2014.02.002

Wang, Z., Fang, B., Chen, X., Liao, M., Chen, J., Zhang, X., Huang, L., Luo, Z., Yao, Z., & Li, Y. (2015). Temporal patterns of gene expression associated with tuberous root formation and development in sweetpotato (*Ipomoea batatas*). *BMC Plant Biology, 15*(1), 180. https://doi.org/10.1186/s12870-015-0567-5

Wang, F., Jiang, Y., Guo, W., Niu, K., Zhang, R., Hou, S., Wang, M., Yi, Y., Zhu, C., Jia, C., & Fang, X. (2016). An environmentally friendly and productive process for bioethanol production from potato waste. *Biotechnology for Biofuels, 9*, 50. https://doi.org/10.1186/s13068-016-0464-7

Wang, H., Yang, J., Zhang, M., Fan, W., Firon, N., Pattanaik, S., Yuan, L., & Zhang, P. (2016). Altered phenylpropanoid metabolism in the maize *Lc*-expressed sweet potato (*Ipomoea batatas*) affects storage root development. *Scientific Reports, 6*, 18645. https://doi.org/10.1038/srep18645

Zhong, R., Ripperger, A., & Ye, Z. H. (2000). Ectopic deposition of lignin in the pith of stems of two Arabidopsis mutants. *Plant Physiology, 123*(1), 59-70. https://doi.org/10.1104/pp.123.1.59

Ziska, L. H., Runion, G. B., Tomecek, M., Prior, S. A., Torbet, H. A., & Sicher, R. (2009). An evaluation of cassava, sweet potato and field corn as potential carbohydrate sources for bioethanol production in Alabama and Maryland. *Biomass and Bioenergy, 33*(11), 1503-1508. https://doi.org/10.1016/j.biombioe.2009.07.014

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# Food Security and Income through Sweet Potato Production in Teso, Uganda

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**Abstract**

Two relevant studies on food security are referred to in the article. Food insecurity from time to time threatens in Teso sub region which houses a viable Teso agricultural system. One study was done during 2001-2003 in Teso on sweet potato production with 650 persons participating and the second one was done in one disaster affected area of Bududa District nearby during 2012-2016 when 1,142 persons participated. Kiryandongo District where Bududa landslide survivors were resettled in Uganda was included in that study. Participatory methods such as focus group discussions, farm observations, in-depth interviews, and questionnaires were used. Both studies used qualitative and quantitative methods for data analysis. The sweet potato stands second after cassava as the crop for famine and disaster periods in Teso to meet the human right to adequate food to complement the well dried cereals & grain legumes that stored longer. Livestock especially was also one of the prime determinants of food security and income in Teso. Free from cyanides with a good content of affordable Vitamin A from orange fleshed varieties, sweet potatoes in Teso contributed about 61% to the yearly food per capita of the population thus a recommendable crop for sustainable food security and some income in Teso and beyond.

**Keywords:** climate change, disaster, farm productivity, food access, food availability, food security, income, policy, right to adequate food, sweet potatoes

## 1. Introduction

Food security only exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. The human right to adequate food is recognized by all peoples of the world including their governments.

Teso sub-region of Uganda is an area of 12,182 sq. km (about 80% is cultivable) and has a human population of about 2,364,569 (Olupot, 2017) that grows at about 3.2% per annum (UBOS, 2014; Fountain Publishers, 2011). It is located in North-Eastern Uganda consisting of eight districts of Amuria, Bukedea, Kaberamaido, Katakwi, Kumi, Ngora, Serere and Soroti (see them numbered 1-8 in Figure 1). Also in Figure 1, Bududa is numbered as 9 and Kiryandongo as 10. The sub-region houses the Teso agricultural system. The system is typified by the growing of annual crops including the sweet potato; keeping of livestock especially cattle (Osekeny, 1996). All these agricultural activities flourish on fairly good climate; and on four moderately fertile soil catenas of Amuria, Bukedea, Buruli and the Usuk series that give Teso mostly sandy loam soils ideal for the sweet potato & also accommodating some pockets of clay loams. Brady (1974) defined catena as a unit of soils of similar age, parent materials and climatic conditions while a series is a family division of soils that are alike in the main profile characteristics. The Ugandan soils and climate, despite climate change effects, can support the growth of nearly 200 different crops and different classes of livestock (Mukiibi, 2001). Teso farmers can grow over ten adaptable crops namely cassava, maize, finger millet, sorghum, rice, groundnuts, beans, cow peas, green grams, simsim, sunflower, citrus, mangoes, cashew nuts & cotton including the sweet potato and keep livestock especially cattle (Osekeny, 1996). Additional to cereals such as finger millet and sorghum with groundnuts as legume, the sweet potato and cassava stand out strongly as food security crops that do well in Teso (Mukiibi, 2001). The sweet potato is more strategic because it bears no threat of cyanides that may be found in cassava and to a less extent in some sorghum varieties. In addition, the crop matures faster (one or two varieties such as *Odiopelap* in a month).

It is adaptable and the orange fleshed sweet potato varieties are well endowed with Vitamin A important in the human diet.

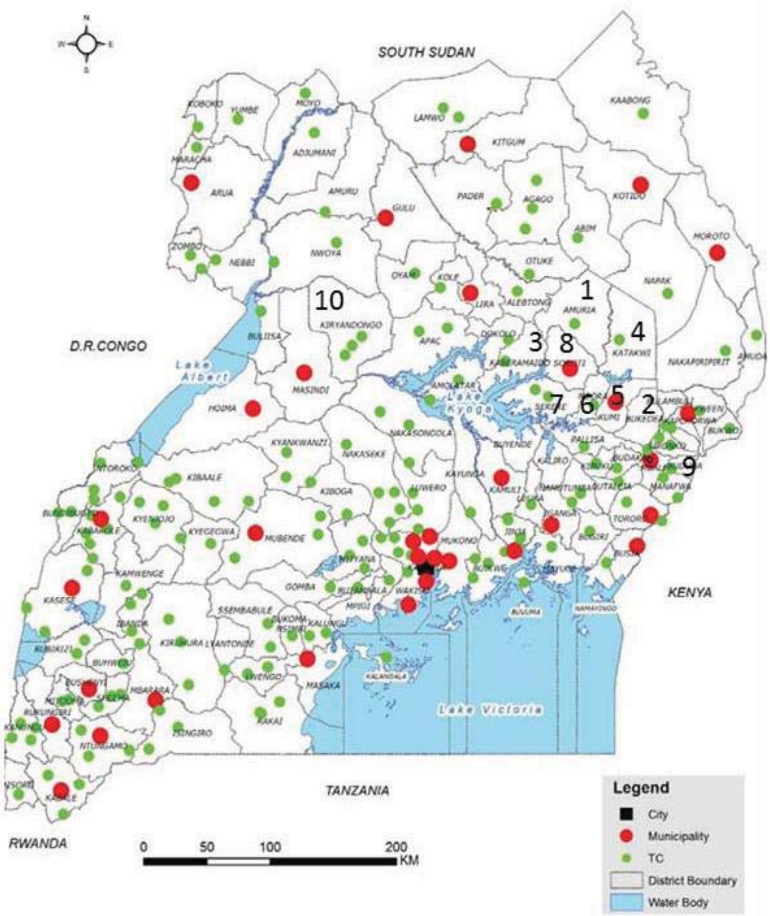


Figure1. Map of Uganda showing Districts and Urban Centres as of March 2016

Source: Uganda Bureau of Statistics. (2016).

## 2. Food Production in the Teso Sub-Region to Meet All-time Needs

Production of food including sweet potatoes in Teso depends on many crosscutting issues supported by the agricultural research system which integrates and interlinks with the different sectors (crops, livestock, fisheries, environment, and natural resources). Consequently, any innovations, knowledge and technologies to bear fruitful interventions should ultimately generate sustainable output and incomes for food security. That requires enhanced farmers' access to needed agricultural information & mechanization, conducive policies, suitable entrepreneurial skills, knowledge including attitudes and values for success. Food production in the Teso sub-region heavily relies on the expanded and sustainable use of oxen for primary and secondary cultivation (Musiitwa & Komutunga, 2001). The system is characterized by division of labour by gender where men open the land through ox-cultivation while the women carry out most of the work up to post harvest handling of the produce. Climate change caused by extreme drought sometimes experienced and flush floods with declining soil fertility have intermittently disturbed the effectiveness of the system. The Government of Uganda and Civil Society Organizations have taken steps in the past to address the food security situation in the sub-region through cattle restocking, relief aid, agricultural research and extension among others (Mukotani, 2007). A number of studies highlight the food insecurity in the Teso sub-region (Epeju, 2003) and in the environs such as that in the landslide disaster district of Bududa overlapping to Kiryandongo District where Bududa survivors were resettled (Rukondo, 2016). This article highlights the search for long lasting solutions such as smart agriculture to food insecurity problems wherever they reared their heads (Esenu, 2005; TPO, 2008; Parliament of Uganda, 2009). Sweet potatoes, cassava, groundnuts, millets and cattle always stood out as the prime determinants of food security in Teso. Incomes among people in Teso are generally lower than the national average of 600 US dollars per annum and so purchasing power is low to assure food security.

## 3. Sweet Potato Production in Teso

The sweet potato ***(Ipomoea batatas (L.) Lam )*** which is highly adaptable to the soils and climate in Teso, is one of the top two crops with cassava (*Manihot esculenta Crantz*) in the sub-region important for food security. In Uganda, Teso is one of the leading producers of sweet potatoes (Mwanga & Ssemakula, 2011; Otieno, 1999; Bashaasha *et al*, 1995). Nationally, it ranks third among the staple food crops after cassava and bananas (National Agricultural Research Organisation, NARO, 2001). Yields of the crop in Teso are sometimes as low as 4 metric tonnes (4,000 kg) per hectare on farmers' fields instead of the 30 metric tonnes (30,000kg) per hectare obtained in the area under research stations (Bank of Uganda, 1992). Per capita production of sweet potatoes yearly in the early 1990s was about 95.4kg grown on 0.1-0.6 ha of a subsistence farm against the consumption per capita of 58 kg (Mwanga & Ssemakula, 2011; Bashaasha, 1995; Woolfe, 1992) which was about 14% and 8% respectively of the food requirement per capita of 700 kg in a year. The World Bank (1993) estimated a food *per capita* output of 960 kilogrammes for Uganda yearly coming from crops alone, but a lower figure of 500 kg *per capita* per year for areas such as Teso sub-region, a figure which may presently be slightly higher than the sub-Saharan food a yearly *per capita* average of 300kg (Kennedy, 2003; Food and Agriculture Organization, 2000). The sweet potato is an important food security crop which alone can supply 429 kg per capita yearly for the Teso population and is a good source of income in Teso (Epeju, 2003).

## 4. Methodology

This paper is based on findings from two independent studies. The first study investigated sweet potato production within the context of farmer education influence in Teso during the period between 2001 and 2003 (Epeju, 2003). Using an *ex post facto design*, 24 out of 51 sub-counties were purposively selected based on district data and farmers' level of engagement in sweet potato growing. Accordingly, they were used to determine the perceptions of sweet potato farmers and of their agricultural advisors (Cashwell, 2002; Edwards, 2002; Kothari, 1992; Wiersma, 1986). A total of 650 persons (288 farmers randomly selected, 33 agricultural advisors and 329 community leaders) participated to also establish food and income levels from the crop. Data were analysed qualitatively under themes, categories and subcategories; and quantitatively using means, frequencies, percentages, and multiple regressions at a confidence level of 0.05 ($\alpha$) (Strauss & Corbin, 1990; Microsoft SPSS Version 8, 1998). Sweet potato varieties used in production are shown in Table 1. Literature search was done on its income with other crops.

The second study investigated the human right to adequate food in the context of disaster in the neighbouring Bududa District and in the away Kiryandongo District where the Bududa disaster survivors were relocated during the period between 2012 and 2016 (Rukondo, 2016). Teso has suffered several disasters such as floods and severe droughts which led to relocation of survivors as in Bududa. Rukundo's study gave some good lessons to Teso in dealing with the human right to adequate food. The study used an inter-disciplinary cross-sectional survey design to get perceptions of duty bearers and rights holders. Duty bearers were those who handled survivors and 52 were purposively selected from relevant State institutions. Rights holders were 1,200 household heads of those households which were affected in 2010 by the landslide disaster. Through a three-stage simple random sampling, the affected households were selected giving the household heads in the sample. Using interviews, a total of 1078 household heads were done for complete statistical analysis. Focus group discussions were also held for groups of youth, 18-35 years old (n=4), adult women (n=4), and men (n=4). A total of 1,142 persons were consulted on the right to adequate food. Qualitative data were transcribed and triangulated by clustering and patterning of information, complemented by relevant literature reviews.

Combining results of the two studies Epeju (2003) in Teso and Rukundo (2016) in tracking the handling of the Bududa survivors resettled in Kiryandongo regarding the human right to adequate food was enlightening to handling food insecurity situations such as those in Teso. Food insecurity situations whenever they occurred in Teso as elsewhere in Uganda called the support of many local and international partners employing several duty bearers for the situation from several institutions. Some findings from Rukundo (2016) were relevant in this article to understand how crops such as sweet potatoes can address human rights to adequate food.

## 5. Results and Discussion

### 5.1 *Sweet Potato Production Level in Teso Sub-region*

The production output, other factors remaining favourable, largely depended on the varieties used by farmers for production. The common varieties used by farmers in the sub-region over the research period and during the last three decades are shown in Table 1.

Table 1. Sweet potato cultivars used by sweet potato farmers of the Teso sub-region

| **Variety (Cultivar)/Root Colour[1]** | **Root Yield t/ha on Farm (NATIONAL)** | **Root Yield on Research Station t/ha[2] (NATIONAL)** | **Released** |
|---|---|---|---|
| Bwanjule (white) | 17 | 21 (7-49) | 1995 |
| New Kawogo (white) | 17 | 23 (6-45) | 1995 |
| Sowola (cream) | 18 | 29 (9-41) | 1995 |
| Wagabolige (white) | 16 | 24 (6-79) | 1995 |
| Tororo-3 (Cream) | 16 | 21 (5-52) | 1995 |
| Tanzania (pale yellow) | 21 | 23 (5-58) | 1995 |
| NASPOT 1(pale yellow) | 20 | 29 (7-45) | 1999 |
| NASPOT 2 (cream) | 18 | 21 (7-33) | 1999 |
| NASPOT 3 (cream) | 17 | 25 (5-29) | 1999 |
| NASPOT 4(pale yellow) | 18 | 21 (5-38) | 1999 |
| NASPOT 5 (orange) | 16 | 23 (7-28) | 1999 |
| NASPOT 6 (white) | 18 | 24 (7-28) | 1999 |
| Ejumula (orange) | 15 | 19 (2-32) | 2004 |
| Kakamega(pale orange) | 12 | 15 (4-36) | 2004 |
| NASPOT 7(pale orange) | 12 | 25 | 2007 |
| NASPOT 8(pale orange) | 16 | 20 | 2007 |
| NASPOT 9 (orange) | 13 | 20 | 2007 |
| NASPOT 10 (orange) | 12 | 18 | 2007 |
| DIMBUKA-BUKULULA (cream) | 16 | 30 | 2007 |
| NASPOT 11 (cream) | 20 | 38 | 2010 |
| NASPOT 12 (orange) | 16 | 43 | 2013 |
| NASPOT 13 (orange) | 11 | 25 | 2013 |

[1]Root flesh colour is shown in parentheses against names of varieties. [2]Root yield ranges on Research stations are indicated for some varieties where the sources gave them.

Sources: Mwanga et al. (1995, 2007); National Crops Research Institute NaCRRI) and National Agricultural Research Organization (NARO). (2010, 2013).

Table 1 shows several releases of 22 sweet potato varieties used by farmers within the period of research and updated to 2013. The orange fleshed sweet potato varieties (OFST) are critical because of the affordable supply of vitamin A they contain in the diet providing improved food and nutrition security especially for malnourished children and pregnant women. Epeju (2003) found that there were different yield levels from on-farm trials across farms nationally. There were no varieties yielding at low and medium levels (0-5,000 kg/ha and 5,001-9,000 kg/ha respectively). Nineteen varieties (19) fell in the high yield level of 9,001-19,000 kg/ha and three (3) were in the very high yield level of 19,001-29,000 kg/ha. No varieties yielded at the excellent level of more than 29,000kg/ha. The national average yield from on-farm trials was 16,000 kg/ha, which was higher than 7,138 kg/ha the average found on Teso farms (Epeju, 2003).

Table 2 shows the output of sweet potatoes possible from the farmers of the entire Teso sub-region. Using the data available on the cultivable land area per district in Teso (Fountain Publishers, 2011) , the possible area that can be put under sweet potato per season per year was determined based on the finding that in Teso 11% of household farm size annually is put under sweet potato production. Therefore, Table 2 gives the output using that area computation for each district multiplied by the sub-region average of 7, 138 kg/ha of sweet potato production to give output per district in metric tonnes (Epeju, 2003). Over the few years, the average is still valid considering the climatic change effects that have prevailed in the area.

Table 2. Output of Sweet Potatoes possible on farms in Teso sub-region per season yearly

| DISTRICT | AREA UNDER SWEET POTATOES IN HECTARES | OUTPUT IN TONNES | PERCENTAGE |
|---|---|---|---|
| Amuria | 28,336 | 202,262 | 20% |
| Bukedea | 11,572 | 82,601 | 8% |
| Kaberamaido | 17,908 | 127,827 | 13% |
| Katakwi | 27,247 | 194,489 | 19% |
| Kumi | 11,825 | 84,407 | 8% |
| Ngora | 7,942 | 56,690 | 6% |
| Serere | 21,604 | 154,209 | 15% |
| Soroti | 15,521 | 110,789 | 11% |
| **TOTAL** | **141,955** | **1,013,275** | **100%** |
| **MEAN** | 17,744 | 126,659 | - |

Considering the current population of the Teso sub-region as 2,364, 569 (Olupot, 2017; UBOS, 2014), it means the sub-region's sweet potatoes alone can supply 429 kg per capita yearly for its population which is 61% of the projected 700 kg of food per capita yearly. The yields are those from fresh roots. It also means that sweet potatoes is an important food security crop in Teso although it may not be as tolerant as cassava to common dry spells in Teso.

Incomes of farmers in the sub-region continue to be low (no more than 300 (three hundred) US dollars per capita). Epeju (2003) established that sweet potato farmers in Teso earned only US dollars 222 (two hundred and twenty two) per hectare annually through sweet potato sales. Table 3 shows resulting incomes computed but using current prices as of March 2017 and using yield levels on farms for the common crops grown in Teso as estimated by the Bank of Uganda (1992). Twenty five years later, yields in the area, have remained low and in some cases declined. Proceeds from livestock have been left out in the computation although they often cushioned the incomes of farmers in Teso. Although the other farm enterprises in terms of income were not in the study of 2003, using literature search to compare with sweet potato incomes was done as shown in Table 3.

Table 3. Income of farmers as of March 2017 possible in Teso from common crops including sweet potatoes using yields per hectare based on 1992 levels on-farm

| CROP ENTERPRISE | [1]YIELD/HA$^{-}$IN KG | [2]CURRENT PRICE (UShs: US $) PER KG | INCOME EXPEXTED IN UShs: US $) | PERCENT INCOME EARNED |
|---|---|---|---|---|
| Sweet potatoes (fresh) | 7,500 | UShs: 980<br>US $: 0.27 | UShs:7, 350, 000<br>US $: 2, 025 | 26% |
| Cassava (fresh) | 4,442 | UShs: 1,000<br>US $: 0.28 | UShs: 4,442,000<br>US $: 1,244 | 16% |
| Finger millet (dry) | 916 | UShs: 2,200<br>US $: 0.61 | UShs:2,015,200<br>US $: 559 | 7% |
| Maize (grain) | 1,000 | UShs: 1,400<br>US $: .39 | UShs:1,400,000<br>US $: 390 | 5% |
| Sorghum (grain) | 1,596 | UShs: 1,250<br>US $: 0.35 | UShs:1,995,000<br>US $: 559 | 7% |
| Groundnuts (grain) | 1,000 | UShs: 5,550<br>US $: 1.54 | UShs: 5,550,000<br>US $: 1,540 | 19% |
| Beans (grain) | 954 | UShs: 2,800<br>US $: 0.78 | UShs: 2,671, 200<br>US $: 744 | 9% |
| Cowpeas (grain) | 400 | UShs: 4,050<br>US $: 1.13 | UShs: 1,620,000<br>US $: 452 | 6% |
| Simsim (grain) | 300 | UShs: 5,000<br>US $: 1.39 | UShs: 1, 500,000<br>US $: 417 | 5% |
| **TOTAL FOOD IN KG** | **18,108** | **UShs: 1,576.27**<br>**US $: 0.438** | **UShs: 28,543,400**<br>**US $: 7,930** | **100%** |

[1]Yield levels per ha for 1992 were used (Bank of Uganda, 1992) because yields have not really changed very much since then representing national average yields on-farm for those crops.

[2]Current prices used were taken from average commodity prices for the week as at March 27, 2017 in order to determine the possible income per hectare from those crops (Infotrade Uganda, 2017).

Table 3 data allows one to demonstrate how the sweet potato as a crop can contribute to food security and income in Teso where it is a very important food crop that continued to earn income after the collapse of cotton as a cash crop (World Bank, 1993). Orange fleshed sweet potatoes from Teso sub-region are well known in Kampala City, Uganda's national capital. Per capita production of sweet potatoes per year in Uganda is 125 kg against the per capita consumption of 85 kg per year (Mwanga & Ssemakula, 2011; Woolfe, 1992). The consumption is about 12% of the yearly expected food per capita of 700 kg. In Table 3, although yields in the Teso sub-region may be lower than the national averages for the nine crops presented, as an income earner sweet potaoes stand at 26% contribution of the nine food crops to income signifying that it adds to food security through access to food. It is known from research that 11% of every smallholder farm in Teso is put under sweet potatoes annually yielding over 4,000 kg ha$^{-1}$ thus an income of over UShs. 3,000,000/= per annum (about US dollars1000, one thousand) other factors remaining favourable (Epeju, 2003). Yield ha$^{-1}$ in Teso of sweet potatoes is known to lie between 4,000 and 7,500 kg.

*5.2 The Human Right to Adequate Food*

Rukundo (2016) vividly described the Bududa disaster situation on the human right to adequate food. There are several lessons from his study for Teso, Uganda and the rest of humanity. The struggle for equality in availability and access to adequate food and the means for its procurement have been known globally from time immemorial (Andreassen, 2007). Through agriculture, Teso sub-region and Uganda as a country continue to strive to assure food security to all citizens through existing laws such as the Constitution of the Republic of Uganda (GOU, 1995) & the law on Food and Nutrition (2009). There are also conducive policies supporting the implementation of the human right to adequate food such as the Food and Nutrition Policy (2003), Uganda Nutrition Action Plan 2011-2016 ( GOU, 2011), and the National Policy on Disaster Preparedness and Management, Government of the Republic of Uganda. Sweet potatoes is one of those crops farmers are encouraged to produce for good food security additional to others shown in Table 3 because it is more adaptable to moderate drought with its quicker maturing thus meeting the pillars of smart agriculture namely *adaptation, mitigation* and *sustainability*. Unlike cassava the king pin root crop on food security in Uganda, it does not contain cyanides and has more affordable Vitamin A through the orange fleshed sweet potato varieties. Masaba *et al*. (2017), under the current food shortage countrywide caused by the ravaging drought of 2016-2017, reported the story of two parents in Teso sub-region mourning their 12-year old who died after eating immature cassava. The parents said: *"We opted to uproot our cassava and dried it before making bread out of its flour. However, the bread was bitter but we insisted on eating it. The boy started vomiting and developed a running stomach. He died on arrival in hospital."* Another two parents in the same sub-region lamented saying they had also lost a son from eating bitter cassava. It shows that although cassava has been known to be a good famine crop, it has varieties that may have high levels of cyanides which are poisonous. Like cassava, sweet potatoes can be used as fresh roots which can store in the ground for a while, and through slicing or crushing the roots they can be dried and used as chips or flour later but without the serious dangers of poisonous cyanides. Free from cyanides sweet potatoes has a high potential as a food crop for famine or disaster situations.

Although Teso, as a part of Uganda, is well covered through the clear recognition of the right to adequate food by the country's constitution and policy framework according to Rukundo (2016), the system seems constrained to timely deliver on its promises. Policy does not match with prudent legislation to appropriate funds and institutional investment to implement related obligations to vulnerable victims of disaster or famine caused by conditions of bad weather/floods or emergency circumstances such as war, landslides and earthquakes. The absence of ready preparedness of capabilities seem to exacerbate the institutionalization of a minimum humanitarian approach of mainly short-term relief to prevent hunger and starvation at the expense of a desirable right to adequate food approach. The key finding of the study stressed that it is of imperative necessity that the responsible actors and relevant processes respond by investing more considerable resources to strengthen local, national and institutional capabilities for rights-based early warning and surveillance, risk mitigation and adequate relief operations, among others. Both at the local, national and regional levels, it is imperative to build food stores especially of sweet potatoes with value addition for emergencies through creating sustainable and secure food silos and cereal banks. Households through legal and policy frameworks should be supported to have sustainable and secure food stores of their own for emergency situations through crops such as sweet potatoes.

### *5.3 Meeting the Human Right to Adequate Food under Disasters in Teso through Sweet Potatoes*

Disasters occur in a number of forms in isolation or in combination with different causes. Uganda has had several of them namely civil wars, earthquakes, landslides, floods, severe long droughts, severe pest and disease attacks on animals, crops and humans. All of them have led to shortages of food. Teso has had a share of such disasters. During the period of civil strife (1986-1995) and floods in Teso, it is widely known there that sweet potatoes rescued many families with food and income. Consequently, food and the struggle to access it have influenced the political development of and life in states of the world (Andreassen, 2007). Food also has strong influence on global stability affecting international trade, and global health associating with lifestyle and behavior (Lang & Heasman, 2004). The Constitution of the Republic of Uganda adopted on 12$^{th}$ May, 1999 declared on accessibility to food sustainably through the establishment of institutional structures, policies such as research in sweet potato production and legislation to ensure that hunger and all forms of malnutrition are prevented in a dignified way. The Uganda Government pledges through its different policies to ensure food security and adequate nutrition services among its people under all circumstances including disasters and emergency situations (GOU, 1995; 2003, 2009; 2010 and 2011).

Rukundo (2016) findings on the human right to adequate food underscore the role of sweet potatoes for food and income in Teso. They also provide a lesson that land is indeed an important source of food and income that guarantees a more stable food security situation with both higher food variety scores and diet diversity scores for nutrition security. Sweet potatoes have a great possibility of supporting the human right to adequate food in Teso.

## 6. Conclusions and Recommendations

Sweet potato yields and the possible income from it underline its great potential for food security in Teso and beyond. In addition, they give the affordable supply of Vitamin A and minerals from orange fleshed sweet potato varieties, without any cyanide dangers, enhances its place in improving the diets assuring nutrition security especially of the pregnant women and the many malnourished children in Uganda lacking Vitamin A. In Teso, there are possibilities of expanding and improving the land base to increase farm productivity other conditions remaining favourable. Although intermittently, there are challenges in the economy and of climate change effects which distort production, it is strategic to develop the processing of the sweet potato roots for value addition to get products of a longer shelf-life such as chips, flour, fortified food, drinks and confectionery products. Sensitizing farmers through early warning by agriculture and disaster experts, farmers can participate better and contribute more to the human right to adequate food in Teso and beyond, through building sustainable food stores such as cereal banks, granaries and silos, enabling the country to deal firmly with situations of disaster and emergency on food.

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**References**

Andreassen, B. A. (2007). Political science, human rights and the right to food discourse. In Eide, W.B., Kraucht, U (eds) *Food and human rights in Development: Evolving issues and emerging applications II*, Antwerpen and Oxford: Intersentia, pp 81-104.

Bank of Uganda, (1992). Yields of Export Crops per hectare, Kampala, Uganda

Bashaasha, B., Mwanga, R. O. M., Ocitti p'Obwoya, C., & Ewell, P. T. (1995). Sweet potato in the farming and food system: A farm survey report. International Potato Center Sub-Saharan Africa Region, Nairobi, Kenya.

Brady, N. C. (1994). The nature and properties of soils (8th ed.), New York, NY: Macmillan Publishing Co. Inc, pp 598, 618, 639.

Cashwell, G.S. (2002). Descriptive research methods. Retrieved from http://ericcas.uncg.educ/research/cashwell.html

Edwards, A. W. (2002). Non-experimental quantitative research. Retrieved from http://kancrm.kckps.k12.ks.us/guide/nonexperimental.html

Epeju, W. F. (2003). Farmers' and Agricultural advisers' perceptions on the role of education in sweet potato (*Ipomoea batatas, L.*) production in Teso, Uganda, Unpublished PhD Thesis, Egerton University, 278 pp.

Esenu, N. B. (2005). Gender relations in livestock production and ownership: Implications for household food security in the Teso farming system (TFS), Unpublished MSc Thesis, Kampala,Uganda: Faculty of Agriculture, Makerere University, 92pp. Available at http://smallstock.info/research/proj/R8108.htm on 13-10-2010

Food and Agriculture Organization. (2000). FAO online data. Retrieved from http://apps.fao.org

Fountain Publishers. (2011). UGANDA DISTRICTS Information Handbook (Ninth Edition),Kampala, Uganda, *Foutain Publishers*, 113-115, 147-149, 172-174, 372pp.

Government of Uganda, GOU. (1995). Constitution of the Republic of Uganda, Republic of Uganda, Kampala, Uganda. Retrieved from http://statehouse.go.ug/sites/default/files/attachments/abridged.1995.pdf accessed on 20th February, 2013

GOU.(2003). Uganda Food and Nutrition Policy, Ministry of Agriculture, Animal Industry and Fisheries and Ministry of Health, Kampala, Uganda. http://extranet.who.int/nutrition/gina/sites/default/filesUGA%202003%2Uganda20%and%Nutrition%Policy.pdf. Accessed on 9-8-2013.

GOU. (2009). Food and Nutrition Draft Bill, Kampala, Uganda. http://www.heallth.go.ug/nutrition/docs/population/FOOD AND NUTRITION.BILL_2009.pdf Accessed on 10-9-2013.

GOU.(2010).National Policy of Disaster Preparedness and Management of the Uganda, Kampala. http://www.opm.go.ug.assests/media/resources/8/Disaster%20Policy.pdf. Accessed on 3-8-2013.

GOU. (2011). Uganda Nutrition Action Plan 2011-2016, National Planning Authority, Kampala, http://www.health.go.ug/docs/NAP_11_16.pdf. Accessed 1-9-2013.

Infotrade, Uganda. (2017). Market Information Services: Current prices for the Week, Average Commodity Prices as at 27, 2017. http://www.infotradeuganda.comindex.php/marketinformationhtml. Accessed on 2-5-2017.

Kennedy, G. (2003). Food security in the context of urban sub-Saharan Africa: Internet Forum of FoodAfrica. Available at http://www.foodAfrica.nri.org on 23-9-2011 in the Proceedings of FoodAfrica:Forum (31st March 2003-11th April,203).

Kothari, C.R. (1992). *Research Methodology: Methods and Techniques* (Second Edition), New Delhi, India: Wiley Eastern Limited, pp 352-358, 468pp.

Lang, T., & Heasman, M. (2004). Food wars: the global battle for mouths, minds and markets: Eathscan.

Masaba, J., Olandason, W., Ojore,G., Okethwengu, B., Kiva, N., Bikala, Obol, W., Asimwe,W. (2017). Hunger ravages the Pearl of Africa. *Saturday New Vision Newspaper, 11*(17) (May 6, 2017), Kampala, Uganda: The New Vision Printing and Publishing Co.Ltd, pp 12-13.

Microsoft Windows. (1998). The Statistical Package fo Social Sciences (SPSS, Version 8.0, Chicago,USA: Dell Company.

Mosher, A. T. (1966). *Getting Agriculture Moving*, New York, USA: Agricultural Development Council.

Mukiibi, J. (ed) (2001). Agriculture in Uganda II Crops, NARO, Kampala, Uganda: The Fountain Publishers, 572p.

Mukotani, R. (2007). Teso region flood victims need Shs.120billion urgent relief. Policy Review newsletter Vol. 7, issue 8; Retrieved on 28th September 2011 from the Uganda Debt network website: http://www.udn.or.ug/pub/prn-Septmber2007.pdf

Musiitwa, F., & Komutunga, E. T. (2001). Agricultural systems. In J. K. Mukiibi (Ed.), *Agriculture in Uganda*. Kampala: National Agricultural Research Organisation (NARO)Fountain Publishers.

Mwanga, R. O. M., Odongo, B., Alajo, A., Kigozi, B., Niringiye,C., Kapinga, R., & Yencho, C. (2007). Release of two orange fleshed sweet potato (OFST), cultivars, Kakamega (SPK004) and ‘Ejumula’ *HortScience, 42*(7), 1728-1730.

Mwanga, R. O. M., Odongo, B., Smit, N., p’Obwoya, C. O., & Gibson, R. (1995). *Submission to the variety release committee for release of sweet potato varieties, 1995*, and Namulonge Agricultural and Animal Production Research Institute (NAARI), Kampala, Uganda.

Mwanga, R. O. M., & Ssemakula, G. (2011). Orange fleshed sweet potatoes for food, health and wealth in Uganda. *International Journal of Agricultural Sustainability, 9*(1), 42-49. https://doi.org/10.3763/ijas.2010.0546

National Crops Research Institute (NaACRRI) & National Agricultural Research Organisation (NARO), (2010, 2013). *Submission to the variety release committee* for *release of sweet potato varieties,* Entebbe, Uganda: Republic of Uganda.

National Agricultural Research Organisation (NARO). (2001). Agriculture in Uganda II Crops, NARO (Edited by J.K. Mukiibi), Kampala, Uganda: The Fountain Publishers, 572p.

Olupot, G. (2017). Citrus pests, diseases threaten Teso juice factory. In *The New Vision Newspaper, Vol. 32*, No, 82, (Tuesday, April 25, 2017): Kampala, Uganda: The New Vision Printing and Publishing Co. Ltd, pp 24-25.

Osekeny, J. C. (1996). Kumi restocks 20,000 cows. In *The New Vision Newspaper, Vol. 11*, No, 44, (Wednesday, 21st February, 1996): Kampala, Uganda: The New Vision Printing and Publishing Co. Ltd, p 13.

Otieno, J. O. (1999). Securing food security or cashing opportunities: The changing roles of sweetpotato in Northeast Uganda. A paper presented at 42nd Annual meeting of African Studies Association, Philadelphia, Pennsylvania, USA, November 14-18, 1999: International Potato centre.

The Parliament of Uganda.(2009). Report of the Committee on Agriculture, Animal Industry, and Fisheries on the Famine Situation in Teso Sub-region, Kampala, Uganda: Republic of Uganda: Available at http://H: AAIF- Famine Situation in Teso Sub-region on 23-9-2011, 21pp.

Rukundo, M. P. (2016}. *The Humn Right to Adequate Food in the Context of Disaster: The Case of the Major 2010 Landslide in Eastern Uganda,* Oslo, Norway, PhD Dissertation, Faculty of Medicine, University of Oslo

Strauss, A., & Corbin, J. (1990). Basic of qualitative research: Grounded theory procedures and techniques, Newbury, Park, California, USA: Sage Publications, 15-194.

Transcultural Psychological Organisation, TPO. (2008). Farming, livelihoods and food security, a case study in Teso.Available at http://www.tpoug.org/paul-case study-teso.shtml accessed on 12-10-2010.

Uganda Bureau of Statistics. (2014). *National Population and Housing Census 2014: Provisional Results* ( November, 2014, Revised Edition ). Kampala, Uganda, 65 pp: Available at www.ubos.org accessed on

17-3-2015.

Uganda Bureau of Statistics. (2016). *The National Population and Housing Census 2014-Main Report*, Kampala, Uganda.

United Nations Administrative Committee on Coordination. (2000). System wide guidance on household food security and nutrition. Occasional Paper.

Wiersema, W. (1986). Researh methods in education: An Introduction (Fourth Edition)Boston, USA: Allyn and Bacon Inc. pp 15, 171-217, 354-359, 466p.

Woolfe, J. A. (1992). *Sweetpotato: An untapped food reserve*, New York, New York: Cambridge University Press, pp 15-40.

World Bank. (1993). Uganda: Agriculture (AWorld Bank Survey), Washington, D.C., USA: A World Bank Publication, pp viii, 1-16, 143-172.

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