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Agricultural Mechanization as an Expansion Factor of Cropland in Benin: The Case of Tractors

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Abstract

We propose in this paper a methodology based on the vector error correction (VCE) model. This modeling approach makes it possible to use a large database to model the impact of agricultural mechanization on cropland in Benin. The results of the VEC model estimates confirm a positive relationship between agricultural mechanization and the areas planted of paddy rice, millet and yams. Moreover, the findings suggest that agricultural mechanization is still far to boost the land uses of cotton, maize and cassava, despite the importance of cotton in the Beninese economy on the one hand, and the key roles of maize and cassava in diet in Benin, on the other hand. Agricultural mechanization is far from being a reality in Benin's agricultural sector to the extent that public agricultural investments are below the Maputo agreements (Note 1). An effective agricultural mechanization must opt for cereals whose investments in agricultural machinery are less expensive compared to cotton. This strategy of agricultural mechanization makes it possible to better ensure food security, unlike the intensive cotton production, whose terms of trade are always unfavorable and dependent on subsidies from the North.

Keywords: agricultural tractors, area planted, VEC model

1. Introduction

In Benin, the agricultural sector occupies more than 85% of the active population and contributes 79% to the gross domestic product (GDP) in 2015, while this contribution amounted to 59% over the period 1990-2009. In addition, agriculture accounts for more than 90% of export earnings (MAEP, 2015). The main crops produced are cereals and cotton. Cotton that is the main cash crop, contributed up to 2007 to 80% of export earnings (Note 2). The most important food crops are maize, millet, sorghum, cassava, yam and cowpea. At the same time, these food crops represent Benin's consumption habits. The challenges of agricultural production remain significant, because only 40% of the arable land is cultivated and the productivity levels are still low. The growth rate in the agricultural sector was 4.58% between 1980 and 1989, 5.1% between 1990 and 2005 and 4.3% between 2006 and 2009. (Note 3)

The Beninese agriculture is characterized by the use of traditional tools (daba, machete and other hand tools). The operations are 76% manual, 23% with animal traction and only 1% is motorized (PPMA, 2015). In addition, barely half of the agricultural products are covered by adequate transport services. Similarly, post-harvest facilities (storage, conservation, processing and marketing) remain rudimentary. In this context, the government set up in 2009 the Agricultural Mechanization Promotion Program (PPMA). This was within the framework of the vision expressed in the Strategic Development Objectives (OSD): "To make Benin, a dynamic agricultural power by 2015, competitive, attractive, respecting the environment, creating wealth meeting the socio-economic development needs of the population". To achieve this, the Ministry of Agriculture, Livestock and Fisheries (MAEP) has developed a national strategy of agricultural mechanization which aims to achieve a mechanization of 20% of land use by 2015 through public-private partnership. This is why the PPMA was set up in 2009. A program that has made it possible today to acquire 450 tractors, 550 tractor plows, 100 3-tonne agricultural trailers, 124 5-tonne agricultural trailers and 250 tillers.

Despite the efforts of agricultural mechanization in Benin, paddy rice production systems are largely dominated by small family-type farms. In addition to this family-owned rice cultivation, there are developed areas with partial or total water control. The majority of the paddy rice farms are concentrated in the lowland either developed or not. However, paddy rice is grown in plateaus and floodplains, especially with the advent of NERICA varieties. On the strength of these investments in agricultural mechanization, statistics from the MAEP (2014) show that the rate of manual plowing and plowing operations amounted to 84%, 12% and 4% for motorized and animal traction, respectively. This motorization is mainly practiced on the irrigated perimeters with collective management of Dévé (150 ha), Koussin-Lélé (250 ha) and Malanville (560 ha).

But since 2009, Benin through the PPMA has invested on its own funds tens of billions of CFA for the promotion of agricultural mechanization through the importation of several hundreds of tractors, tillers with their accessories (plows, mowers, trailers), and about ten harvesters. Cereals and pulses recorded increases in both land uses and production. However, for cereals, the land use and production of paddy rice, compared to those of 2014, decreased by 3.98% and 2.56%, respectively. Compared with the average of the last five years, this same crop has achieved a rise of 28.45% in the area planted and 35.23% for production. We also note that for legumes, peanuts recorded a 2.99% and 3.62% decrease in land use and production compared to 2014, respectively (ONASA, 2016). Mechanization has the potential to increase production, improve timing of operations, expand energy application to improve crop processing, irrigation and infrastructure, offset shortages and labor-saving, which is particularly important when the aging and feminizing workforce continues to use mainly the manual hoe for primary cultivation.

Despite these perceived benefits and the fact that animals were largely replaced by tractors in the United States and Western Europe in the 1950s there were still advanced arguments to urge caution in the developing world (FAO, 2008). The main concern in this article is the effect of mechanization on agricultural land uses in Benin. What are the lands uses that benefit from mechanical innovations in Benin?

2. Theoretical and Empirical Literature Review

The mechanization of production is ultimately based on economic criteria and is part of the economic revolution of agricultural trade. Thus, it can be argued that the accelerated mechanization of agriculture is transforming the economic structure of the industry, as well as the particular agricultural units that make it up. Therefore, mechanization plays a key role in the agricultural regrouping. The farmer can indeed, equipped with modern equipment, work alone on large surfaces. In addition, many already highly mechanized farmers will find that they can, with their current equipment, cultivate a large area. It is postulated, moreover, that mechanization acts as a fundamental determinant of the increase in agricultural land use. The answer depends on the validity of two hypotheses: a) farmers (especially the small ones) are forced to abandon their farm, because the mechanization is no longer profitable on a small scale; (b) although farmers who immobilize funds to acquire a whole range of machines cannot do otherwise than to mechanize themselves to excess and are therefore obliged to enlarge their production base in order to extract from their machines an efficient level of output. These two hypotheses are far from being verified. These two hypotheses are based on a double premise: first, the machines being relatively massive, they cannot always be proportionate to the arable surface of the farm. Secondly, modern machines tend to combine several spots into one, which is more and more important, rather than just mechanizing such a particular task. Consequently, in order to make farming methods effective, with a small staff, it is necessary to bring the required machines at great expense. It may be well thought that these pressures are being felt by farmers on very small farms and are pushing farmers to expand their farms or close their businesses, but it is hard to believe that these problems are found on farms covering up to 640 acres, many of which have been amalgamated on the prairies.

In its broadest sense, mechanization is the set of tools and machines that can be used in manual, hitched, or motorized cultivation for all operations from clearing and land management to processing (Brordet et al., 1988). More specifically, mechanizing agriculture means using machinery and using more energy, especially to increase labor productivity and, often, to achieve results that are out of proportion to the results of this work (FAO/UNIDO, 2008).

Agricultural machinery refers to the various machines used in agriculture (tractors, combine harvesters, etc.), as well as, by extension, all the political, economic or industrial doctrines aimed at developing the use of these machines to replace the labor and/or to increase agricultural productivity. According to the FAO, (2008), agricultural mechanization in the broad sense can be defined as all agricultural equipment used for agricultural purposes: - off the farm and in this case it includes all agricultural work development and production from tillage to harvesting, both on-farm and in all the technology for animal production and primary processing of agricultural products. According to the FAO (2014), the mechanization of agriculture has made it possible to extend cultivable areas and increase yields, essentially improving the precision of farming techniques. In fact, most farmers in developing countries spend more, every year, on energy inputs, fertilizers, seeds or agrochemicals. According to Yurdakul (1994), there are three indicators for measuring the level of agricultural mechanization in a country: (i) traction power per ha; (ii) the number of tractors per 1000 ha; (iii) the SAU per tractor. FAO (2014) summarizes the main reasons for replacing, for crop production, muscle energy (human or animal) by tractors: (i) the possibility of extending the cultivated area; (ii) the ability to perform the operations at the right time to maximize production potential; (iii) the multifunctional characteristics of mechanization, as tractors can be used not only for agricultural production, but also for stationary transport and feeding, as well as for the improvement of infrastructure (irrigation and drainage canals and road works); (iv) mechanization can compensate for seasonal labor shortages (or, indeed, free labor for more productive work), and (v) mechanization reduces the arduousness associated with the use of human muscular strength for difficult tasks such as hoeing by hand for the first plowing. This is particularly important in tropical regions, where high temperatures and high humidity (possibly associated with inadequate feeding) make manual work extremely difficult.

The strategic problem that the farmer must solve is the adjustment of needs-production income. Thus, in traditional agriculture, where most of the food needs are met by self-production, the question of the increase of production is acute. In this sense, mechanization (animal traction and/or tractors), encouraged by the need to cultivate large areas in the face of ever-increasing food needs and low yields, has become unavoidable. Well introduced and accepted, it has made it possible, according to Campagne (1989), to develop forms of crop-livestock association favoring yield improvement by the transformation of manure techniques. Agriculture must move towards new alternatives to meet the different demands. Thus, cultural intensification becomes a necessity and one of the main alternatives is to mechanize (Campagne, 1989). The work of Havard et al. (1988) shows that agricultural mechanization is essential to increase production but also productivity. This agricultural mechanization requires the necessary investments to maintain the level of mechanization. Taking the number of four-wheeled tractors as an indicator of the progress of mechanization, FAO (2008) reports the following trends over the last 40 years: in Asia, the number of tractors increased five-fold between 1961 and 1970 from 120,000 to 600,000 units. Later, the number has increased tenfold to reach 6 million units in 2000. Since then, these figures have continued to increase, especially in India, which had 2.6 million tractors in 2010 - FAO (2013a) -and China, which exceeded 2 million units in 2008 - FAO (2013b); in Latin America and the Caribbean, the number of tractors was multiplied by 1.7 between 1961 and 1970, from 383 000 to 637 000 units, then tripled to 1.8 million units in 2000; in the Near East, the situation is similar to that of Latin America, with the number of tractors having doubled from 126 000 to 260 000 units between 1961 and 1970, before being multiplied by 6.5 to 1, 7 million units in 2000; in sub-Saharan Africa, the trend has been quite different. In 1961, the number of tractors used was higher than in Asia and the Near East (172,000 units). Later, their number slowly increased to a peak of 275,000 units in 1990, before falling back to 221,000 units in 2000. Despite this adoption of agricultural mechanization in some parts of the world, concerns remain mainly about the surge in world population (now at 7.31 billion) is well on track to reach 9 billion in 2050 and to exceed 11 billion by the end of the century.

The 500 million small farms in the world currently produce about 80% of our food and they will have to bear the brunt of the necessary increase of more than 60% of the food production that will have to be realized in 2050 compared to the levels of 2007 (FAO, 2011). Currently, many of these small farms have limited access to production inputs, including mechanization, and thus achieve low levels of productivity. They also have fewer opportunities to access markets to take advantage of the many value-added activities that more developed food systems can provide. At the same time, the rural population is expected to decline as people, especially healthy young people, migrate to urban centers in search of a life less hard than agriculture can offer; there is also a growing feminization of peasant agriculture, particularly in sub-Saharan Africa, with farm control being increasingly left to women. The potential of rural mechanization for women in rural areas and the development of local economies are often underestimated. Currently, half of the population in developing countries is working in the rural sector, a figure that is expected to fall to 30% in 2050. Given the current importance of human muscle energy in small farms, the consequences of the limits of this type of energy are severe (Sims and Kienzle, 2015). The adoption of agricultural mechanization has led to an increase in smallholder productivity that must be achieved in a sustainable way, as the story of the Green Revolution (GR) model tells us. By the 1950s and throughout the 1960s, GR caused changes in crop species and agricultural practices worldwide (Royal Society, 2009). The production model, initially focused on introducing high-yielding varieties of wheat, rice and maize into high-potential regions (Hazell 2008, Gollin et al. 2005), had as aim homogeneity: the choice was made of varieties with genetic uniformity, cultivated with large volumes of complementary inputs in various forms (irrigation, fertilizers and pesticides), which often replaced more ecological practices. Fertilizer use replaced soil quality management, while herbicides offered an alternative to crop rotations for weeds, pests and diseases (Tilmann, 1998). Havard et al. (1988) note that for decades, mechanization has been part of agricultural policies. The author concludes that a timid intensification did not have a major effect on rain-fed cereal crops. Downing attempted to determine the extent to which the use of machinery had contributed to improved crop yields. Among cereals, he concludes, it is probably oats that have benefited the most from the benefits of mechanization. The improvement of potato crops would be directly related to the adoption of new machines allowing a better use of the fertilizer and the improvement of the equipment of plowing, planting and harvesting.

The empirical review concludes that the adoption of new and improved machines and the new operations made possible have resulted in a more productive agriculture. Agriculture was formerly only a profession characterized by the heavy and heavy foot of the horse pulling its cart and whose pace and pace were almost entirely governed by climatic and biological considerations; today it can hear that it has changed its physiognomy. The modern farmer controls a series of quasi-industrial operations and uses vast sources of mechanical energy and all kinds of machines to accomplish these operations quickly, without depending too much on weather and climatic conditions.

3. Data Sources and VAR Model Specification

3.1 Data Sources

The paper makes use of secondary data. These data come mainly from the FAO statistical sources and cover the period from 1961 to 2016. These data relate to the number of agricultural tractors and the areas planted for the different crops in Benin. The variables used in this article are: the number of agricultural tractors (lntracg). This variable represents agricultural mechanization and explains the adoption of tractors by producers in Benin. The land uses of cotton (lnsupcot), maize (lnsupma), cassava (lnsupmc), millet (lnsupmils), paddy rice (lnsupriz) and yam (lnsupigm) are chosen in this article to the extent to which the production of these crops play a decisive role in the economy, especially cotton, which is the second source of foreign exchange on the one hand, and the others contribute enormously to diet and food security. We postulate in this article that an increase in the number of tractor is likely to induce increase in areas planted.

Table 1. Descriptive statistics of agricultural machineries and land uses

Statistics	***Agricultural machineries and land uses***						
	Lnsupard	Lnsupcot	Lnsupma	Lnsupmc	Lnsuprz	Lnsupmil	Lntracg
Mean	12.6363	11.4155	13.1188	11.7976	9.168661	10.14968	4.57214
Median	12.64433	11.4560	13.0539	11.6673	8.988943	10.27461	4.53254
Maximum	12.99203	12.9322	13.8217	12.6002	11.21971	10.79409	5.84354
Minimum	12.14367	9.80818	12.4749	11.1562	7.351158	9.193092	3.33220
Std. Dev.	0.179021	1.06839	0.33386	0.43660	1.018698	0.471428	0.54175
Skewness	-0.599150	0.038366	0.477519	0.405979	0.227092	-0.312416	-0.06601
Kurtosis	3.490108	1.476411	2.389276	1.744559	2.282704	1.631485	2.485951
Jarque-Bera	3.771292	5.236228	2.891431	5.029671	1.621796	5.092309	0.633775
Probability	0.151731	0.072940	0.235577	0.080876	0.444459	0.078383	0.728413
Sum	682.3649	616.4386	708.4181	637.0725	495.1077	548.0829	246.8958
Observations	54	54	54	54	54	54	54

3.2 Econometric Estimates and Policy Implications

For reasons specific to the size of the data, the maximum lag is fixed at 7. Above 7, the estimates could suffer from a lack of precision. For each value of p ranging from 1 to 7, the following model is estimated:

$$Y_t = A_1 Y_{t+1} + A_2 Y_{t+2} + -- + A_p Y_{t+p} + \varepsilon$$

where

$$Y_t = (lntracg_t;\ lnsupcot_t;\ lnsupma_t;\ lnsupmc_t;\ lnsupmils_t;\ lnsupriz_t;\ lnsupigm_t)$$

Then the values of the information criteria are calculated. The results are presented in Tables 2 and 3. Two information criteria (AIC and SC) give the optimal lag of 2. The SC and AIC criteria lead to convergent estimators of p whereas the AIC criterion gives an efficient estimator of p. The value used is $\rho = 2$ because of the length of our series. The search for the number of cointegrating relations was made according to Johansen's approach. The test was carried out with specification 1) that is to neither say, the model without constant neither in the ECM nor in the long term relation, do the series not present a trend. The test is carried out with a lag of 1.

The results are presented in Table 4. The trace test indicates the presence of a cointegration relationship at the 1% level of significance and two relations at the 5% significance level. As for the test of the maximum eigenvalue, it indicates the existence of a cointegration relation at 1% and at 5%. The VAR representation is no longer valid; an error-correction model is then used.

In this context, Johansen and Juselius test various hypotheses. First, they present two tests concerning the dimension of the cointegration subspace (test of the trace and test of the maximum eigenvalue). On the other hand, they consider the hypothesis $H_0: \mu = \alpha\beta_0$, which means that the model is written in fact:

$$\Delta X_t = \sum_{i=1}^{k-1} \Gamma_i \, \Delta X_{t-i} + \alpha(\beta' X_{t-k} + \beta_0) + \varepsilon_t$$

That is, the constant actually occurs in cointegration relations, and not in the form of a deterministic trend. Finally, they present linear restriction tests on α and β, allowing in particular to test if the hypotheses of long-term relations resulting from economic theory are compatible with the results. This method is currently experiencing significant success. It has the advantage of being fairly simple to implement, whether in the estimation or testing procedure Juselius (1990, 1991a) and Johansen and Juselius (1988, 1990, 1991). The results in Table 2 show that all the ADF statistics are lower than the critical statistics of the different thresholds, that after the first differentiation they are thus integrated of order one (I (1)). So we can conclude that there may be a cointegration relationship. For the verification of cointegration, the optimal lag that minimizes the information criteria of AIC (p) and SC (p) are provided in Table 3. This number is equal to one for the variables in this article.

The results of the Granger causality test in Table 5 in first difference indicate whether the addition of one of the seven variables improves the forecast of the number of agricultural tractors, which relies solely on the past evolution of the latter. If this is the case the variable in question includes information on the number of future agricultural tractors. Variables with first difference were used with a maximum lag of 2 years. The hypothesis tested is that of a non-causality of Granger. The rejection of the hypothesis tested is marked with an asterisk. One, two or three asterisks mean that the hypothesis tested is rejected with a significance level of 10%, 5% and 1%, respectively. The test takes place in pairs of variables and without taking into account possible cointegration relationships. The number of agricultural tractors (lntracg) causes the land use of millet (lnsupriz), paddy rice (lnsupriz), and yam. We note that there is no causal relationship between the number of agricultural tractors (lntracg) and land uses of cotton, maize and cassava. The direction of causality between the number of agricultural tractors and land use of yam over the period from 1961 to 2016 is not bidirectional. This result is explained by the major role played by yam production in Benin's diet. Agricultural mechanization seems to be used for the production of yam, which looks more profitable than cotton. The number of agricultural tractors does not cause the area planted of maize and cassava, as both crops are produced on almost all land with rudimentary tools.

Table 6 shows a strong correlation between the areas planted of paddy rice, millet, yams and the number of agricultural tractors. On the other hand, there is a weak relationship between the areas planted of cotton, maize, cassava and the number of agricultural tractors. These surprising results indicate that the sown areas of cotton, maize and cassava seem not to benefit from mechanical innovations in Benin. Despite this lack of agricultural mechanization, there are strong relationships between the areas of cotton, maize and cassava. This last result seems to indicate the effects of crop rotations.

Table 2. Results of unit root tests

Variables	*In level*		*In first difference*		*Trend*	*Cte*	*Lag*	*order*
	Augmented Dickey-Fuller test statistic	t-Statistic	Augmented Dickey-Fuller test statistic	t-Statistic				
Lnsupard	-2.917650	-1.997948	-2.919952	-9.653**	Yes	Yes	2	I(1)
Lnsupcot	-2.917650	-0.815129	-2.918778	-6.173**	Yes	Yes	2	I(1)
Lnsupma	-2.919952	0.772450	-2.919952	-7.580**	Yes	Yes	2	I(1)
Lnsupmc	-2.917650	-0.797314	-2.918778	-7.722**	Yes	Yes	2	I(1)
Lnsuprz	-2.917650	0.338691	-2.918778	-7.150**	Yes	Yes	2	I(1)
Lnsupmil	-2.919952	-1.439335	-2.918778	-7.150**	Yes	Yes	2	I(1)
Lntracg	-2.918778	2.413381	-2.916566	-13.23**	Yes	Yes	2	I(1)

** Significant at the 5% significance level

Table 3. Choice of optimal lag for the variables of the VAR model

Lag	**AIC**	**SC**
1	-25.562	-22.762

Table 4. Johansen test for the variables of VAR model

H0	Statistique de la de valeur propre maximale	Statistique de la Trace	Valeur critique au seuil de 5%	probabilités
r=0	0.863221	421.9920	334.9837	0.0000**
r≤ 1	0.731021	318.5439	285.1425	0.0009**
r≤ 2	0.698276	150.2617	239.2354	0.5145
r≤ 3	0.610741	187.9531	197.3709	0.1325
r≤4	0.516908	198.8906	159.5297	0.3746
r≤5	0.455777	101.0580	125.6154	0.5682
r≤ 6	0.363500	99.42140	95.75366	0.7415
r≤ 7	0.298668	75.92935	69.81889	0.7999

** Significant at the 5% significance level

Table 5. Granger causality test

Granger Causality Tests Lags: 2			
Null Hypothesis	Obs	F-Statistic	Prob.
d(Lnsupigm) does not Granger Cause d(Lntracg)	**54**	**5.23323**	**0.0089*** **
d(Lntracg does not Granger Cause d(Lnsupigm)		**7.23016**	**0.0618**
d(Lnsupcot) does not Granger Cause d(Lntracg)	**54**	**1.44937**	**0.0030** **
d(Lntracg) does not Granger Cause d(Lnsupcot)		**1.71010**	**0.0019** **
d(Lnsupma) does not Granger Cause d(Lntracg)	**54**	**0.81470**	**0.00489** **
d(Lntracg)does not Granger Cause d(Lnsupma)		**3.59824**	**0.0352** **
d(Lnsupmc) does not Granger Cause d(Lntracg)	54	0.68287	0.0001***
d(Lntracg) does not Granger Cause d(Lnsupmc)		9.76392	0.0003***
d(Lnsuprz)does not Granger Cause d(Lntracg)	**54**	**4.02453**	**0.0244** **
d(Lntracg) does not Granger Cause d(Lnsuprz)		**3.39161**	**0.421**
d(Lnsupmil) does not Granger Cause d(Lntracg)	**54**	**0.00023**	**0.0019** **
d(Lntracg) does not Granger Cause d(Lnsupmil)		**1.93734**	**0.1554**
d(Lnsupcot) does not Granger Cause d(Lnsupigm)	54	0.42846	0.6540
d(Lnsupigm) does not Granger Cause d(Lnsupcot)		1.64817	0.2033
d(Lnsupma) does not Granger Cause d(Lnsupigm)	54	0.29194	0.7482
d(Lnsupigm) does not Granger Cause d(Lnsupma)		1.59345	0.2140
d(Lnsupmc) does not Granger Cause d(Lnsupigm)	54	1.37541	0.2627
d(Lnsupigm) does not Granger Cause d(Lnsupmc)		0.49174	0.6147
d(Lnsupma) does not Granger Cause d(Lnsupigm)	54	0.29194	0.7482
d(Lnsupigm) does not Granger Cause d(Lnsupma)		1.59345	0.2140
d(Lnsuprz) does not Granger Cause d(Lnsupigm)	54	1.57823	0.2171
d(Lnsupigm) does not Granger Cause d(Lnsuprz)		1.90082	0.1608
d(Lnsupmil) does not Granger Cause d(Lnsupigm)	54	0.06205	0.9399
d(Lnsupigm) does not Granger Cause d(Lnsupmil)		0.64371	0.5299
d(Lnsuprz) does not Granger Cause d(Lnsupcot)	54	1.79510	0.1773
d(Lnsupcot) does not Granger Cause d(Lnsuprz)		2.13179	0.1300
d(Lnsupmil) does not Granger Cause d(Lnsupigm)	54	0.06205	0.9399
d(Lnsupigm) does not Granger Cause d(Lnsupmil)		0.64371	0.5299
d(Lnsupmil) does not Granger Cause d(Lnsupcot)	54	0.98698	0.3803
d(Lnsupcot) does not Granger Cause d(Lnsupmil)		7.57091	0.0014***
d(Lnsupmc) does not Granger Cause d(Lnsupma)	54	0.90094	0.4131
d(Lnsupma) does not Granger Cause d(Lnsupmc)		10.6752	0.0002***
d(Lnsuprz) does not Granger Cause d(Lnsupma)	54	7.13301	0.0020***
d(Lnsupma) does not Granger Cause d(Lnsuprz)		1.26155	0.2926
d(Lnsupmil) does not Granger Cause d(Lnsupma)	54	0.11288	0.8935
d(Lnsupma) does not Granger Cause d(Lnsupmil)		1.82345	0.1727
d(Lnsupmil) does not Granger Cause d(Lnsupmc)	54	7.83174	0.0012***
d(Lnsupmc) does not Granger Cause d(Lnsupmil)		3.08603	0.0550*
d(Lnsupmil) does not Granger Cause d(Lnsupmc)	54	1.31845	0.2773
d(Lnsupmc) does not Granger Cause d(Lnsupmil)		3.92266	0.0266**
d(Lnsupmil) does not Granger Cause d(Lnsuprz)	54	3.52337	0.0375**
d(Lnsuprz) does not Granger Cause d(Lnsupmil)		1.54148	0.2247

** Significant at the 5% significance level

Table 6. Correlation matrix

Variables	*d(Lnsupigm)*	*d(Lnsupcot)*	*d(Lnsupma)*	*d(Lnsupmc)*	*d(Lnsuprz)*	*d(Lnsupmil)*	*d(Lntracg)*
d(Lnsupigm)	1.000000	0.035034	0.017182	-0.045321	0.075409	-0.057174	0.9116**
d(Lnsupcot)		1.000000	0.8964**	0.08592**	-0.091367	0.352346	0.0041
d(Lnsupma)			1.000000	0.017783	-0.226257	-0.034030	0.0045
d(Lnsupmc)				1.000000	-0.019356	-0.076366	0.00315
d(Lnsuprz)					1.000000	-0.072481	0.8325**
d(Lnsupmil)						1.000000	0.0815**
d(Lntracg)							1.000000

** Significant at the 5% significance level

The estimation results include the estimation of the cointegration vector, i.e. the long-term relationship, and the estimation of the coefficients of the adjustment or short-term equations. These results are shown in Table 7. The coefficients for the areas planted of cotton (lsupcot), maize (lnsupma) and cassava (lnsupmc) are not significant at the 5% threshold in the long-run relationship, and the Student's statistic is -0.645. The other coefficients are significant, the areas planted of millet (lnsupmils), paddy rice (lnsupriz) and yam (lnsupigm). These areas planted have positive and significant coefficients, they are worth respectively: 0.1356; 0.4297 and 0.5885. Thus, over the long run, an increase in the area planted of millet (lnsupmils), paddy rice (lnsupriz) and yam (lnsupigm) by 10 points leads to an increase of 1.356, 4.297 and 5.885, respectively in agricultural tractors, ceteris paribus.

In Table 8 CointEq1 denotes the vector associated with the cointegration relation containing coefficients of the error correction terms. Its coefficients translate the speed of adjustment from the short run towards the long-run equilibrium. The coefficients of the restoring forces relating to the number of agricultural tractors (lntracg) and the land uses of cotton (lnsupcot), maize (lnsupma) and cassava (lnsupmc) are positive, these results which may seem surprising insofar as in Benin, cotton benefits more from material and financial state support on the one hand and the backward effects of cotton are captured by maize and cassava on the other hand. The other coefficients of return to long-run equilibrium are negative, which reflects a return to the long-term equilibrium. Short-term dynamics show that the number of agricultural tractors is influenced by one-year and two-years lagged paddy area, with respective elasticities of -0.27 and -0.21. Similarly, this short-term dynamics also indicates that the number of agricultural tractors is influenced by one-year and two-years lagged milled land use, with elasticities of -0.34 and -0.09. Finally, this same short-term dynamic also shows that the number of agricultural tractors impacts one-year and two-years lagged yams land use, with respective elasticities of -0.9 and -0.47. This short-term dynamic is confirmed by the Granger causality tests (Table 5).

The error correction model used to measure the impact of the number of agricultural tractors on the areas planted of cotton (lnsupcot), maize (lnsupma), cassava (lnsupmc), millet (lnsupmils), paddy rice (lnsupriz) and yam (lnsupigm) in Benin during the period from 1961 to 2016 show a weak causal structure between the different areas planted. At the significance level of 5%, there is basically no causal relationship between the areas planted of cotton (lnsupcot), maize (lnsupma), cassava (lnsupmc) and the number of tractors. These surprising results show that although cotton contributes more to the formation of agricultural growth in Benin, agricultural mechanization remains far from being a reality. The problem of adopting agricultural mechanical innovations is acute.

Table 7. Cointegration vector

lnTracg =	*0.090617* lnsupcot*	*+*	*0.243711* lnsupma*	*-*	*0.13562* lnsupmc*	*+*	*0.1356* lnsupmils*	*+*	*0.4297* lnsupriz*	*+*	*0.5885* Lnspigm*	*C*
	(0.06783)		(0.18132)		(0.2363)		(0.11822)		(0.0741)		(0.2428)	5.7
	[1.3359]		[1.3441]		[-0.5738]		[-4.74200]		[-5.7956]		[-1.0659]	

Standard errors in ( ). t-student in [ ]

Table 8. Coefficients of the short-run dynamics

Error Correction	*d(Lntracg)*	*d(Lnsupcot)*	*d(Lnsupma)*	*d(Lnsupmc)*	*d(Lnsuprz)*	*d(Lnsupmil)*	*d(Lnsupigm)*
CointEq1	-0.647239	-0.577014	-0.038211	-0.437358	0.698915	0.069883	0.112596
	(0.20037)	(0.29226)	(0.13448)	(0.16616)	(0.25609)	(0.18085)	(0.15408)
	[3.23027]	[-1.97429]	[-0.28414]	[- 2.63222]	[2.72914]	[0.38643]	[0.73076]
d(Lntracg)(-1)	-0.155508	-0.200441	-0.012616	-0.136607	-0.595928	0.280010	-0.305966
	(0.22309)	(0.32541)	(0.14973)	(0.18500)	(0.28514)	(0.20136)	(0.17155)
	[-0.69706]	[-0.61596]	[-0.08426]	[-0.73842]	[-2.08997]	[1.39063]	[-1.78349]
d(Lntracg)(-2)	-0.039371	-0.088905	0.106864	0.171254	-0.533492	0.438005	-0.049343
	(0.17949)	(0.26181)	(0.12047)	(0.14884)	(0.22941)	(0.16200)	(0.13802)
	[-0.21935]	[-0.33958]	[0.88709]	[1.15058]	[-2.32552]	[2.70372]	[-0.35749]
	0.086945	0.008637	-0.076225	-0.142423	-0.163438	-0.045735	0.009784
d(Lnsupcot)(-1)	(0.11560)	(0.16862)	(0.07759)	(0.09586)	(0.14775)	(0.10434)	(0.08890)
	[-0.75211]	[0.05122]	[-0.98244]	[-1.48570]	[-1.10617]	[-0.43833]	[0.11006]
d(Lnsupcot)(-2)	0.389124	-0.079188	-0.036582	-0.065119	0.083415	-0.023471	-0.049401
	(0.11693)	(0.17056)	(0.07848)	(0.09697)	(0.14945)	(0.10554)	(0.08992)
	[3.32780]	[-0.46428]	[-0.46613]	[-0.67157]	[0.55814]	[-0.22239]	[-0.54939]
d(Lnsupma)(-1)	0.156391	-0.305125	-0.266541	-0.038219	0.555520	-0.221127	0.125701
	(0.30118)	(0.43931)	(0.20214)	(0.24975)	(0.38494)	(0.27184)	(0.23160)
	[0.51926]	[-0.69455]	[-1.31859]	[-0.15303]	[1.44312]	[-0.81346]	[0.54274]
d(Lnsupma)(-2)	**-0.023713**	-0.601999	-0.422628	-0.388748	0.054637	-0.165505	0.210485
	(0.28769)	(0.41964)	(0.19309)	(0.23857)	(0.36770)	(0.25966)	(0.22123)
	[-0.08243]	[-1.43457]	[-2.18881]	[-1.62951]	[0.14859]	[-0.63739]	[0.95143]
d(Lnsupmc)(-1)	0.126107	- 0.500505	0.024339	-0.022685	-0.356933	0.169167	-0.003841
	(0.26841)	(0.39152)	(0.18015)	(0.22258)	(0.34306)	(0.24226)	(0.20641)
	[0.46983]	[1.27837]	[0.13510]	[-0.10192]	[-1.04043]	[0.69828]	[-0.01861]
d(Lnsupmc)(-2)	0.161708	0.648725	0.183830	0.068870	0.271960	0.090022	-0.300846
	(0.23793)	(0.34706)	(0.15969)	(0.19731)	(0.30411)	(0.21475)	(0.18297)
	[0.67963]	[1.86920]	[1.15115]	[0.34905]	[0.89429]	[0.41919]	[-1.64425]
d(Lnsuprz)(-1)	**-0.270894**	-0.483329	-0.218936	0.094273	--0.116515	0.126114	0.055970
	(0.18946)	(0.27636)	(0.12716)	(0.15711)	(0.24216)	(0.17100)	(0.14570)
	[-1.42980]	[-1.74891]	[-1.72173]	[0.60003]	[-0.48115]	[0.73749]	[0.38415]
d(Lnsuprz)(-2)	**-0.213323**	0.126092	0.132552	0.099354	0.218316	0.061417	0.098621
	(0.18114)	(0.26422)	(0.12158)	(0.15021)	(0.23152)	(0.16349)	(0.13930)
	[-1.17765]	[0.47722]	[1.09028]	[0.66142]	[0.94296]	[0.37565]	[0.70799]
d(Lnsupmil)(-1)	**-0.121988**	-0.031955	0.085291	0.089607	0.419768	-0.087572	0.004545
	(0.13052)	(0.19038)	(0.08760)	(0.10823)	(0.16682)	(0.11780)	(0.10037)
	[-0.93465]	[-0.16785]	[0.97366]	[0.82791]	[2.51633]	[-0.74339]	[0.04528]
	-0.349412	-0.042756	-0.086420	0.039017	-0.435080	0.134465	0.068142
d(Lnsupmil)(-2)	(0.11823)	(0.17246)	(0.07935)	(0.09804)	(0.15112)	(0.10671)	(0.09092)
	[-2.95530]	[-0.24792]	[-1.08906]	[0.39795]	[-2.87912]	[1.26006]	[0.74947]
d(Lnsupigm)(-1)	**-0.93679**	-0.322457	0.235144	0.340385	-0.318617	0.165048	-0.597375
	(0.23778)	(0.34684)	(0.15959)	(0.19718)	(0.30391)	(0.21461)	(0.18285)
	[-0.39397]	[-0.92971]	[1.47344]	[1.72626]	[-1.04839]	[0.76905]	[-3.26701]
d(Lnsupigm) (-2)	**-0.47073**	-0.499944	-0.154252	-0.290802	-0.521875	0.108914	-0.309225
	(0.23304)	(0.33992)	(0.15641)	(0.19325)	(0.29786)	(0.21034)	(0.17921)
	[-0.63111]	[-1.47075]	[-0.98622]	[-1.50479]	[-1.75211]	[0.51781]	[-1.72552]
C	0.055255	0.098784	0.032227	0.024501	0.042856	0.033457	0.022483
	(0.03180)	(0.04638)	(0.02134)	(0.02637)	(0.04064)	(0.02870)	(0.02445)
	[1.73770]	[2.12979]	[1.51006]	[0.92918]	[1.05447]	[1.16576]	[0.91944]

Standard errors in ( ). T-student in [ ]

Moreover, the hypothesis of a transfer of labor from agriculture to the industrial sector is difficult to observe in Benin. On the one hand, the industrial sector is not structurally able to absorb the underemployed labor force in the agricultural sector. On the other hand, this workforce is not sufficiently qualified. The transfer of labor is then to the informal sector with the phenomenon of rural exodus. In recent years, there has been a growing trend of the informal sector in the Beninese economy with the proximity of Nigeria. Agricultural mechanization, by its expansion, can induce sustainable agricultural growth, reduce poverty, unemployment, rural exodus and improve food security. Agricultural mechanization can also lead to the development of other sectors such as agribusiness, tourism and trade. Since the independence in 1960, the Beninese government has always put agriculture at the epicenter of economic development. During the five-year plans, Beninese farmers were not in some way accompanied by mechanization. The government is still advocating for the valorization of agricultural sectors. Although Beninese agriculture is family-oriented, it does not even benefit from small mechanization. The income derived from this family farming is not meant to finance the development of the industrial sector, more able to set up real conditions for economic development, and at the same time, the share of the agricultural sector in the GDP was doomed to decline as theories of development predict. The reasons given in the literature point to many problems, including the mismanagement of agricultural investments.

4. Conclusion

The objective of this article was to evaluate the impact of agricultural mechanization on land uses in Benin. Agricultural mechanization in Benin is far from being effective. Despite the fact that cotton production benefits from numerous physical and financial support from the State, this production seems not to have actually benefited from effective agricultural mechanization. The cotton sub-sector has always been at the center of Benin's economic policy. This agricultural sub-sector has undergone changes throughout Benin's history, with since 1990 a redefinition of the roles played by the various actors in this agricultural sub-sector that has never led to mechanization. This agricultural subsector is still slow to have a ripple effect in order to start a real economic take-off because of the real non-existence of mechanization. Estimates using data on the number of agricultural tractors and areas planted of cotton, maize, cassava, paddy rice, millet and yams in Benin show that there is a long-run relationship only between the number of agricultural machinery and the areas planted of paddy rice, millet and yams. Thus, agricultural mechanization in Benin has evolved in certain stability at the level of agricultural policy. This long-term relationship shows that an increase in the area planted of cotton, maize and cassava leads to a drop in the number of agricultural tractors. Estimates also show that the development of agricultural mechanization has not caused the land uses of cotton, maize and cassava. These results can be explained on the one hand by the traditional character of agricultural activity in Benin, the agricultural sector is still slow to modernize completely. On the other hand, the agricultural economy is still relatively disjointed. We could add external factors. The producers are price takers on the world market, so there is a risk of losses linked to the drop in commodity prices, as was the case in the early 1980s. These various results lead to a few recommendations: Strengthen the link between agricultural mechanization and sustainable agriculture. This reinforcement can be effective if and only if substantial agricultural public investments are spent in agriculture accompanied by training and adequate research in order to boost a sustainable green revolution. Economic theory shows this necessity and many empirical examples provide an illustration. For the Beninese authorities, many measures are needed: there is a need to promote greater local processing of commodities. This proposal is not original, it has been mentioned for decades in Benin's economic analyzes. The transformation of commodities adds more value to the products, and thus increases the wealth created. At the same time, there is job creation. The export of raw commodities contributes to the deterioration of the terms of trade. The food industry is one of the industries using agricultural products. Food imports have greatly increased in Benin. Incentives must be put in place to allow the development of local agro-industries using raw materials from the agricultural sector. With the boom of agribusiness, the demand structure for agriculture would be modified so that the agricultural sector would serve as an upstream sector for other sectors.

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Notes

Note 1. At least 10% of budget must be allocated to agriculture.

Note 2. Patrice Cokou Kpade et Jean-Pierre Boinon, 2011. « Dynamique des politiques cotonnières au Bénin. Une lecture par la dépendance de sentier », Économie rurale, 321, 58-72.

Note 3. Banque mondiale, (2012), African Development Indicators sur l'économie Béninoise, Base de données.

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Effects of Heifer Calving Date on Longevity and Lifetime Productivity in Western Canada

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Abstract

The objective of this study is to determine the effect of calving early as a heifer on lifetime production in western Canada. This study evaluated the longevity and life time production data on 211 individual heifers (data gathered for 16 years) at the Western Beef Development Centre (WBDC), Saskatchewan. Heifers were classified as calving in the first (period 1; n= 87), second (period 2; n = 66), or third (period 3; n = 58) 21-day period of the calving season. For each subsequent calf born to the cow, calving period was reassigned in the same manner. The current study showed that the average life time number of calves weaned for heifers that calved in the 1st, 2nd, and 3rd 21-day period was 5.4 ± 0.32, 4.5 ± 0.37, and 4.2 ± 0.39, respectively. Retaining percentage rate of period 1 cows was 4.3-17.8 and 2.1-19.1% units greater than those of period 2 and period 3 cows, respectively. Period 1 heifers had the greatest life time produced total cumulative weaning weight (p <0.01) value of 1157 kg/cow, followed by period 2 and period 3 heifers, 947 and 841 kg/cow, respectively. Period 1 cows generated an additional $718 to $1077 in weaned calf revenues over their lifetime. This study suggested that, in western Canada, heifers that calved earlier had greater pregnancy rates, remained in the herd longer, and produced one more calf in their lifetime than those that calved in the later periods.

Keywords: beef, fertility, heifer, calving distribution, lifetime production, reproductive longevity

1. Introduction

The sustainability and profitability of a cow-calf operation is dependent on the longevity of each breeding female and the production of a live calf every year. If a heifer calves earlier in the calving season (first 21-day period), they have more time to heal and resume cycling before the next breeding season commences in order to maintain a 365 d calving interval. A limited number of reports are available regarding the relationship between cow calving time as a heifer and subsequent longevity and production as cows (Burris & Priode, 1958; Wiltbank, 1970; Lesmeister, Burfening, & Blackwell, 1973; Sprott, 2000; Funston, Musgrave, Meyer, & Larson, 2012; Cushman, Kill, Funston, Mousel, & Perry, 2013). Burris and Priode (1958) showed that cows calving late in one year tended to continue that trend, calving late in the following year or coming up open. Similarly, Wiltbank (1970) stressed the importance of heifers conceiving early in their first breeding in order to have good lifetime production performance and was one of the first to suggest calving heifers earlier than the rest of the herd given their longer post-partum interval (80-100 days vs. 50-60 days for cows). Lesmeister et al. (1973) demonstrated the importance of breeding heifers to calve early to maintain calving period throughout their time in the herd and that heifers that calve early will produce more kilograms of calf in their lifetime than heifers that calve later in their first calving. Sprott (2000) analyzed calving records from five Texan herds to show that average lifetime calf weight is highest for females whose first calf was born in the first 21 d of the calving season. Similarly, Funston et al. (2012) reviewed thirteen years of production records from Gudmundsen Sandhills Laboratory, Nebraska and found calving period influenced a heifer's herd performance with heifers that were born in the first calving period having higher first conception rate, percentage calving in first 21 d, first calf weaning weight and second conception rate than heifers born in the second or third calving period. Furthermore, Cushman et al. (2013) showed that having heifers calve early in their first calving resulted in increased herd retention and the additional kilograms of calf weaned by an early-calving heifer equated to the production of an extra calf during her lifetime. To our knowledge, no publications could be found on the influence of calving early as heifer on future and lifetime performance in western Canada. The objective of this study is to determine the effects of calving early as heifer on her lifetime reproductive performance and productivity using a western Canadian data set.

2. Materials and Methods

2.1 Source of Data

Data were aggregated into a database from the Western Beef Development Centre's (WBDC; Saskatchewan) beef cattle research herd production records. The University of Saskatchewan Animal Research Ethics Board (Protocol No. 20090107) approved the procedures and facilities used in this experiment and animals were cared for according to the guidelines of the Canadian Council of Animal Care (2009). The WBDC follows typical management practices of western Canada for beef heifer development, cow breeding and nutrition, as described elsewhere (Krause et al., 2013; Lardner, Damiran, Hendrick, Larson, & Funston, 2014; Damiran, Lardner, Larson, & McKinnon, 2016; Damiran, Penner, Larson, & Lardner, 2018; McMillan et al., 2018). Data for the spring calving herd collected between 2001 and 2017 were used for this study. The breeding season at WBDC began approximately June 20 each year and lasted for ~65 days. Weaning occurred each year in late October (at ~160 d of age). Data were trimmed to remove heifers that produced a twin at any point during their life. Females sold or culled for non-breeding reasons (e.g., mothering, milk, conformation, temperament) were removed from the data set. Heifers were also eliminated from the data set if proper assignment to an initial calving group was not possible due to abortion, or birth of an abnormal or premature calf. The final data set for this study consisted of 211 Black Angus and Angus crossbred heifers born from 1999 to 2008.

Each female's calving date was assigned a number (Julian date) corresponding with calving span. Postpartum recovery period was estimated by subtracting 282 d (average gestation length) from the calving interval (Damiran et al., 2016). Two-year old first-calf heifers were assigned to one of three 21-day calving periods based on the date their first calf was born. Each subsequent calf born to the cow was also assigned to a calving group (or period), but for analysis purposes the female remained in the group number assigned for her first parturition. For example, a cow that calved in Period 2 as a heifer but then had her next three calves in Period 3, was analyzed as a Period 2 female. Average lifetime production was calculated as the mean production of all calves whose dams were classified in a particular calving group as heifers. Weaned calf revenue was calculated, $/cow = Calf cumulative weaning BW, kg/cow × WCP, $/kg, where WCP = weaned 249.4 kg (550 lb) calf prices, over the last nine years (2008-2017) in Saskatchewan, Canada, have averaged $3.68/kg (CANFAX, 2017). All dollar values are in Canadian dollars.

2.2 Statistical Analysis

Data (heifer age of birth, Julian day of calving, calf birth weights, calving interval, calf weaning age and weight, adjusted 205-d weaning weight of all calves that survived until weaning, and longevity of cows) were analyzed using the MIXED procedure of SAS 9.2 (SAS, 2003). The model used for the analysis was: $Y_{ij} = \mu + T_i + e_{ij}$; where Y_{ij} was an observation of the dependent variable $_{ij}$; μ was the population mean for the variable; T_i was the fixed effect of the contemporary heifer calving group (Period 1, Period 2, and Period 3); and eij was the random error associated with the observation ij. Heifer was considered an experimental unit. For all statistical analyses, significance was declared at $p < 0.05$.

3. Results and Discussions

3.1 Cow Retention and Longevity

As indicated previously, in the current study, cows were culled or sold from the herd if they failed to be become pregnant (e.g., open). Figure 1 depicts percentages of cows remaining in the herd over time out to 9th calving based on retention data. Retaining percentage of period 1 cows was 6.5-18.3 and 2.9-24.1% units greater than those of period 2 and period 3 cows, respectively. Thus, heifers that calve later at their first calving fail to remain in the herd as long as heifers that calve earlier (first 21 days) at their first calving. The results of the current study agree with the previous findings (Cushman et al., 2013) in that having heifers calve early in their first calving would increase their retention in the herd.

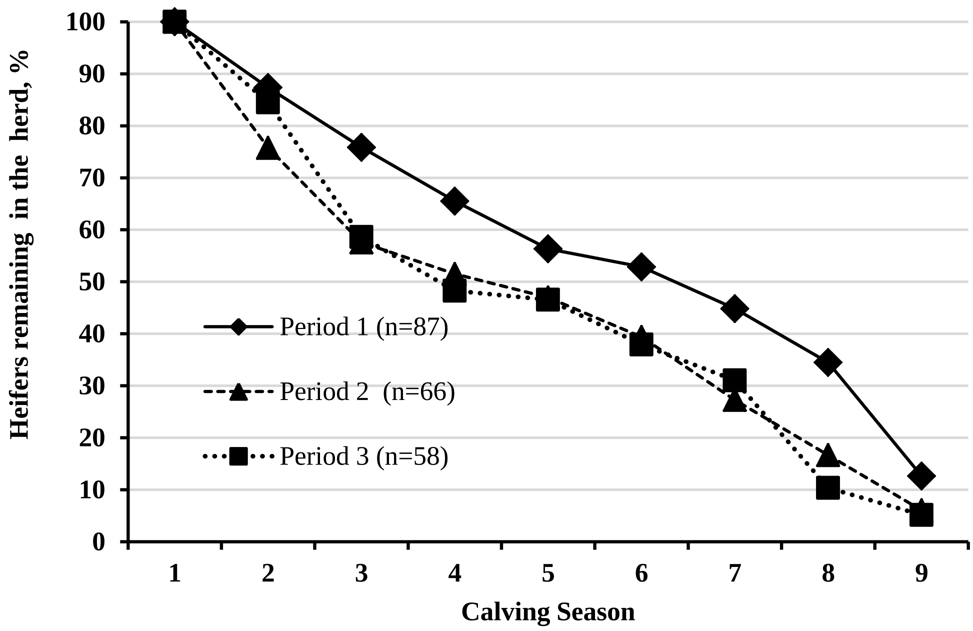

Figure 1. Analysis of the influence of calving period on herd survival from Western Beef Development Centre, Saskatchewan

Note. Results from Angus and Angus crossbred heifers (n = 211). Period 1 = calved in the first 21 days, - 2 = calved in the second 21 days, - 3 = calved in the third 21 days and after as heifer.

The longevity of a beef female is important to the sustainability and profitability of any beef operation (Cushman et al., 2013). Increasing longevity by improving retention of females can increase herd size. Figure 2 presents influence of calving period on beef cow average longevity from WBDC. In the current study, heifers that had their first calf during the first 21-day period of the calving season had increased ($p < 0.05$) longevity compared to heifers that calved in the second and third 21-day periods (7.2 ± 0.3, 6.5 ± 0.4, and 6.2 ± 0.4 yr for period 1, period 2, and period 3, respectively).

However, no difference ($p > 0.05$) was observed between period 2 and period 3 groups in longevity. The reason for the obtained results on cow retention time and longevity can be explained as Bridges (2013) noted, if a heifer conceives late and subsequently calves late, she has less time from calving until the start of the subsequent breeding season, so she is more likely to be anestrus, or not having estrous cycle, at the start of the breeding season and will likely conceive late again in the second breeding season; this cycle continues to repeat until eventually she fails to conceive in a confined breeding period and is culled from the herd.

3.2 Effect of Initial Calving Group on Cow Calving Performance

Effect of first calving period on a beef cow's lifetime calving performance are presented in Table 1. Age of the heifer at first calving affected calving group ($p < 0.01$). Heifers classified as calving in the first calving period were on average 19 d younger than those in the second period and 48 d younger than those in the third period ($p < 0.01$). Heifers need to calve by 24 mo. (730 day of age) of age to achieve maximum lifetime productivity (Patterson et al., 1992). In the current study, only period 1 heifers reached the mentioned benchmark.

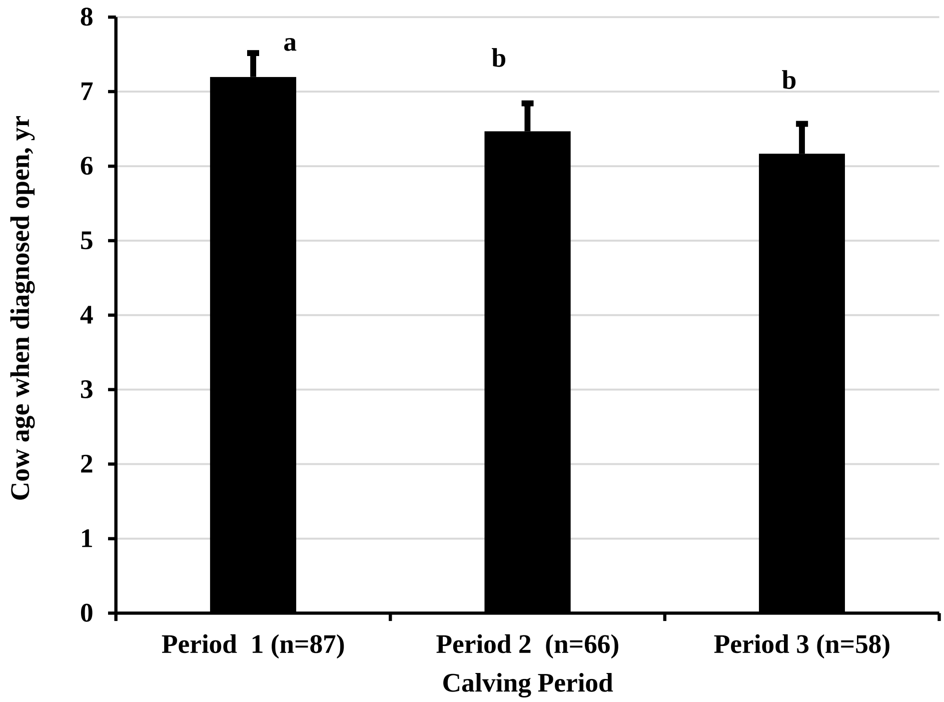

Figure 2. Effect of first calving period on life time in herd from Western Beef Development Centre, Saskatchewan

Note. Period 1 = calved in the first 21 days, -2 = calved between day 22-43, -3 = calved after day 44 or later. [a,b]Bars with different superscripts are different at $p < 0.05$.

Table 1. Effect of first calving period on beef cow calving performance

	Calving period[1]				
Item	Period 1	Period 2	Period 3	SEM[2]	*p*-value
Initial heifer, n	87	66	58		
Age at first calving, d	731[a]	751[b]	778[c]	3.6	<0.01
Calving interval, d	376[a]	372[a]	358[b]	1.8	<0.01
Postpartum interval, [3] d	95[a]	90[a]	76[b]	2.1	<0.01
Calf birth date, Julian day	107[b]	110[b]	119[a]	1.1	<0.01
Calf birth BW, kg	40	40	40	0.5	0.80

Note. [1]Period 1 = calved in the first 21 days, Period 2 = calved between day 22 to 43, Period 3 = calved day 44 or later. [2]SEM, pooled standard error of means. [3]Estimated postpartum interval from calving to conception based on consecutive calving dates and assuming a 282-d gestation length. [abc]Means without a common superscript differ ($p \leq 0.05$).

When production data for each year was pooled, cow groups were different from each other ($p < 0.05$) in calving date; and were 107 (±0.9), 110 (±1.1), and 119 (±1.3) d for period 1, period 2, and period 3 cows, respectively. This result indicated that the females that calved early as heifers tended to calve earlier throughout the remainder of their productive lives than the females that calved later in their first calving. The interval between postpartum estrus and beginning of pregnancy is the other component of the reproductive cycle. In the current study, period 1 (95 d) and period 2 (90 d) cows were similar ($p > 0.05$) in the length of estimated postpartum interval; both groups were greater ($p < 0.01$) than period 3 cows (76 d). A shorter calving interval was also observed for the Period 3 (late calving) females. These two results may seem counter intuitive at first, but can be explained by fall out with a defined 65 d breeding season. Only the most reproductive females from Period 3 remained in the study (the ones with short post partum intervals), while females in Period 1 and 2 had the leeway to not conceive in their first (and even second) cycle of the breeding season and still end up pregnant at the end of the breeding season. As cows (2nd through 9th calving), estimated postpartum interval did not differ ($p > 0.05$; data not shown) by heifer calving group and averaged ~81 d (Period 3 group) to 87 d (Period 1 group). All 3 cow groups had similar ($p > 0.05$) calf birth BW.

3.3 Effect of Initial Calving Group on Calf Weaning Performance and Lifetime Productivity

It is typical for cow-calf operations are to wean all calves on a particular timeframe rather than on a weight-constant or age-constant basis; as such calves born early in the calving season are usually heavier at weaning than those born later. This tends to increase the total lifetime production of early-calving dams (Morrow & Brinks, 1968; Roberts et al., 1970). Therefore, calving date and actual weaning weight of calves are crucial for beef producers to measure. Effect of first calving period on a beef cow's lifetime calves weaning performance are presented in Table 2. When lifetime productivity for each animal was pooled, calf actual average weaning weights were 15 kg heavier ($p < 0.01$) and average adjusted 205-d weaning weights were 9 kg heavier ($p < 0.01$) for the period 1 and 2 cows than period 3 cows. Calf gain to weaning (ADG) was lower ($p < 0.05$) for the calves from period 3 cows (1.05 kg/d) than for the calves born to period 1 (1.08 kg/d) and period 2 cows (1.09 kg/d).

Table 2. Effect of first calving period on calf weaning performance and beef cow lifetime productivity

	Calving period[1]				
Item	Period 1	Period 2	Period 3	SEM[2]	*p*-value
Initial heifer, n	87	66	58		
Total produced calves, n/cow	5.4[a]	4.5[b]	4.2[b]	0.36	0.03
Calf age at weaning, Julian day	167[a]	164[a]	149[b]	2.0	<0.01
Calf weaning BW, kg	218[a]	217[a]	202[b]	2.5	<0.01
Pre-weaning ADG, kg/d	1.1[ab]	1.1[a]	1.0[b]	0.02	0.06
Calf adjusted 205-d weaning BW, kg/cow	264[a]	264[a]	255[b]	2.1	<0.02
Calf cumulative weaning BW, kg/cow	1157[a]	947[ab]	841[b]	84.5	0.04
Calf cumulative adjusted 205-d weaning BW, kg/cow	1401[a]	1156[ab]	1064[b]	97.4	0.03

Note. [1]Period 1 = calved in the first 21 days, Period 2 = calved between day 22 to 43, Period 3 = calved day 44 or later. [2]SEM, pooled standard error of means. [abc]Means without a common superscript differ ($p \leq 0.05$).

Reproductive performance is one of the biggest factors affecting beef cow production efficiency and profitability. Reproduction has been estimated to be 3 to 9 times more influential on profitability than other production traits (Melton, 1995). Average lifetime calves weaned for WBDC cows that calved in the 1st, 2nd, and 3rd 21-day periods was 5.4 ± 0.32, 4.5 ± 0.37, and 4.2 ± 0.39/cow, respectively. Due to combined effects of greater average number of calves weaned over lifetime and actual calf weaning weights, cows that had their first calf during the first 21-day period had ($p < 0.01$) greater total weight weaned (1157.1 ± 70.0 kg) compared to heifers that calved in the second (946.6 ± 82.1 kg) or 3rd (841.4 ± 87.6 kg) 21-d period (Table 2).

One of the most important findings of this study was females that calve early when they are heifers can produce more cumulative kilograms of weaned calf in their lifetime than females that calved later (after first 21 days) as heifers (i.e., cumulative kilograms of calf was 18.2% and 27.3% greater than that of period 2 and period 3 cows, respectively), which agrees with others' findings (Roberts, Spencer, LeFever, & Wiltbank, 1970; Lesmeister et al., 1973).

3.4 Effect of Initial Calving Group on Weaned Calves Revenue

The Period 1 cows were either numerically or significantly greater than period 2 ($p > 0.05$) and period 3 cows ($p < 0.01$); generated an additional $773 to $1160 in weaned calf revenues over their lifetime (Figure 3). This represents a large financial advantage for cow-calf producers. The differences in average lifetime production between cow groups in the current study were likely associated with differences in total number of calves weaned over lifetime, but some differences were associated with calf weaning weight. In general, in western Canada, where cost of production has been measured at just under $962 per cow wintered (Alberta Agriculture and Forestry, 2016) a heifer will need to wean a minimum of five consecutive calves to recoup her development costs (Kathy Larson, Western Beef Development Centre, Humboldt, SK, personal communication). This economic threshold of needing to wean five calves was only reached by the females that calved early as heifers. Thus the findings of this study demonstrate why it is so important for cow-calf producers to ensure that their replacement heifers conceive as early as possible in their first breeding exposure.

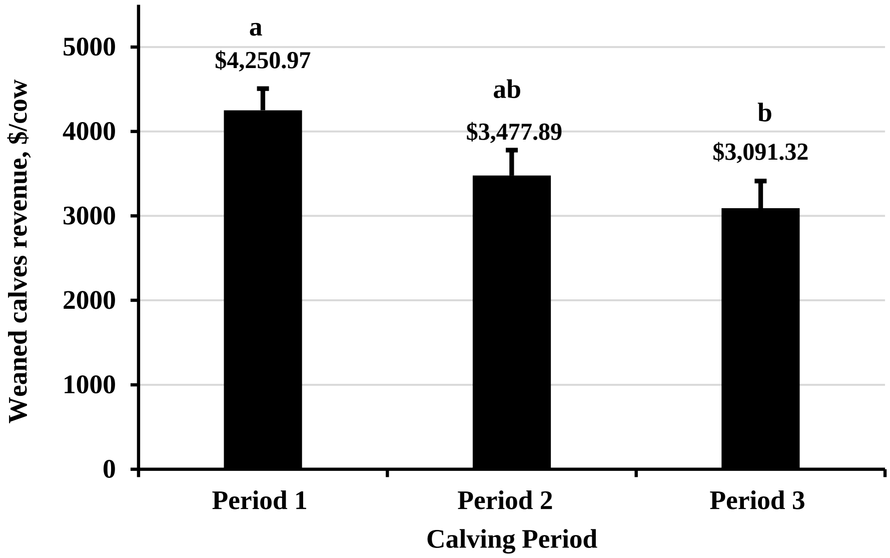

Figure 3. Influence of calving period on lifetime weaned calf revenue

Note. Revenue calculated as cumulative pounds weaned × estimated market value of $3.68 per kg (which represents the 2008-2017 average price for 249.4 kg calves in Saskatchewan). [a,b]Bars with different superscripts are significantly different ($p < 0.05$).

4. Conclusions and Implications

As evidenced by the findings of the current study, heifers that calved early in their first calving season had increased longevity (pregnancy rates) and weaned more calves, compared with heifers that calved later in the calving season. Moreover, in her lifetime, heifers that calved during the first 21-day period of their first calving season weaned approximately one more calf compared (210-316 kg) to heifers that calved later in the calving season. Therefore, developing heifers so that they conceive early in the breeding season and subsequently calve early in the calving season is critical for heifer longevity in the herd as well as the performance of her progeny in subsequent generations.

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Predicting Farmers' Willingness to Adopt Liquid Pollination and Polycarbonate Drying House Technologies: A Case Study from the Date Palm Growers in the Sultanate of Oman

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Abstract

The aim of this research paper is to assess the adoption level of the two technologies (liquid pollination and polycarbonate drying houses) in the Sultanate of Oman with emphasis on identifying influencing factors of the adoption process and exploring resulting policy implications. The methodological framework used is based on the implementation of the ADOPT (Adoption and Diffusion Outcome Prediction Tool) tool in two localities of the Sultanate of Oman through focus groups discussion (FGD's).

Empirical findings obtained from the assessment of the Liquid Pollination (LP) technology indicate that peak adoption rate for liquid pollination technology in "North Al Batinah" is high and predicted to be around 95% (of the total population) after a period of 14.5 years. The predicted adoption level after 5 and 10 years from introducing the technology in the region is estimated to be 46.9% and 91.5%, respectively. The assessment of the rate of adoption of the Polycarbonate Drying Houses (PDH) technology and the identification of factors affecting the peak and adoption levels, and constraints that limit the adoption process and widespread of such technology among the date palm growers of Oman indicates that peak adoption rate for PDH technology in the target study region is predicted to be 95% after a period of 21 years. The predicted adoption level after 5 and 10 years is expected to be 23.5% and 72.9%, respectively.

The presented results suggest that sustainable increase in date palm productivity can be achieved if farmers are encouraged to adopt the LP and PDH technologies. However, the adoption of such technology needs to be accompanied by a supporting extension system and an enabling policy environment to ensure the scaling-up and widespread use of these promising and profitable technologies.

Keywords: adoption, liquid pollination, polycarbonate drying houses, date palms, FGD's, ADOPT, Oman

1. Introduction and Background

Within the framework of the project "*Development of sustainable date palm production systems in the GCC countries of the Arabian Peninsula*", funded by the Gulf Cooperation Council (GCC) Secretariat, researchers succeeded to introduce two promising technologies: liquid pollination (LP) and polycarbonate drying houses (PDH). The aim to introduce LP technology is to improve the quality of fruits, reduce and save the time and effort during the pollination operation, reduce the risk of low fruit setting by pollination during the peak period of flowering, contribute to reducing harvesting losses. Therefore, the objective to introduce PDH technology is to improve the quality of dried dates, accelerate their drying process, and obtain cleaner fruits that are free from dust. The justification for solar driers is that they are more effective than sun drying traditional system (*Mistah*), with lower operating costs than mechanized drier.

These technologies have received a great deal of attention from the Government decision makers in recent years, but there is still no clear assessment of its current level and intensity of adoption, and the factors affecting its adoption. The success of both technologies will not only depend on how well from a technical perspective, but also on its affordability and profitability. The utilization and critical mass adoption of appropriate innovations is an important prerequisite for agricultural development, particularly in the Cooperation Council for the Arab States of the Gulf (GCC) countries in general and in the Sultanate of Oman, in particular.

The aims of this research paper is to assess the adoption level of the two technologies in the Sultanate of Oman with emphasis on identifying influencing factors of the adoption process and exploring resulting policy implications.

2. Date palm sector in the Sultanate of Oman: Setting the Scene

Date palm (*Phoenix dactylifera* L.) is a major fruit crop in the Arabian Peninsula, where it has been closely associated with the life of the people since pre-historic times. Date palm is a multipurpose tree used for food, feed, and fuel (firewood). It provides fiber, carbohydrates, minerals, and vitamins besides having certain medicinal properties (Al-Farsi et al., 2005; Al-Yahyai and Khan, 2015). In Oman, date palm is considered as the first agricultural crop, and it constitutes 80% of all fruit crops produced and represents about 50 % of the total agricultural area in the country (FAO, 2013). Oman is the eighth largest producer of dates in the GCC countries and even in the world with an average annual production of 260,000 tons per year (FAO, 2013). There are approximately more than over seven million date palms and 250 cultivars in cultivation in the Sultanate. From the production point of view, around 70 % of the total date production is harvested from only 10 cultivars, and a small fraction (2.6%) of the total date production is exported. The literature assessment reveals that only half of the dates produced are used for human consumption, with the other half being utilized primarily for animal feed or considered surplus and wasted (Al-Yahyai and Khan, 2015).

According to Al-Marshudi (2002) and Al-Yahyai (2007), the yield of the date palm is considered to be low (40-80 kg/tree) compared to the yields in neighboring countries (i.e. Saudi Arabia and UAE). This low yield is a result of traditional management, lack of farmer know-how, high infestation by several pests, limited field expansion because date growing regions are fully dependent on groundwater extraction for irrigation, in addition to logistic problems, including an insufficient number of skilled laborers and underdeveloped facilities (transport, storage, market outlets, and large processing factories).

3. Liquid Pollination Technology (LPT) in the Sultanate of Oman: An Appraisal

3.1 Characteristics of the LPT

Pollination of date palm is normally carried out by hand in almost all date palm groves in Oman. Farmers are unaware of Liquid pollination, which may be easiest and most productive and convenient. According to Al-Yahyai and Khan (2015), there are several male palm cultivars that are used for pollination, most notably *Khoori* and *Bahlani*. El Mardi *et al.* (2002) reveals that pollinated varieties of date palm by hand, and using a hand duster and motorized duster with no effect on fruit yield, despite the larger fruit volumes when dusters were used. They also reported that a pollen/flour (1:5) ratio for mechanical pollination, used in Oman, produced lower sucrose and dry matter and a higher yield. In this regard, the project develops a new liquid pollination technology.

3.2 Advantages of Using LPT

The advantages of using LP technology in the Sultanate of Oman are as follows:

- Saves time and effort (reducing labor cost and improving the effectiveness and productivity of the labor used);
- Reduces the quantity of pollen needed;
- Reduces labor and pollen costs;
- Reduces the risk low fruit setting by pollinating during the peak period of flowering;
- Improves the quality of the fruits and consequently the profitability of the varieties intended for export;
- Contributes to reducing harvesting losses;
- Reduces the risk of climbing accidents to laborers.

3.3 Constraints of Using LPT

With respect to the main constraints of using the LP could be as follows:

- No interest from the younger generation in date palm production;
- The pollination extraction device is expensive (around OMR3500), which small-scale farmers cannot afford;
- Limited number of date palm trees per farmer (the investment in the pollination extraction device is not profitable);
- Resistance of farmers to adopting the new technology and to changing their practices (farmers are accustomed to the old technology of hand pollination);
- Lack of specialized extension services for the date palm;
- Limited number of extension staff with massive responsibilities.

3.4 Socio Economic Evaluation of LPT

The intervention introduced by the project for the pollination of date palm trees was evaluated economically against the manual method for the *Fardh* cultivar based on the data collected from researchers and experts at the Date Palm Research Center, Experimental and Research Farm - Wadi Quriyat. In the findings reported in Dhehibi *et al.* (2016a), it was assumed that the yield would be maintained the same using the two options (LP technology and manual pollination). The premise that even if the quantity produced of dates is slightly reduced using liquid pollination, the weight of fruit will increase - given the advantage of a decreased proportion of the fruit setting and concomitant increase in the quality of the fruit. In this case, it was considered as natural fruit thinning. This improvement in the quality will affect the market price and for that, it was considered a higher price for the dates produced using liquid pollination. From this research study, it was found that a reduction in pollination cost using liquid pollination was observed in comparison to that for manual pollination of about 89.05% and, consequently, a reduction in the total variable costs per hectare against those for manual pollination of about 56.48%.

Moreover, the analysis revealed a total reduction in the variable costs of OMR1273.95 from using liquid pollination. This reduction in total variable costs results from an increase in the net revenue over that resulting from manual pollination of OMR2593.95/ha. Economic indicators showed also the clear profitability of using liquid pollination where the percentage change in net returns is very high (+ 674.71%). The benefit-cost ratio (BCR) is three times higher when using liquid pollination. Thus, with an internal rate of return of 12.04 and higher BCR, it was concluded that liquid pollination will be highly profitable for Omani farmers.

From the same study, it was reported also that similar results were achieved from the data obtained from farmers for the *Khalas* cultivar. With the same assumptions on yield and related price-quality, it was found that an increase in the value of production of about 20% from using liquid pollination rather than the manual pollination. The analysis showed that using liquid pollination reduced the pollination operation costs by 89.05% (which is the equivalent of OMR1273.95/ha) compared to traditional pollination. The reduction in pollination induces a reduction in the total variable costs of 22.10%. Economic analysis results revealed also that the net benefit to date palm farmers, using the cultivar *Khalas*, and applying liquid pollination was OMR15,310.5/ha (an increase of around 42.60% compared to manual pollination). The analysis of the Internal Rate of Return (IRR) indicates that investment in liquid pollination technology is a profitable decision. Generally, using LP will yield a cost-benefit ratio that reaches 3.41, which is almost twice the ratio, obtained from using manual pollination.

4. Polycarbonate Drying House for Date Palm Products (PDH) Technology in the Sultanate of Oman: An Assessment

4.1 Characteristics of the PDH for Date Palm Products

The PDH dryer is a unique cost efficient method of drying agricultural products such as date palm products at commercial scale. It consists of a drying chamber and an exhaust fan. Transparent plastic films that are mounted on a metal frame make the roof and the wall of a PDH.

Shahi *et al.* (2011) found that the solar drier sheet has a transmissivity of approximately 92% for visible radiation, which traps the solar energy during the day and maintains an optimum temperature for drying of produce. In addition, the authors indicated that UV-stabilized films play an important role in PDH dryers. The UV radiation in the sunrays tends to cause changes in the organoleptic properties such as texture, color and flavor of food materials (Shahi *et al.*, 2011). From technical characteristics, UV-stabilized polyethylene sheets used to prevent such deterioration, and consequently the sheet allows only short wavelength, which is converted into long wavelength when it raids on the surface of the dried product. Since the long wavelength cannot move out, it increases the temperature inside the dryer. In addition to the outlined advantages mentioned above, the sheet has superior properties in terms of transparency, transmissivity, property, anti-corrosion, tensile properties, tear-resistant, anti-puncture, waterproof, moisture proof, and dust-proof.

According to Janjai *et al.* (2011), polycarbonate covers have been used recently for PDH construction. Contrary to the polycarbonate, plastic sheets and glass covers have the distinct property to allow light to enter the PDH dryer and retaining it inside the chamber, the heating mechanism is as black surface inside the PDH improves the effectiveness of converting light into heat. Hence, the objective of a PDH dryer is to maximize the utilization of solar radiation. Based on the mode of heat transfer, the technology is classified into passive and active PDH dryers. The passive mode dryer works on the principle of thermosyphic effect i.e. the moist air is ventilated through the outlet provided at the roof of the dryer (Janjai *et al.*, 2011).

Sangamithra *et al.* (2014) showed that trapped light is converted into heat energy to remove moisture from dates in the PDH dryer. The dryer can be connected in series, hence its capacity can be enhanced as per requirement, and it can be dismantled so that its transportation is easy from one place to another. Prakash and Kumar (2014) study suggests that two energy sources namely the air saturation deficit and the incident global solar radiation are used to active the PDH dryer. They indicated that both natural and forced convection methods circulate the hot air to the food material.

4.2 Advantages of Using the PDH for Date Palm Products

The principal advantages on using the PDH technology are the following:

- Improves the quality of the fruits, especially in humid areas;
- Avoids the contamination of dates by insects, birds, dust, and rain;
- Accelerates the drying process;
- Reduces the loss rate;
- Could be used for other purposes (e.g. drying other products, such as fish).

4.3. Constraints to Using the PDH for Date Palm Products

Although the high range of advantages on using the PDH technology, some constraints or limitations still exist and could be as follows:

- High initial investment cost (needs to be subsidized by the government);
- Concerns over the impact of heat on the quality of product (transfer of the plastic material);
- Farmers lack knowledge on the maintenance of the system;
- Not profitable for date palm growers with very small holdings;
- Lack of extension agents specialized in date palm.

4.4 Socio Economic Viability of PDH for Date Palm Products

The traditional methods used in Oman for drying dates under direct sunshine called "*Mustah*" is a slow process with problems like dust contamination, insect infection, bad quality of fruits, and spoilage due to unexpected climatic changes. To overcome this problem, one of the main objectives of the "*Development of Sustainable Date Palm Production Systems in GCC*" project is to produce new knowledge and practices to improve date palm production systems in the Gulf region.

Other alternative options are available to overwhelm the problem such as the use of conventional fuel fired or electrically operated dryers. However, in many rural areas, the supply of electricity is not available or it is too expensive and could not be affordable by the small date palm growers for drying purpose. Moreover, the fossil fuel fired dryer's technology possesses several financial barriers due to large initial investment and operational running cost which are beyond the reach of small farmers. The main objective if introducing this technology by this development project was to improve the quality of dried dates, accelerate their drying process, and obtain cleaner fruits that are free from dust. This technology is considered one of the most attractive and promising applications of solar energy systems in the GCC countries can be utilized in date palm production areas as a better alternative to dehydrate the date and other agricultural products without any difficulties. Also from environmental perspective, the use of PDH can result in reduced emissions if conventional fuel is replaced.

The implementation of this improved technology can have positive socioeconomic impacts on local income generation, food security and consequently a sustainable date palm farming system. In the practice, Chavada (2009) found that the lifetime cost of drying with solar power is only a third of the cost of using a dryer based on conventional fuels. According to Janjai *et al.* (2009, 2011), the price of dates dried in PDH was found to be 20% higher than that obtained from the open sun drying. The estimated payback period (PBP) of the former technology was 2.3 years. Dhehibi *et al.* (2016b) found that a PDH dryer could function successfully and efficiently with minimum maintenance at low cost.

With no further disadvantages, it could be a substitute to the conventional dryers thereby making it assessable and affordable by local farmers in the Omani date palm producers. In this study, PDH dryer for dates were evaluated economically for two types (small vs large PDH) under two scenarios: with and without governmental subsidies. Empirical findings reveal the high profitability of the PDH, even when the government does not subsidize it. At a real discount rate of 5.1%, the net present value (NPV) is positive and very high in all cases. Thus, such an investment is usually acceptable if the NPV is positive, (the investment is profitable). This criterion was also supported by both the IRR and the PBP criteria (Figures 1-4).

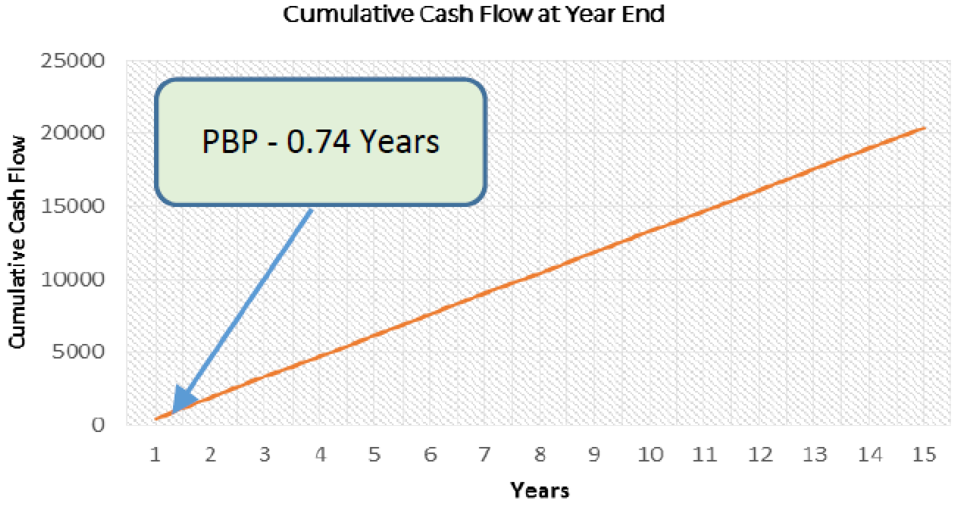


Figure 1. Cumulative Cash Flow at end of year (PBP when the small PDH subsidized)

Source: Dhehibi et al., (2016b).

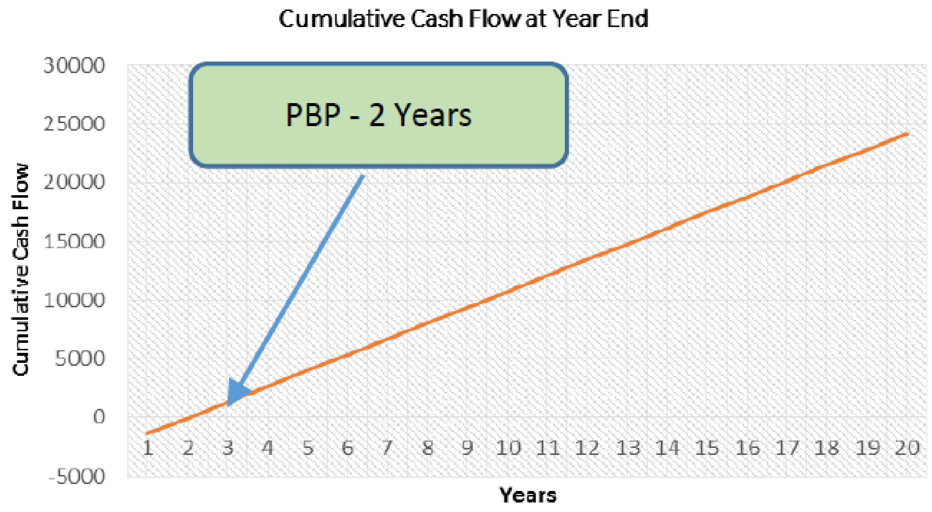


Figure 2. Cumulative Cash Flow at end of year (PBP when the large PDH subsidized)

Source: Dhehibi et al., (2016b).

The estimated IRR was higher than the current interest rate in the Sultanate, which could encourage both date palm growers and private investors to invest in polycarbonate drying houses. The PBP figure was found, in the worst-case scenario, to be 3.77 years, which is relatively short considering the life of the system (15-20 years). This suggests that investment or action costs in this dryer system are recovered quickly reducing the risk involved in the investment.

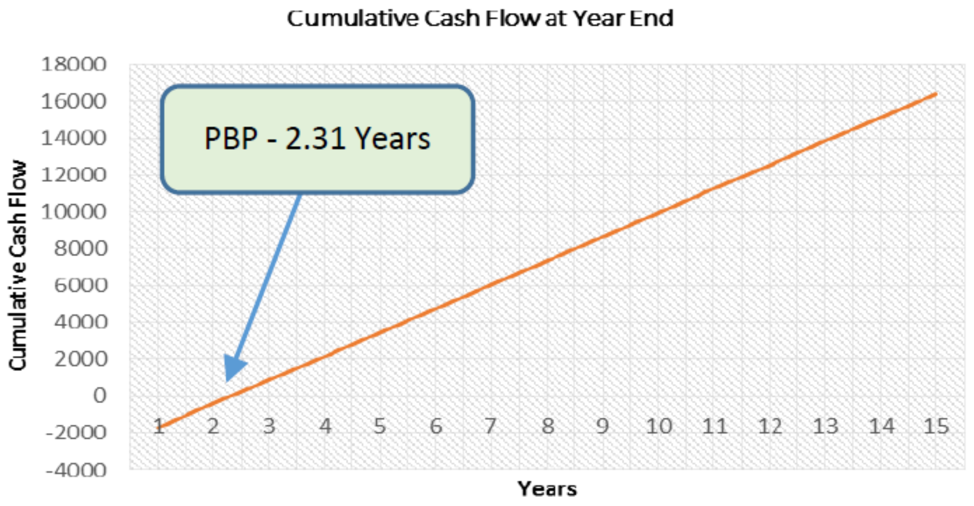


Figure 3. Cumulative Cash Flow at end of year (PBP when the small PDH is not subsidized)
Source: Dhehibi et al., (2016b).

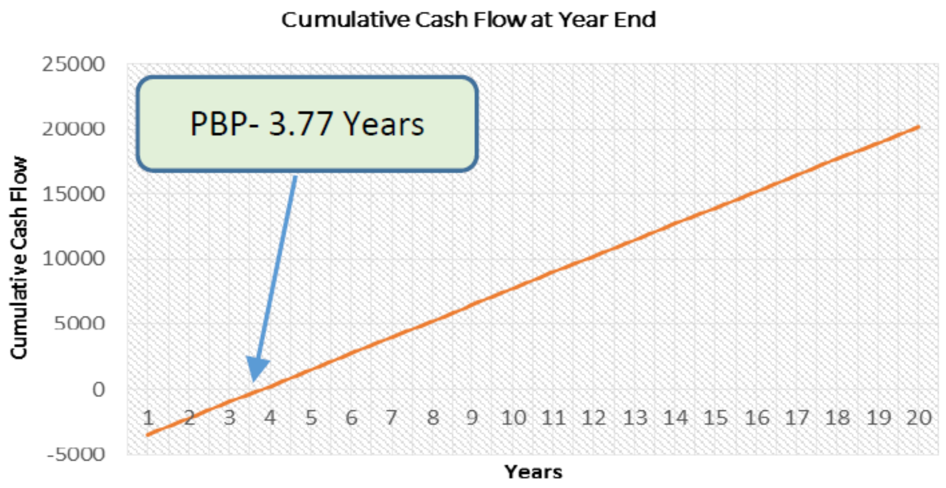


Figure 4. Cumulative Cash Flow at end of year (PBP when the large PDH is not subsidized)
Source: Dhehibi et al., (2016b).

5. Adoption Assessment of LP and PDH Technologies in the Sultanate of Oman

5.1 Conceptual Framework

The adoption of new agricultural technologies has generally been found to be a function of farm and farmer characteristics and specific features of the particular technology (Feder et *al*., 1985; Marra and Carlson, 1987; Rahm and Huffman, 1984). A considerable set of research documents was developed regarding factors affecting the adoption of new agricultural technologies by farmers through use of innovation theory (Feder et *al*., 1985; Griliches, 1957, and Rogers, 1995). In addition, adoption and diffusion theory also have been widely used to identify factors that influence an individual's decision to adopt or reject an innovation. In this regards, Rogers (1995) defined an innovation as *"…an idea, practice or object that is perceived as new by an individual or other unit of adoption. The perceived newness of the idea for the individual determines his or her reaction to it*". Five characteristics of an innovation have been identified and could affect an individual's adoption decision:

- (i) **Relative advantage**: how the innovation is better than existing technology;
- (ii) **Compatibility**: the degree to which an innovation is seen as consistent with existing experiences, needs, and beliefs of adopters;
- (iii) **Complexity**: how difficult the innovation is to understand and use;

- (iv) **Trialability**: the degree to which the innovation may be used on a limited basis; and
- (v) **Observability**: the degree to which the results of an innovation are visible to others.

The relative advantage and observability of an innovation represents the immediate and long-term economic benefits from using it, whereas compatibility, complexity, and trialability indicate the ease with which a potential adopter can learn about and use an innovation (Boz and Akbay, 2005; King and Rollins, 1995). As the relative advantage, compatibility, complexity, trialability, and observability of liquid pollination and polycarbonate drying house have caused more farmers to adopt them in the GCC countries, in general and, in the Sultanate of Oman, in particular, we can consider the adoption of the two technologies as an innovation. The utilization and critical mass adoption of such technologies is an important prerequisite for agricultural development, particularly for the date palm producing countries in the Arabian Peninsula.

5.2 Methodological Framework: Adoption Analytical Model: Adoption and Diffusion Outcome Prediction Tool (ADOPT) (Note 1)

ADOPT is an MS Excel-based tool that evaluates and predicts the likely level of adoption and diffusion of specific agricultural innovations for particular target population. The tool uses expertise from multiple disciplines to make the knowledge about adoption of innovations more available, understandable and applicable to researchers, extension agents and research managers. ADOPT predicts the proportion of a target population that might adopt an innovation over time (Figure 5).

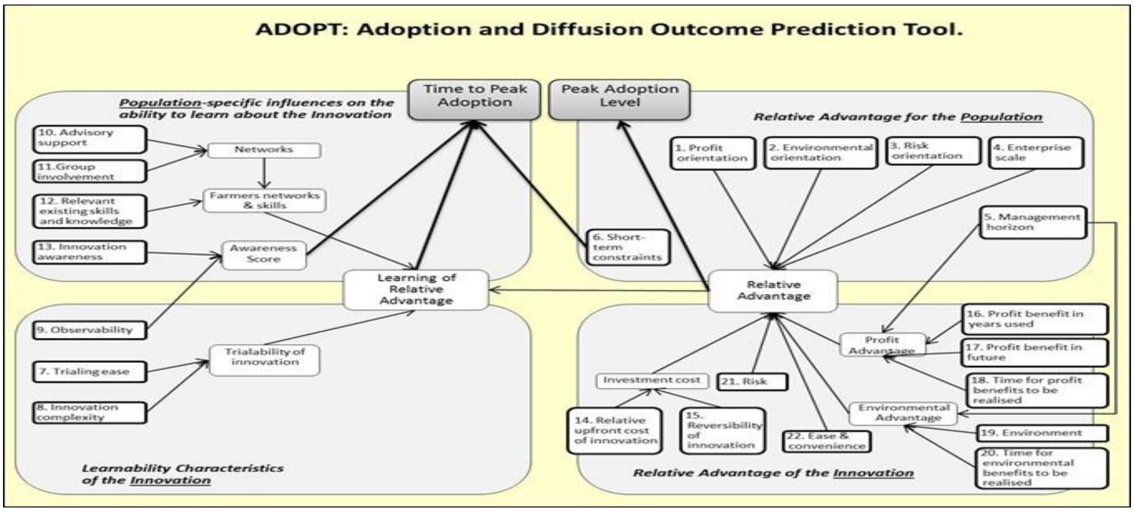


Figure 5. Adoption and Diffusion Outcome Prediction Tool (ADOPT)

Source: http://aciar.gov.au/files/node/13992/adopt_a_tool_for_evaluating_adoptability_of_agric_94588.pdf.

The tool makes the issues around the adoption of innovations easy to understand. ADOPT is useful for agricultural research organizations and people interested in understanding how innovations are taken up.

The tool has been designed to:

1. **Predict** the likely peak level of adoption of an innovation and the time taken to reach that peak.
2. **Encourage** users to consider the factors that affect adoption at the time that projects are designed.
3. **Engage** research, development and extension managers and practitioners by making adoptability knowledge and considerations more transparent and understandable.

ADOPT users respond to qualitative and quantitative questions for each of twenty-two variables influencing adoption. Going through this process also leads to increased knowledge about how the variables relate to each other, and how they influence adoption and diffusion. ADOPT framework is structured around four categories of influences on adoption (Figure 5 above): (1) Characteristics of the innovation; (2) Characteristics of the target population; (3) Relative advantage of using the innovation; and (4) Learning of the relative advantage of the innovation.

5.3 Data Collection and Data Sources

The study took place in two governorates in the Sultanate of Oman (South and North Al Batinah) characterized by an extensive date palm production and the common testing of the liquid pollination technology and implementation of the polycarbonate drying houses. The data were collected using focus group discussion (FGD) methodology (Krueger, 2002) to apply the ADOPT tool (Kuehne *et al.*, 2013) with a group of farmers in the two Governorates. To assess the liquid pollination technology, we interviewed 24 date palm growers divided in two equal FGD's, each covering 12 farmers'. For the polycarbonate drying house technology, a different group of ten (10) farmers have been interviewed. The study took place in the two governorates during January 2017.

We also organized a FGD with Ministry technical staffs representing both Agricultural Development Centers. All of them were males. One researcher from the Omani Date Palm Research Centre, the date palm project manager and the socio economic leader of the project economic activities from the International Center for Agricultural Research in the Dry Areas (ICARDA: http://www.icarda.org) conducted the FGD's with farmers. In the two cases, we streamlined 22 discussion questions around four categories of influences on adoption. The format of the discussion group consisted of both analytical questions (i.e., they discuss and collectively decide what they believe the answer is), and clarifying questions (i.e., questions that help clearing up confusion and explain why they had chosen this answer). Farmers have been asked to think about their problems related to implementing liquid pollination and the most challenging for them.

6. Results and Discussion

6.1 Factors Influencing Adoption Level and Time to Peak Adoption Level of LP Technology

The issue of this technology adoption by agricultural producers has not been assed. This study has generally focused on the technology adoption processes at the firm level and on identifying the main factors affecting its adoption process. The results of the program predicted that 95% of the South and North Al Batinah Communities would adopt the innovations after 16.9 and 14.5 years, respectively (Table 1).

Table 1. Predicted Adoption Levels of LPT at North and South Al Batinah - Sultanate of Oman

Predicted Peak Level and Time of LP Adoption	North Al Batinah Governorate	South Al Batinah Governorate
Predicted years to peak adoption	14.5	16.9
Predicted peak level of adoption	95%	95%
Predicted adoption level in 5 years from start	46.9%	35.8%
Predicted adoption level in 10 years from start	91.5%	85.8%

Source: Own elaboration from ADOPT (2017).

Note: Focus groups (# 12 farmers).

As displayed in the table above, the peak adoption rate for liquid pollination technology in the "North Al Batinah" is predicted to be 95% after a period of 14.5 years. The predicted adoption level in 5 years and 10 years from start is expected to be 46.9% and 91.5%, respectively. In "South Al Batinah" Governorate, the predicted adoption levels are similar. Indeed, the predicted years to peak adoption is 16.9 years and the peak level of adoption is around 95%. This peak is predicted to be 35.8% and 85.8% after 5 and 10 years from start, respectively.

Results from the sensitivity analysis (Figures 6 & 7) indicates that farmers' conditions of severe short-term financial constraints, the trialability of the innovation on a limited basis before a decision is made to adopt it on a larger scale, the perception and evaluation of the liquid pollination technique; i.e. how the innovation allow the effects of its use to be easily evaluated when it is used, the paid advisory delivery system, the development of substantial new skills and knowledge to use the innovation by the farmers, and finally the size of the up-front cost of the investment relative to the potential annual benefit from using the innovation are the driving adoption factors for the liquid pollination technology in the two targeted areas.

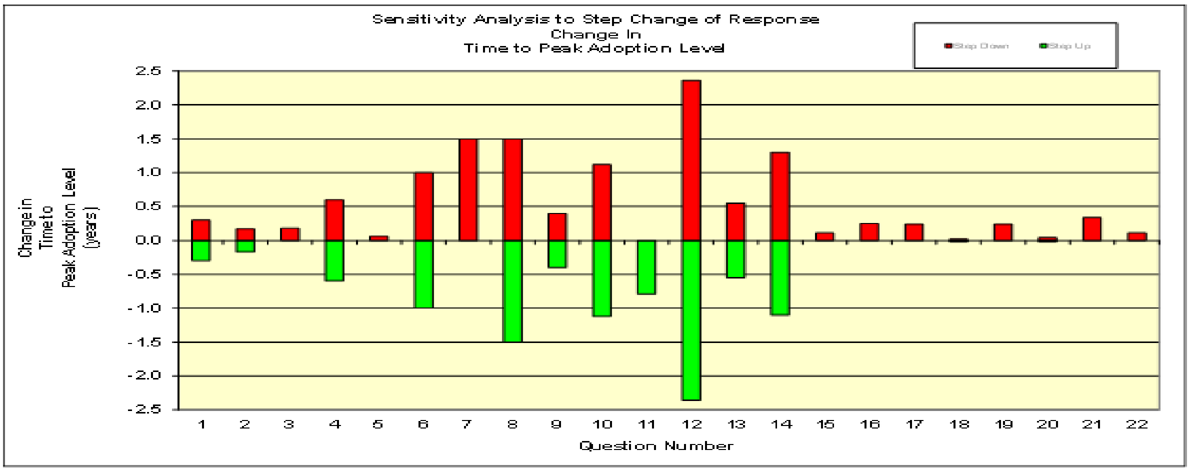


Figure 6. Sensitivity Analysis of Adoption Curve of LPT at “North Al Batinah” Governorate - Sultanate of Oman

Source: Own elaboration from ADOPT (2017).

Note 1: Red Column: Step Down; Green Column: Step Up.

Note 2: Focus groups (# 12 farmers).

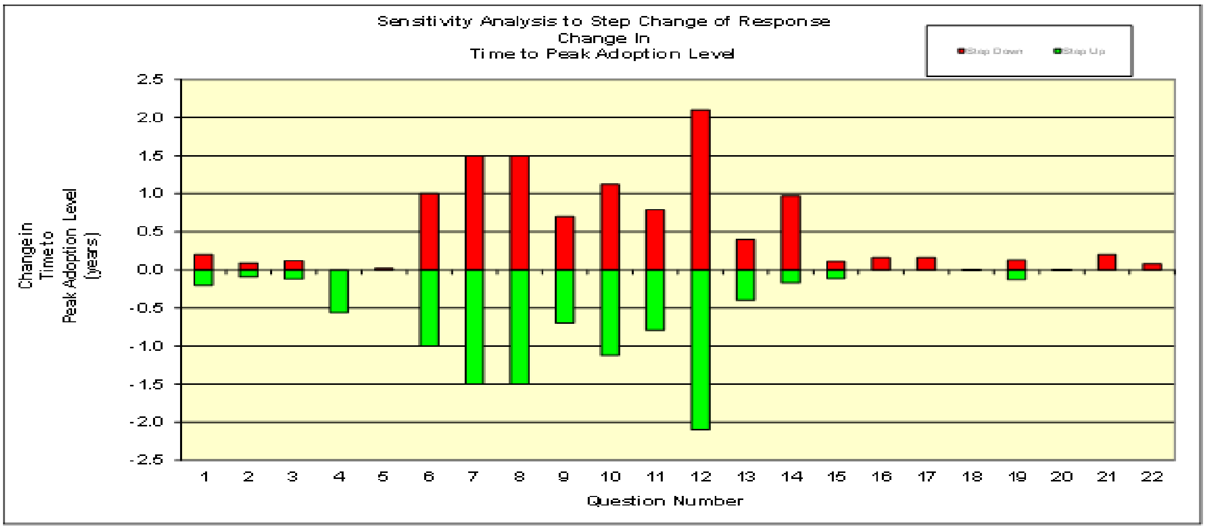


Figure 7. Sensitivity Analysis of Adoption Curve of LPT at “South Al Batinah” Governorate - Sultanate of Oman

Source: Own elaboration from ADOPT (2017).

Note 1: Red Column: Step Down; Green Column: Step Up.

Note 2: Focus groups (# 12 farmers).

6.2 Factors Influencing Adoption Level and Time to Peak Adoption Level of PDH Technology

The predicted years to peak adoption and the predicted adoption level, including the level in 5 and 10 years from start, is presented in Table 2. Even though adoption and diffusion of the PDH dryer is very difficult to forecast—the issue is complex and crosses economic, social and psychological disciplines—there is an ongoing need and demand for specific estimates to be made.

Empirical findings from the table below revealed that 95% of “South Al Batinah” Community would adopt the innovations after 20.9 years. However, the predicted adoption levels after 5 and 10 years from start is 23.5% and 72.9%, respectively. Even though the time to peak adoption was longer than what we expected (bearing in mind that this figure affected the attractiveness of the technology in the future funding), these results are expected since the upfront cost of investment is quite high while the economic viability of this technology make the evidence of its profitability. Indeed, the outcomes from this tool could be considered as real values to inform the different stakeholders about the influences on adoption and diffusion of the PDH technology in Oman.

Table 2. Predicted Adoption Levels of PDH Technology at "South Al Batinah" Governorate - Sultanate of Oman

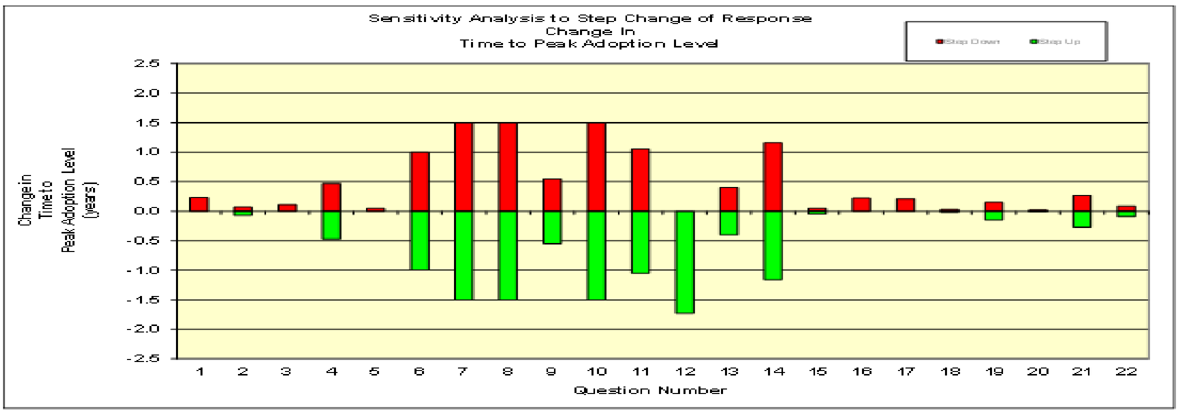
Predicted Peak Level and Time of PDH Adoption	South Al Batinah Governorate
Predicted years to peak adoption	20.9
Predicted peak level of adoption	95%
Predicted adoption level in 5 years from start	23.5%
Predicted adoption level in 10 years from start	72.9%

Source: Own elaboration from ADOPT (2017).

Note: Focus groups (# 10 farmers).

After presenting these indicators, the FGD's outputs discussion outlined that farmer's most commonly cited motivations for adopting this technology although the high upfront cost of investment. Our study and FGD's discussion found that both adopters and non-adopters saw the greatest benefits of this technology in terms of its potential benefit on the quality of the final agricultural dried products (dates, in this case). Another assessment framework to better understand the factors associated the rapid and large adoption of the PDH technology was by conducting a sensitivity analysis. Important factors to farmer decision making differ according to geographic, economic, and social context.

Figure 8: Sensitivity Analysis of Adoption Curve of PDH Dryer Technology at the "South Al Batinah" Governorate - Sultanate of Oman



Source: Own elaboration from ADOPT (2017).

Note 1: Red Column: Step Down; Green Column: Step Up.

Note 2: Focus groups (# 10 farmers).

However, taken together, the results from the sensitivity analysis regarding the main factors affecting the adoption decision of PDH technology in AL Batinah Governorate are displayed in Figure 8. The figure content indicates that trialability of the innovation on a limited basis before a decision is made to adopt it on a larger scale, the perception and evaluation of the PDH technique; i.e. how the innovation allow the effects of its use to be easily evaluated when it is used, the paid advisory delivery system capable of providing advice relevant to the use and management of the technology, and finally the size of the up-front cost of the investment relative to the potential annual benefit from using the innovation are the driving adoption factors for the PDH technology in the target area.

7. Concluding Remarks and Policy Implications

The objective of this paper is to analyze the main factors affecting the predicted adoption level, the peak to reach this level, and the constraints of adoption of LP and PDH technologies introduced by the date palm project in the sultanate of Oman. The methodological framework used was based on the implementation of the ADOPT tool to focus groups of date palm growers in two localities of the Sultanate. In the FGD we streamlined 22 discussion questions around four categories of influences on adoption: characteristics of the innovation, characteristics of the target population, relative advantage of using the innovation and learning of the relative advantage of the innovation.

The empirical findings obtained from the liquid pollination technology assessment indicates that peak adoption rate for liquid pollination technology in "North Al Batinah" is predicted to be 95% after a period of 14.5 years. The predicted adoption level in 5 years and 10 years from start is expected to be 46.9% and 91.5%, respectively. In "South Al Batinah" Governorate, the predicted adoption levels are similar. Indeed, the predicted years to peak adoption is 16.9 years and the peak level of adoption is around 95%. This peak is predicted to be 35.8% and 85.8% in 5 and 10 years from start, respectively. The assessment of the rate of adoption of the PDH technology and the identification of factors affecting the peak and adoption levels, and constraints that limit the adoption process and widespread of such technology among the date palm growers of Oman indicates that peak adoption rate for PDH technology in the target study region is predicted to be 95% after a period of 21 years. The predicted adoption level after 5 and 10 years is expected to be 23.5% and 72.9%, respectively.

The presented results suggested that sustainable increases in productivity of date palm in the Sultanate of Oman could be achieved if farmers are encouraged to adopt the liquid pollination and polycarbonate drying chambers technologies. However, the adoption of such technology needs to be accompanied by a supporting extension system and an enabling policy environment to ensure the scaling-up and widespread use of this promising and profitable technology. Such findings can provide a useful framework for decision-making as date palm producers and policy makers confront sustainable date palm farming system. In addition, the results can facilitate the policy formulation process as policy makers, responding to societal pressures, attempt to move date palm farming system in a more sustainable direction while trying to improve the profitability of the sector, in general. Implications could be derived for producers for whom local environmental quality is closely linked to date palm production systems in Oman. The results from the present research study suggest the following:

- Creation of private service companies to carry out and monitor the LP operations. These companies can even be operated by small farmers in order to diversify their income sources;
- Enhancing the extension services (more and specialized extension agents) and the development of an effective extension service for Omani date palm growers;
- Reinstatement of the subsidy system in the sector;
- Creation of private services and marketing companies with support from the government;
- Enhancing the awareness of farmers regarding the profitability of using this technology in comparison to the manual pollination method;
- Development of an agricultural management program for date palm tree services, the application of quality control measures, and an increase in capacity building to reduce the cost of production;
- Make introducing the technology to the responsibility of the government; it cannot be left to farmers;
- Valorization of the date palm by-products (to generate more profit for the date palm producers).
- Polycarbonate projects should targeted high levels date palm productions areas.

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Declarations of conflict of interest

The authors report no declarations of conflict of interest.

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Notes

Note 1. All information concerning how ADOPT works is found at: http://aciar.gov.au/files/node/13992/adopt_a_tool_for_evaluating_adoptability_of_agric_94588.pdf.

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Evidence of Soil Health Benefits of Flooded Rice Compared to Fallow Practice

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Abstract

Flooded rice (*Oryza sativa L.*) in south Florida is grown commercially in rotation with sugarcane and vegetables. From 2008 to 2018, rice production has doubled. During the spring-summer, nearly 200 km^2 of fallow sugarcane land is available for rice production. In 2017, approximately 113 km^2 of rice were planted in the region. The net value of growing rice as a rotation crop far exceeds its monetary return. This study evaluated soil health parameters before and after rice cultivation and compared them against two other common summer farming practices - fallow fields and flooded-fallow. The soil health parameters that were tested as part of this study included soil pH, bulk density, water holding capacity, cation exchange capacity, organic matter, active carbon and nutrient content. Results indicated an increase in soil pH, and a significant reduction in soil bulk density due to rice cultivation. Water holding capacity increased significantly under all flooded land use practices compared to fallow fields. Cation exchange capacity significantly increased when sugarcane fields were cultivated with rice and ratoon rice, nearly doubled from 58 to 101 cmolc kg^{-1}. Small, yet significant 3% increase in organic matter was observed when sugarcane fields were cultivated with ratoon rice. Almost 16 g kg^{-1} of active C is being generated within fallow soils, whereas less than half that under flooded practices, limiting the amount of soil loss via oxidation. Based on the soil health index, rice cultivation and flooded-fallow improved overall soil quality compared to fallow lands.

Keywords: flooded-fallow, rice cultivation, histosols, soil health, active carbon

1. Introduction

1.1 Rational & Justification

Soil health is a term synonymous with soil quality. It refers to the chemical, biological, and physical characteristics of a soil that influences its ability to function sustainably, and to satisfy the needs of humans, support plants, and cycle elements, water, and energy between Earth systems (Doran et al., 1994). It is often said that a handful of productive soil contains more living organisms than people living on Earth. Managing soil health involves maintaining a habitat for these living organisms, which include bacteria, algae, fungi, and plants (Alkorta et al., 2003). When these soil organisms die and decay, organic matter is created, which is primarily made up of carbon compounds. Organic matter is a key component of soil health because it fuels the diverse biological functions of soil organisms, which obtain their energy and nutrients by breaking down plant residues (Follett et al., 1987). Organic matter improves soil structure, reduces compaction, and minimizes soil erosion by enhancing macropore stability and water infiltration. Enhanced soil structure also improves the ability of agricultural fields to withstand conditions of drought or extreme rainfall. Such hydrology considerations are particularly relevant to the health of Florida soils because potential drainage and surface runoff issues are widespread. Mineralization of organic matter helps supply crops with essential nutrients, including nitrogen (N), phosphorus (P), potassium (K), and most of the micronutrients. Therefore, agronomic practices should consider these various biological, physical, and chemical characteristics of soil health and the integrated role soil organic matter plays in supporting agricultural systems.

1.2 Study Area

The Everglades Agricultural Area (EAA) consists of a portion of the original Everglades region of south Florida, USA, which was artificially drained in the mid-twentieth century to sustain a farming industry within the region. Nearly 80% of the 1,800 km^2 of farming land is used to grow sugarcane while the remaining 20% is used in rotation to grow winter vegetables and rice. Soil loss due to oxidation is a major concern for growers in the region. The organic soils formed over a period of thousands of years as a result of organic matter accretion within the flooded sawgrass prairies south of Lake Okeechobee. Beginning early 1900s, soils within the EAA were drained for crop production. Gradually, organic matter decomposition exceeded accretion, resulting in loss of soil and lowering of the surface elevation, a process referred to as "subsidence". Underneath these organic soils is hard limestone bedrock, and this makes subsidence all the more important since land cultivation and water management would be difficult. It is apparent that soil loss due to subsidence is not constant, and in fact has decreased by nearly 50% between 1924-1967 to 1968-2009 (Wright & Snyder, 2009). A major factor influencing the decline in soil subsidence has been improved water management throughout the EAA. Studies have shown that soil loss due to oxidation is directly related to the redox condition of the soil (Ponnamperuma, 1984; Reddy & Patrick, 1975). Generally, well drained soils oxidize at a faster rate than under flooded or poorly drained conditions. Implementation of Best Management Practices (BMPs) in the mid-1990s has led to more water storage on EAA fields, which helps to reduce organic matter decomposition and decrease soil oxidation rate (Bhadha & Schroeder, 2017). Another commonly implemented BMP in the EAA is to rotate sugarcane with rice. Since rice in the EAA is typically grown under flooded conditions, it is an optimal rotational crop planted in late spring-early summer which helps reduce soil oxidation by field flooding. Continuation of BMP implementation by growers, development of flood-tolerant crop cultivars, reduced tillage, and adoption of crop rotations, has the potential for minimizing subsidence and increase the longevity for agricultural use. Soil-forming factors are well known and soil properties are measurable, but the current emphasis on soil health requires an integrative assessment of how intrinsic soil properties are affected by soil management. Evaluating changes in soil properties associated with flooded rice fields during the summer months in the EAA provides us an opportunity to assess the effect of soil management associated with flooding versus fallow.

1.3 Rice Cultivation in South Florida

Rice has been commercially grown in the EAA since 1977 after it was demonstrated that rice could be successfully grown in rotation with sugarcane during the summer fallow period (Alvarez et al., 1979). The EAA comprises 1,800 km^2 of Histosols that are devoted to sugarcane production. During the summer period, more than 200 km^2 of fallow sugarcane land is available for rice production. In 2017, approximately 113 km^2 of rice were planted in the EAA (FRG, 2017). The net value of growing rice in the EAA as a rotation crop far exceeds its monetary return. In addition to being a food crop in Florida, production of flooded rice provides several benefits to the agroecosystem. By flooding fields, growers greatly reduce the negative impacts from issues related to soil subsidence (Wright & Snyder, 2009), nutrient depletion, and insect pests (Cherry et al., 2015). This, in turn, enhances the subsequent sugarcane crop and maximizes the longevity of the soil by reducing soil loss due to oxidation. In addition, incorporating rice as a rotation crop in the EAA during the summer months also provides local employment (Schueneman et al., 2008).

1.4 Objectives

The objectives of this study were to (i) evaluate soil health response of cultivating flooded rice in South Florida compared to alternative practices such as flooded fallow and fallow; (ii) develop a soil health index that will rank land use practices based on its impact on soil quality. Six different farming practices were evaluated for a suit of soil health indicators. The six farming practices included sugarcane followed by ratoon rice (two successive rice crops), sugarcane followed by single rice crop; sweetcorn followed by rice; lettuce followed by rice; sugarcane followed by flooded fallow; and sugarcane followed by fallow. The six farming practices are shown in Figure 1. These farming practices are typical of the EAA during the summer period.

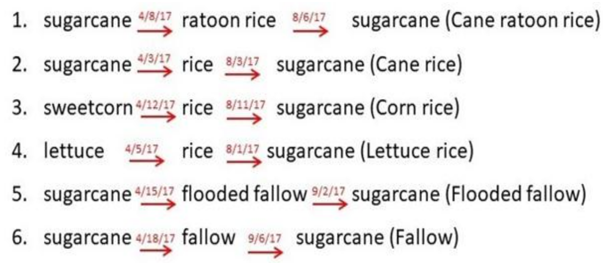

Figure 1. Six farming practices in the summer. The red arrows indicate when soil samples were collected

2. Material and Methods

2.1 Soil Health Indicators

Six 0.16 km^2 commercial fields were selected for each farming practice, and a composite soil sample was collected from the top 15 cm from each field. A composite sample comprised of mixing ten soil samples collected along a transect from individual fields. The soil samples from each field were collected twice, just before rice was planted (pre) and right after the rice was harvested (post), approximately 120 d apart. In the case of flooded fallow, the soil samples were collected just before the flooding was initiated and right after the water was drained, approximately 140 d apart. In case of the fallow fields, soil samples were collected just before the fields were left fallow and just before they were tilled to prepare fall planting, approximately 130 d apart. All soil samples were collected in 1-gallon Ziploc pouches and transported to the Soil, Water and Nutrient Management Laboratory at the Everglades Research and Education Center where they were analyzed for the various soil health indicators.

Pre and post soil samples were collected from each field were air dried, passed through 2 mm sieve and analyzed for various soil health parameters. Soil health indicators tested include pH, bulk density (BD), organic matter content (OM), maximum water holding capacity (MWHC), cation exchange capacity (CEC), potassium permanganate oxidizable active carbon (Active C), Mehlich 3 phosphorus (M3P) and potassium (M3K), total phosphorus (TP) and total Kjeldahl nitrogen (TKN). pH was determined using 1:10 soil:water extract using Accumet AB250 pH meter. Bulk density was calculated measuring soil mass in the known core volume. Organic matter content was determined based on loss on ignition (LOI) at 550 ℃. Maximum water holding capacity was determined using modified method described by Jenkinson and Powlson (1976) measuring amount of water retained in soil after saturation. Cation exchange capacity was estimated using the ammonium acetate method (Sumner and Miller, 1996) and ammonium concentrations were analyzed with flow injection analysis on a Lachat analyzer (QuikChem Method 10-107-06-2-A. Hach Company, Loveland, CO). The ammonium concentration in mg L^{-1} was converted to its equivalent on cmolc kg^{-1} soil. Active C was determined based on potassium permanganate ($KMnO_4$) oxidizable carbon using 0.2 M $KMnO_4$ for muck soils. Approximately 2 g of soil was reacted with 20 mL of 0.2 M $KMnO_4$ for two minutes, filtered and supernatant solution was analyzed for remaining concentration of $KMnO_4$ using Thermo Scientific Genesys 30 spectrophotometer at 550 nm. Active C concentration was determined from the amount of $KMnO_4$ oxidized. Extractable P and K were determined based on Mehlich-3 extraction technique analyzed using Agilent 5110 inductively coupled plasma-optical emission spectrometer (ICP-OES, Santa Clara CA). Total P was determined by ashing samples followed by extraction with 6M HCl and analyzed using ICP-OES. Total Kjeldahl nitrogen was determined by digestion followed by colorimetric determination (EPA method 351.2). Statistical analysis was done using t–test for two sample replicates assuming unequal variances at $\alpha = 0.05$ level of significance with Microsoft Excel.

2.2 Soil Health Index

Soil health index (SHI) was developed based on three step framework of (i) indicator selection, (ii) interpretation, and (iii) indexing based on Cornell Comprehensive Assessment of Soil Health Manual (Moebius-Clune et al., 2016) adapted from (Andrews et al., 2004). The indicators were used to develop scoring function between 0 to 100 by estimating the cumulative normal distribution (CND) function using the mean and standard deviation of soil samples collected from rice fields in the EAA. Details regarding the indexing and scoring is available at Cornell Comprehensive Assessment of Soil Health Manual (Moebius-Clune et al., 2016). Increase in value was given positive score and decrease in indicator value was given negative score for all parameters except pH, BD and Active C as increase in these parameter value are non-desirable from sustainable agricultural perspective within the EAA (Table 1). Overall scores were calculated in two ways – first based on average of all the scores;

and alternatively excluding nutrient scores (M3P, M3K, TKN and TP).

Table 1. Soil health scoring guide

	pH	BD[†]	OM	MWHC	CEC	Active C	M3P	M3K	TKN	TP
Increase	-	-	+	+	+	-	+	+	+	+
Decrease	+	+	-	-	-	+	-	-	-	-

+= positive; - = negative. †BD= bulk density; OM= organic matter content; MWHC= maximum water holding capacity; Active C= active carbon; CEC= cation exchange capacity; M3P= Mehlich 3 phosphorus; M3K= Mehlich 3 potassium; TP= total phosphorus; TKN= total Kjeldahl nitrogen

3. Results

3.1 Change in Soil Health Indicators

The pH for all the soil samples were neutral to alkaline and ranged from 7.08 to 8.06. Pre and post sample pH remained similar for ratoon rice and corn rice; however, there was significant increase in soil pH for rest of the farming practices (Figure 2).

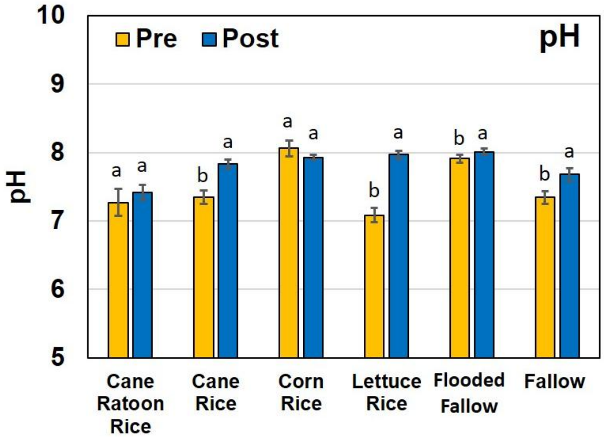

Figure 2. Changes in soil pH pre and post six farming practice (mean and standard deviation). Different lower case alphabets correspond to significant differences ($p \leq 0.05$)

Bulk density of the soils ranged from 0.50 to 0.66 g cm^{-3} (Figure 3). While all farming practices that involved rice cultivation showed a slight decrease in BD; there was a significant decrease in BD observed between pre and post soil of the Cane rice farming practice. There was also a significant increase in soil BD between pre and post farming practice of the flooded fallow fields.

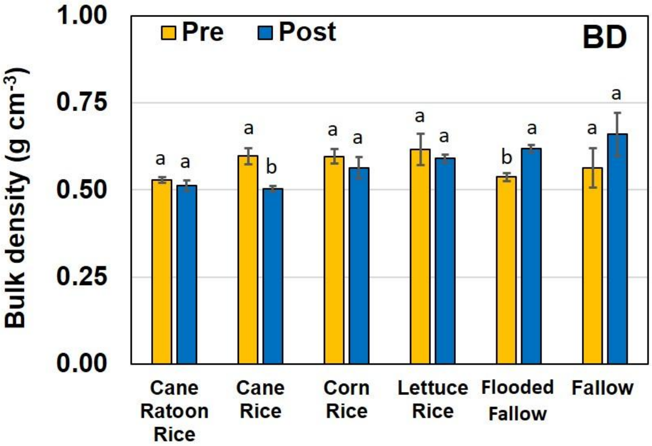

Figure 3. Changes in soil bulk density (BD) pre and post six farming practice (mean and standard deviation). Different lower case alphabets correspond to significant differences ($p \leq 0.05$)

Maximum water holding capacity of soils in Cane rice, Cane ratoon rice, Corn rice, Lettuce rice and Flooded fallow farming practices all showed significant increase between pre and post samples; while fallow treatment remained similar (Figure 4). The MWHC capacity of all post study samples were in range of 125 to 283%.

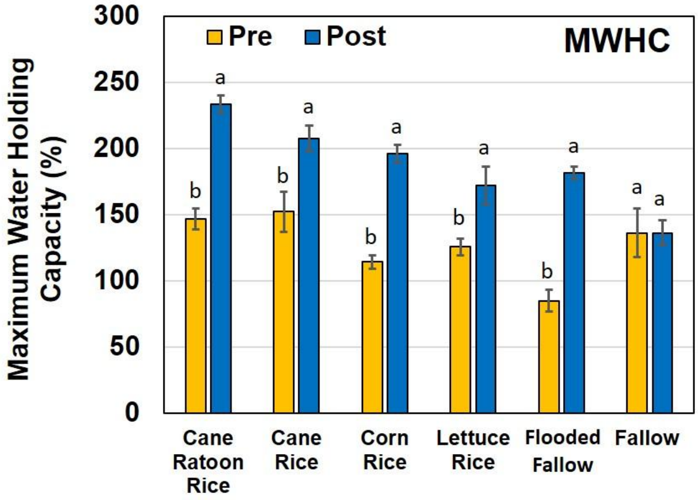

Figure 4. Changes in soil maximum water holding capacity (MWHC) pre and post six farming practice (mean and standard deviation). Different lower case alphabets correspond to significant differences ($p \leq 0.05$)

Cation exchange capacity of soils collected pre farming practice ranged from 46 to 94 cmolc kg^{-1} and post farming soil samples were in the range of 73-101 cmolc kg^{-1} (Figure 5). Cation exchange capacity significantly increased for Cane ratoon rice and Cane rice treatments; whereas remained statistically similar for Corn rice, Flooded fallow and Fallow treatments.

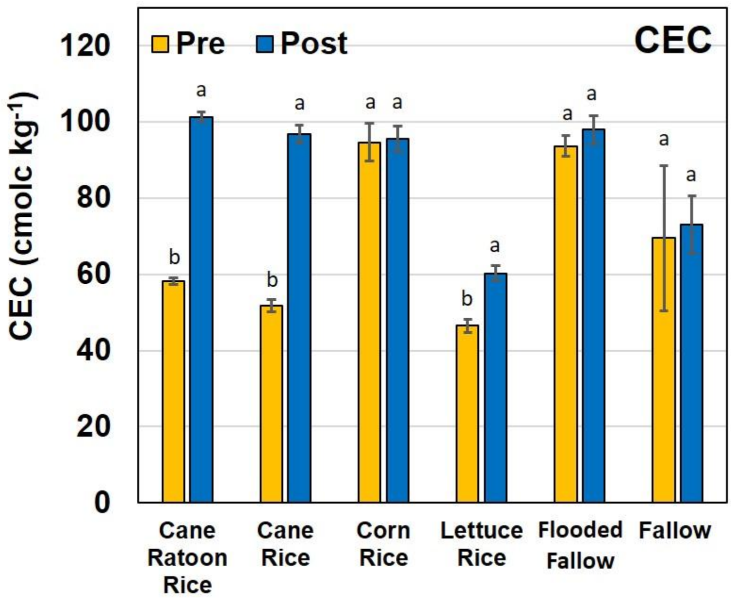

Figure 5. Changes in soil cation exchange capacity (CEC) pre and post six farming practice (mean and standard deviation). Different lower case alphabets correspond to significant differences ($p \leq 0.05$)

Organic matter content of samples ranged from 72-83% except for fallow treatments which had 56-57% OM (Figure 6).There was significant increase of 3% OM content for Cane ratoon rice, while other farming practices remained statistically similar and showed no change between pre and post soil samples.

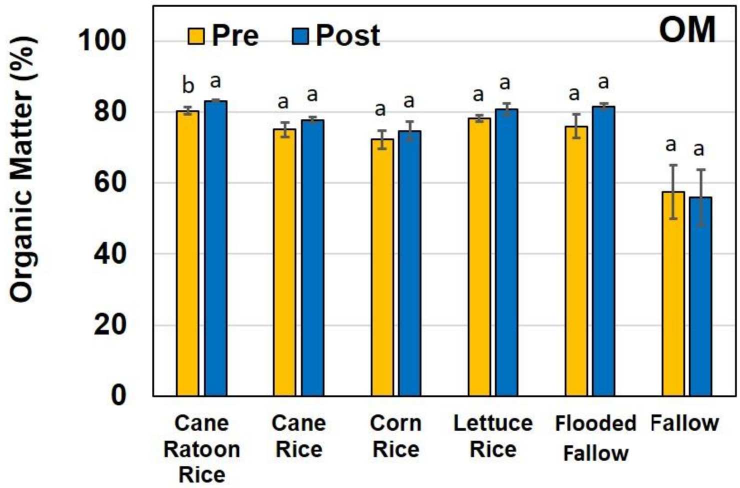

Figure 6. Changes in soil organic matter (OM) content pre and post six farming practice (mean and standard deviation). Different lower case alphabets correspond to significant differences ($p \leq 0.05$)

There was significant increase observed in the soil active carbon content for Cane ratoon rice, Corn rice and Fallow treatments (Figure 7). Active C content decreased for Lettuce rice treatment; whereas it remained statistically similar for Cane rice and Flooded fallow treatments.

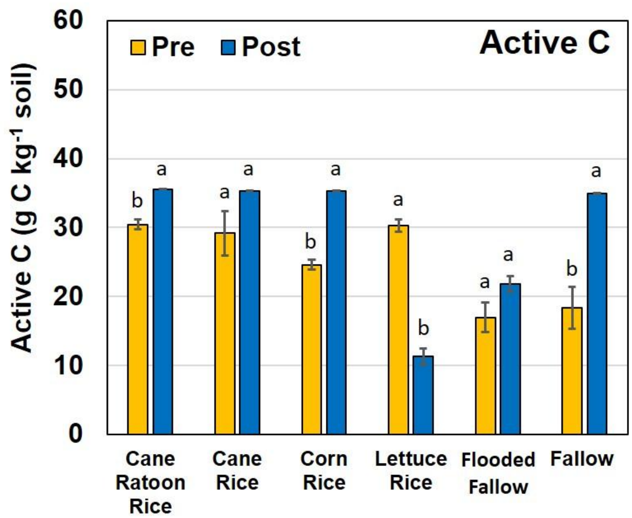

Figure 7. Changes in soil active carbon content pre and post six farming practice (mean and standard deviation). Different lower case alphabets correspond to significant differences ($p \leq 0.05$)

Except for Lettuce rice and Flooded fallow treatments, there was no significant change in TP concentration for other treatments between pre and post soil (Figure 8). Mean TP concentrations reduced in Cane ratoon rice, Cane rice, and Lettuce rice between the pre and post soil, whereas it increased in Corn rice, Flooded fallow and in Fallow fields. Lettuce rice TP concentration decreased from 928 to 600 mg kg^{-1} whereas Flooded fallow TP increased from 950 to 3478 mg kg^{-1}. Total Kjeldahl nitrogen concentration of soil samples ranged from 15000 mg kg^{-1} to 21000 mg kg^{-1}. Mean TKN concentrations reduced in all except the Fallow treatment between the pre and post soil. Total Kjeldahl nitrogen did not change significantly for Corn rice, Flooded fallow and Fallow treatments; whereas there was significant decrease for rest of the treatments. Mean M3P concentration between the pre and post soil was significantly reduced in Lettuce rice treatment. M3K concentration was in range of 148 to 722 mg kg^{-1} for pre samples and 102 to 278 mg kg^{-1} for post soil samples. Mean M3K concentration did not change for Corn rice and Fallow treatments, whereas reduced for all other treatments (Figure 8).

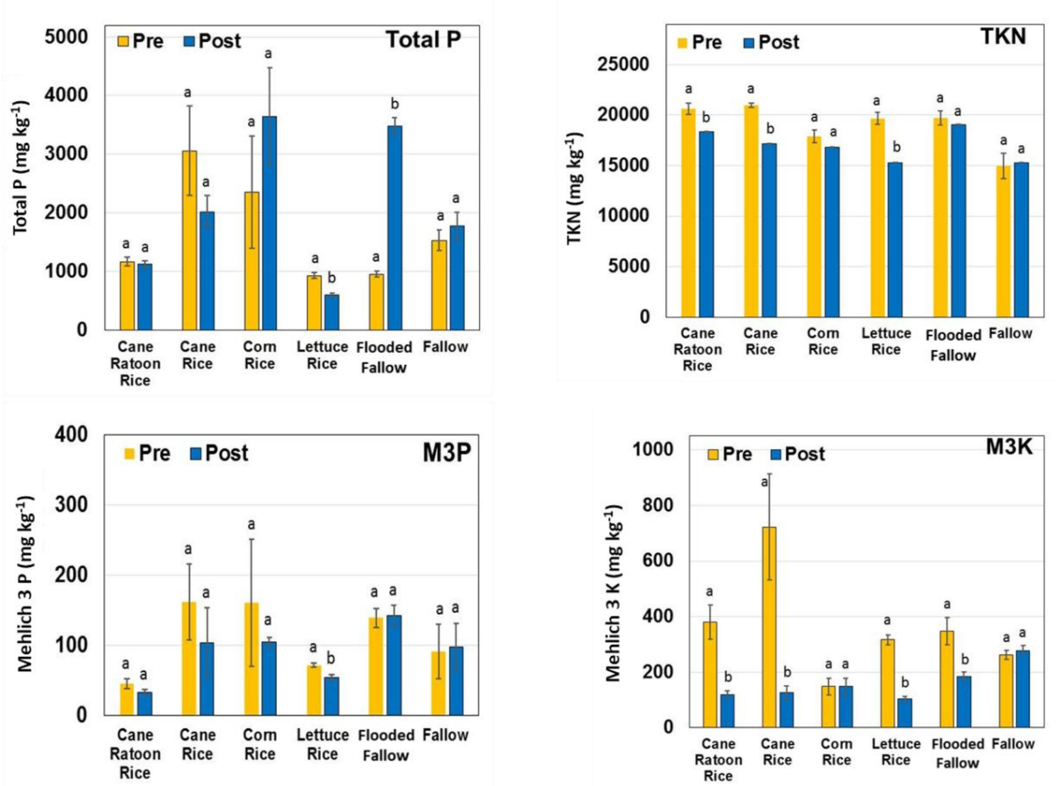

Figure 8. Changes in soil TP, TKN, Mehlich 3 P, and Mehlich 3 K concentrations pre and post six farming practice (mean and standard deviation). Different lower case alphabets correspond to significant differences ($p \leq 0.05$)

Soil Health Index for various soil health parameters from different crop rotation practices are summarized in Table 2.

Table 2. Cumulative normal distribution values (a) and scores (b) for various soil health parameters for pre and post rice study

a. CND‡																				
	pH		BD†		OM		MWHC		Active C		CEC		M3P		M3K		TP		TKN	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Cane Ratoon Rice	0.18	0.29	0.29	0.24	0.69	0.77	0.41	0.95	0.66	0.84	0.22	0.84	0.33	0.30	0.69	0.25	0.30	0.29	0.78	0.48
Cane Rice	0.23	0.69	0.61	0.20	0.52	0.61	0.46	0.86	0.60	0.83	0.15	0.79	0.59	0.46	0.98	0.26	0.86	0.58	0.81	0.32
Corn Rice	0.86	0.77	0.61	0.46	0.43	0.51	0.18	0.80	0.40	0.83	0.76	0.77	0.58	0.46	0.29	0.34	0.69	0.94	0.42	0.28
Lettuce Rice	0.08	0.80	0.69	0.58	0.62	0.70	0.25	0.62	0.65	0.04	0.11	0.24	0.38	0.35	0.58	0.23	0.24	0.16	0.67	0.13
Flooded Fallow	0.76	0.83	0.33	0.70	0.55	0.72	0.06	0.70	0.13	0.29	0.75	0.80	0.54	0.54	0.64	0.35	0.24	0.93	0.67	0.58
Fallow	0.23	0.54	0.45	0.85	0.08	0.06	0.33	0.33	0.17	0.82	0.38	0.43	0.43	0.44	0.49	0.51	0.42	0.50	0.11	0.13
b. SCORE																				
	pH		BD		OM		MWHC		Active C		CEC		M3P		M3K		TP		TKN	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Cane Ratoon Rice	82.36	70.84	70.60	76.41	68.91	76.61	41.35	94.70	34.22	16.20	22.07	83.52	32.72	30.26	68.84	25.20	30.13	28.81	78.11	48.47
Cane Rice	76.61	30.72	39.00	79.94	51.83	61.00	45.79	85.69	39.66	16.87	15.07	78.57	58.67	45.51	97.78	26.15	86.23	58.21	81.46	32.17
Corn Rice	13.90	22.70	39.30	54.37	42.58	50.65	18.13	79.58	59.95	17.01	75.93	77.06	58.46	45.83	29.44	34.37	68.91	94.42	42.32	28.33
Lettuce Rice	91.90	19.88	30.60	42.20	62.05	69.99	25.16	62.19	34.75	96.06	10.59	24.47	38.33	34.52	58.17	22.89	23.59	15.89	66.59	13.17
Flooded Fallow	24.12	16.96	66.60	29.71	54.84	72.44	6.30	69.71	86.71	71.33	74.71	79.88	53.63	54.33	63.58	35.21	24.16	92.65	66.93	58.47
Fallow	77.00	45.60	54.71	15.29	7.65	6.06	32.87	32.87	83.10	17.94	37.56	43.17	42.74	44.17	48.66	51.44	41.73	49.82	10.63	13.17

‡CND= cumulative normal distribution. Positive Score =100*CND; Negative Score =100*(1-CND). †BD= bulk density; OM= organic matter content; MWHC= maximum water holding capacity; Active C= active carbon; CEC= cation exchange capacity; M3P= Mehlich 3 phosphorus; M3K= Mehlich 3 potassium; TP= total phosphorus; TKN= total Kjeldahl nitrogen

Overall changes in SHI due to rice planting are summarized in Figure 9a. and Table 3a. There was overall increase in SHI for Cane ratoon rice, corn rice and flooded fallow treatments while there was net decrease in SHI for Cane rice, Lettuce rice and Fallow treatments. We also developed SHI for the treatments including all scores expect nutrients (M3P, M3K, TKN, TP) to see soil health change in other parameters excluding nutrients (Fig. 9b and Table 3b). There was net increase in SHI for all rice rotation practices along with flooded fallow treatment; whereas there was net decrease in SHI for fallow treatment only when excluding the nutrients.

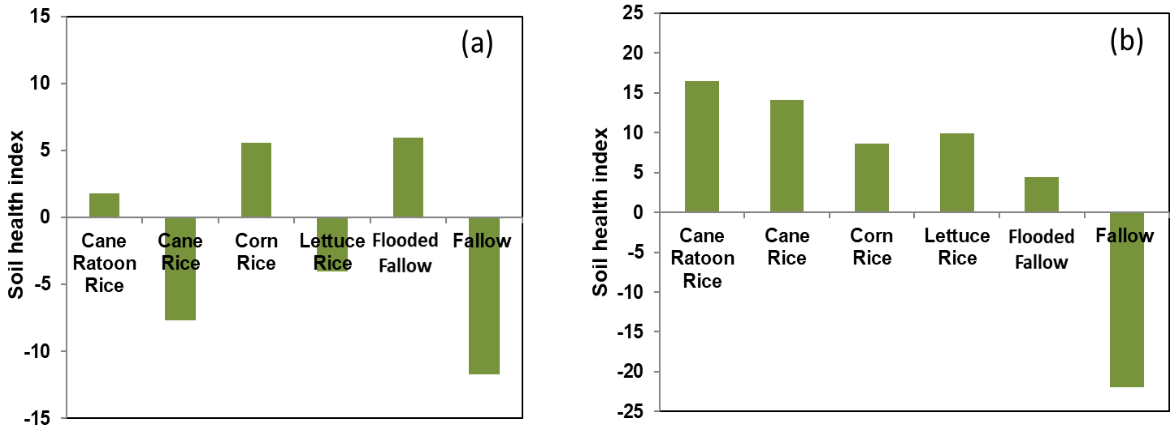

Figure 9. (a) Changes in overall soil health index for pre and post samples for various farming practices. (b) Changes in soil health index derived from indicators excluding nutrients (Mehlich-3P, Mehlich-3K, TKN, TP) for pre and post samples for various farming practices

Table 3. Changes in overall soil health index for pre and post samples for various farming practices including nutrients (a) and excluding nutrients (b)

a. Overall Score			
	Pre	**Post**	**Score change**
Cane Ratoon Rice	50.97	52.74	1.77
Cane Rice	59.21	51.48	-7.73
Corn Rice	44.89	50.43	5.54
Lettuce Rice	44.17	40.13	-4.05
Flooded Fallow	52.16	58.07	5.91
Fallow	43.67	31.95	-11.71
b. Score (w/o nutrients)			
	Pre	**Post**	**Score change**
Cane Ratoon Rice	53.25	69.72	16.46
Cane Rice	44.66	58.80	14.14
Corn Rice	41.63	50.23	8.59
Lettuce Rice	42.51	52.47	9.96
Flooded Fallow	52.21	56.67	4.46
Fallow	48.81	26.82	-21.99

4. Discussion

4.1 Changes in Soil Health Indicators

The high pH of the soils are a result of years of mixing of underlying limestone (calcium carbonate) bedrock with the top soil. As these soils get shallower, the mineral fraction comprising of Ca and Mg-based minerals gets larger raising the soil pH. The significant increase in soil pH post rice cultivation is probably due to the high pH (up to 9) observed in the irrigation water of local farm canals (Daroub et al., 2017). Increase in soil pH is a major concern for growers in the EAA as it can potentially lower the bioavailability of micro-nutrients from the soils (Sims & Patrick, 1978). The slight decrease in bulk density observed between the pre and post soil samples of all rice cultivation farming practices may be due to the increase in OM content associated with the rice root density in the top soil. Once rice is harvested the roots and a few cm of the stalks remain in the soil, and gets tilled prior to planting of the subsequent crop. This lowering of soil BD is preferred because it facilitates aeration, better tilth, and limits root constriction. The significant increase observed in soil BD in the flooded fallow fields is due to compaction of the soil and lack of root density associated with rice cultivation. There was a significant increase in soil MWHC of soils that were flooded, this included all four treatments of rice cultivation and the flooded fallow fields. This increase in MWHC is probably related to the increase in the OM content of the soil. Bhadha et al. (2017) were able to demonstrate that by adopting farming methods that increase soil OM, growers can increase the MWHC of their soils. According to the USDA-NRCS, the most conservative estimates suggest that every 1% increase in soil OM will help soils hold up to 75,000 L more water per acre (Bryant, 2015). Cation exchange capacity significantly increased between the pre and post soils for the Cane ratoon rice and Cane rice framing practices. The CEC of soils is primarily controlled by the carbon content and clay sized particle fraction of soils (Parfitt et al., 1995). The histosols within the EAA inherently have very high carbon content (> 70%), hence the CEC values are higher than 50 cmolc kg^{-1}. An increase in soil CEC between the pre and post soils is considered as a positive change because it can potentially retain non-foliar fertilizer and pesticides longer in the soil matrix. Pal and Vanjara (2001) were able to demonstrate that malathion (insecticide) and butachlor (herbicide) had greater affinity for soils composed of minerals like bentonite with higher CEC and higher surface area compared to kaolinite. Increasing soil OM is key to improving soil health (Doran & Zeiss, 2000). Soils with high OM and aggregates can absorb and hold water during rainfall events and deliver it to plants during dry spells. Water is increasingly becoming the most limited natural resource supporting agriculture (Rijsberman, 2006), but growers in the EAA can improve their water storage capacity by raising their soil's OM content (Bhadha et al., 2017). Results indicate that flooded rice cultivation is a beneficial farming practice towards soil OM compared fallow fields. The amount of Active C content in a soil is a measure of the C that is susceptible to being mineralized to CO_2 under ambient conditions over a short period of time. While Honeycutt (2017) showed that Active C was one of the three most important indicators of soil health that was positively correlated with crop yields; Roper et al. (2017) showed that Active C present in soils was increased with reduced tillage and often with organic amendments. Soil loss via oxidation is a concern in the EAA, hence an increase in Active C is not necessarily perceived as an ideal situation. However, while comparing flooded rice cultivation farming practices to fallow fields almost 16 g kg^{-1} of Active C is being generated during summer when the fields are left fallow, whereas no more than 8 g kg^{-1} of Active C is being generated under flooded practices. From a land management practice point of view, this is a great find because it demonstrates that cultivating flooded rice during summer in the EAA can lower the rate of carbon (soil) loss via oxidation.

Changes in P, N, and K in the soil was highly variable between the pre and post soil sampling. The reduction in M3P between the pre and post soil samples can be attributed to uptake by rice plant. Similarly, reduction in TKN can also be attributed to rice uptake. With no N, P, or K added as fertilizer, rice cultivation in the EAA solely relies on the soils and irrigation water for its nutritional needs. While this may be beneficial from an environmental point of view, from a soil health perspective, rice cultivation does not seem to serve as a nutrient sink that can benefit the subsequent crop. Recent study conducted by Tootoonchi et al. (2018) indicated that flooded rice cultivation in the EAA can significantly lower P loading due to particulate settling and plant P-uptake during the growing season.

4.2 Soil Health Index Used to Assess Farming Practice

The SHI was developed taking into account all measured indicators, causing the scores generated from some indicators to mask others. This mostly occurs when the degree of variability of the indicator being measured is large, as was the case with nutrient concentrations. When SHI was estimated excluding nutrients, SHI increased for all treatments except fallow treatment. It was clear that soil nutrients had masked the effect of increase in soil health indices for other indicators. Crops require nutrients, and the decrease in nutrient concentration (M3P, M3K, TKN, TP) following rice cultivation is natural and inevitable especially in this scenario since no N, P, K was added to the soils. Aside from nutrient uptake, there was net improvement in soil health due to rice planting. The depleted nutrients can always be replenished by adding fertilizers if needed. Even flooded fallow practice might me a sustainable agriculture practice rather than leaving the land completely fallow. Use of indices helps normalize the results and provides a board picture; however, it can also skew important information, so one should be careful while using results for interpretation without adequately disusing them.

5. Conclusions

Flooding the soils in general had a positive effect on soil health compared to fallow practices. Increase in soil pH within treatments between pre and post soil sampling was not considered as a positive response to soil health because these soils are high in calcium carbonate with pH ranging inherently upward of 7.2. The MWHC increased significantly under all "flooded" land practices compared to fallow fields; and from a soil health perspective this is advantageous, especially for water storage during dry spells. Significant increases in CEC observed in Cane ratoon rice, Cane rice, and Lettuce rice treatments suggests that the soils have a greater ability to retain insecticides and fertilizer within the topsoil. An increase in soil OM is extremely beneficial from a soil health perspective; however, its impact on histosols that are inherently composed of more than 60% OM can only be perceived moderately. In terms of soil loss, left fallow, soils within the EAA generates up to 16 g kg^{-1} of Active C that is highly susceptible to oxidation during the hot summer months in South Florida; compared to only about 8 g kg^{-1} if the soils are either flooded or planted with rice. Nutritionally, it was not surprising that soils contained lower N, P, and K concentrations after rice cultivation due to plant uptake and subsequent harvest. With no added N, P or K fertilizer the soils are the main source of labile (or extractable) nutrients to the rice plant. This was the premise for determining the SHI in two ways – (i) using all the measured indicators, and (ii) excluding soil nutrient indicators. It was evident from both approaches of SHI that leaving the fields fallow in the summer resulted in lower SHI values compared to flooded treatments. We hope that results from this study will encourage growers to plant more acreage of rice during the summer that will ultimately improve soil health and sustainability within the region.

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Optimizing Soil Moisture and Nitrogen Use Efficiency of Some Maize (*Zea mays*) Varieties under Conservation Farming System

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Abstract

In Zambia, small holder farmers depend on producing maize (*Zea mays*), which is a major staple food for many Zambians. Maize productivity among the smallholder farmers is quite low, giving only 2.3 tons per hectare. The low yields are attributed to insufficient and erratic rain fall, low soil fertility, and poor farming practices. Therefore, the objective of this study was to evaluate the performance of maize genotypes for nitrogen use efficiency and soil moisture utilisation under conservation farming system. The trials were carried out at two sites with different soil types. Three maize varieties i.e. ZMS 606, GV 640 and GV 635 were evaluated in maize – cowpea rotation. Four cowpea varieties used for rotation with maize, i.e. Bubebe Lutembwe, BB 14-16-2-2 and LT 11-3-3-12. BB 14-16-2-2 and LT 11-3-3-12 are mutation-derived lines of Bubebe and Lutembwe cowpea parent varieties respectively. The experimental design used was split plot with three replications. The NUE was significantly ($P< 0.05$) higher in CF and accounted for 27 % and 15% more than conventional farming system which valued 17% and 3% at Chisamba and Batoka, respectively. while soil moisture content was higher at Batoka than Chisamba in CF system. ZMS 606 and GV 640 varieties were superior over GV 635 for NUE. Cowpea variety BB 14-16-2-2 significantly increased NUE of maize varieties. Therefore, smallholder farmers in Zambia can increase maize productivity in maize - cowpea rotation system due to the increased NUE. Recommendations are made for farmers to select improved nitrogen efficient maize varieties to optimize productivity of maize in conservation farming system.

Keywords: conservation farming, nitrogen use efficiency, rotation, soil moisture content

1. Introduction

About 80% of the one million five hundred smallholder farmers in Zambia depend on producing maize (*Zea mays*) which is a major staple food for well over 90% of the Zambians. Productivity of the maize crop among the smallholder farmers over the years has become quite low giving a national average yield of 2.3 tons per hectare (Indaba Agricultural Policy Research Institute [IAPRI], 2015). The major causes of low yields countrywide are attributed to prolonged droughts, erratic rain fall pattern, low soil fertility, insufficient plant nutrients and poor farming practices (Cakir, 2004).

The soil fertility status in several parts of Zambia is also generally low and low soil fertility status in most cases could be caused by poor farming practices such as conventional farming or inherently unproductive soils at Smallholder farms. The evidence on soil fertility improvement by cover crop was explained by Karsky, Patrice and Salini (2003) that cowpea increases nitrogen in the soil up to 80kg N $ha^{-1.}$ Being a food legume, cowpea provides the needed proteins in rural households through both grain and leaves that are used as relish. Cowpea also plays a multipurpose role of potential to be used for human food; livestock feed and weed control (Rao & Mathuva, 2000).

Fertilizer prices have in the past few years almost become unaffordable by the majority of the smallholder farmers (Aagaard, 2011). Despite the Government subsidies on fertilizers for smallholder farmers, yields of the crop do not seem to improve.

There is much evidence that climate change is also likely to lead to decreases in Global efficiency and resilience of agriculture production while at same time being confronted with increasing demand from a growing population (Food and Agriculture Organization [FAO], 2010). Measures that promote climate change mitigation there by contain the potential to strongly co-benefit adaptation and food security, if targeted in an adequate way.

In the advent of Climate change (CC) where rain fall pattern have reduced and temperatures increased, use of climate smart agriculture technologies could improve maize productivity among smallholder farmers in Zambia. Climate Smart Agriculture refers to all farming practices that contribute to improve maize productivity. FAO (2010) defined Climate Smart Agriculture (CSA) as a farming system that seeks to increase productivity and food security sustainably, strengthen farmers' resilience to climate variability and change and remove greenhouse gases emissions. Improving soil quality is one of the fundamental activities of CSA, as higher quality soils are better able to retain moisture and reduce run off-two important features in responding to drought and flooding (Peter & Bram, 2010).

Therefore, use of improved maize varieties tolerant to low nitrogen and water in the nitrogen and water stressed environment under the minimum tillage with maize- cowpea rotation could contribute to increased NUE of maize and adoption of the system in Zambia. This makes alternative option for improving maize production by the smallholder farmers. Maize- Cowpea Rotation involves planting of maize crop after the cowpea legume crop and this technology facilitates improvement of maize productivity through increased soil fertility from cowpea nitrogen fixation (Verhulst et al., 2010). Sumanta et al., 2013 reported that conservation agriculture increased use efficiency of nitrogen by 11% over conventional system.

In order to respond to these challenges, the experiment was established during the 2014/2015, 2015/2016 and 2016/2017 growing seasons whose main objective was to increase maize productivity in conservation farming system, while the specific objectives of this study were (i) to evaluate the performance of maize genotypes for nitrogen use efficiency; (ii) to evaluate soil moisture utilisation and (iii) to identify maize – cowpea combinations with high NUE and soil moisture utilization for high maize productivity under conservation farming system.

2. Materials and Methods

The study focused on evaluating improved selected maize and cowpea genotypes in Zambia for effective uptake and partitioning of nitrogen under Maize- cowpea rotation system.

2.1 Location

The study was conducted at two sites which were Chisamba of Chibombo district on coordinates S 14.96783^{o}, E 028.09408^{o}; and Batoka of Choma district on coordinates S16.79993^{o}, E 027.20181^{o} in region II of the Zambian agro-ecological zones but having different soil types. Chisamba has clay loam while Batoka has loamy sand soils.

2.2 Source of Seeds (Maize and Cowpea Varieties)

Three maize varieties were evaluated for water and nitrogen use efficiency. Two (2) maize varieties (GV 640 and GV 635) having good traits of water and nitrogen use efficiency were selected from Zambia Agricultural Research Institute (ZARI) maize breeding programme. The third variety was ZMS 606 from Zamseed Company and is mostly purchased by small holder farmers for Region II of the Zambian agro-ecological zone. The four cowpea genotypes were evaluated for improved Biological nitrogen fixation and maize productivity in the maize- cowpea rotation. Cowpea genotypes were two parents (Bubebe and Lutembwe) and two mutants (BB 14-16-2-2 and LT 11-3-3-12) one from each parent obtained from the University of Zambia School of agricultural sciences, Department of Plant Science.

2.3 Experimental Design

The experimental design used was a split plot arranged in and replicated three times. The main treatments were two different farming systems adjacent to each other. (a) Conservation farming system (CF) which included minimum tillage by ox- drawn ripping, maize-cowpea rotation and crop residue retention. (b) Conventional farming system (CONV) which involved complete tillage of soil by ox-drawn ploughing, mono-cropping and removal of crop residues after harvesting. The sub treatments were three maize varieties and these were ZMS 606(M1), GV 640(M2) and GV 635(M3).

2.4 Trial Establishment

In year 1 (2014/15 season) Maize varieties in the conventional farming systems and cowpea varieties in the conservation farming systems were evaluated. The trials in year 1 aimed at establishing the rotation system for maize- cowpea in the CF and mono cropping system for maize in the conventional system. Four cowpea genotypes were analyzed for productivity and potential for rotation with maize on the already established CA field plot (Field plot that had received minimum tillage and rotation for at least 3 years.

In year 2 (2015/2016) season maize varieties were assessed for water and nitrogen use efficiency in the maize – cowpea rotation system on the four cowpea genotypes in the CF field as compared to same maize varieties under maize mono cropping system (conventional). ^{15}N labeled urea which was diluted from 5.18 atom% ^{15}N to 2.58 atom % ^{15}N was applied to all treatment plots on 1.5m^2 area at four weeks after planting maize and two weeks after planting cowpeas for determination of nitrogen uptake by both crops. The access tubes for moisture content reading were inserted per each plot. A diviner 2000 was used to measure moisture content up to 1.0 m depth once per week for a period of 12 weeks and started at five weeks after planting maize crop at Chisamba site. While at Batoka, soil moisture content was measured with HH2 soil meter using auger marked at 15cm, 30cm, 40cm and 60cm depth. Four (4) rows of 6 m length spaced at 0.75 m were marked and planted with maize at an intra -row spacing of 0.25 m. Each plot of cowpea crop had 12 rows of 6 m length spaced at 0.75 m. Cowpea seed was drilled along the ripped furrows to about 7cm between seeds. 2 guard rows at each end of the block for both crops were included.

2.5 Crop Management

Maize seed was planted at 25cm between stations in the ripped furrows. Cowpeas used for rotation with maize was drilled along the ripped furrows at seed rate of 30 kg/ha. Fertilizer nutrients were applied at 112 kgha^{-1} Nitrogen, 40 kgha^{-1} Phosphorus and 20 kgha^{-1} Potassium on maize crop. Basal Fertilizer nutrients (20 kgha^{-1} Nitrogen, 40 kgha^{-1} Phosphorus and 20 kgha^{-1} Potassium) application were at planting and top dressing 92 kgha^{-1} Nitrogen was at vegetative stage, five weeks after planting. Cowpea crop received basal dressing only of 20 kgha^{-1} Nitrogen, 40 kgha^{-1} Phosphorus and 20 kgha^{-1} Potassium. Two separate sprays against pests and diseases were made on cowpeas plots. The first control was at two weeks after cowpea emergency and the second at flowering stage. At planting, weed control started with Glyphosate spray targeting emerged weeds in the trial field. The next weeding was done manually twice at two and four weeks after planting the crop. Two rows of maize crop were harvested for biomass and grain yield analysis. 0.5 m was discarded at each end of the row. Two plants and cobs were sampled from ^{15}N treated rows for analysis of N and C. Eight rows of cowpea were harvested for dry biomass and grain yield analysis.

2.6 Data Analysis

The data collected were agronomic maize and cowpea yields, %N and atom% ^{15}N for maize. Nitrogen use Efficiency was calculated as a percentage of nitrogen uptake in maize grain to the Nitrogen applied (International Atomic Energy Agency [IAEA], 2008). Data were analysed with Genstat 18th edition.

3. Results and Discussions

3.1 Soil Characteristics of the Test Sites

The results of the soil chemical and physical properties at the experimental sites before planting are represented in Table1 and 2. Between the two sites, Chisamba had more fertile soil with higher soil pH, organic matter and nitrogen content than Batoka. The Batoka site however, had higher bulk density, soil water content at field capacity and plant available than Chisamba hence soil texture at Batoka was described as loamy sand and Chisamba was Clay loam. The results were in agreement with Hamza and Anderson (2003) who found that Cation exchange capacity and exchangeable calcium increased more on the clayey than on the sandy soil.

Table 1. Baseline Soil chemical properties of the sites

Farming Systems	Site	Depth	pH	OM	N	P	K	Ca	Mg	Zn
		Cm		%		mg/kg	cmol/kg			mg/kg
CONV	Batoka	0-15	4.12	1.68	0.08	17.4	0.1	1.27	0.29	0.04
CONV	Batoka	15-30	4.31	0.96	0.06	14.62	0.08	1.78	0.37	0.06
CF	Batoka	0-15	3.8	0.64	0.03	34.06	0.1	1.66	0.19	0.24
CF	Batoka	15-30	3.71	1.12	0.03	37.88	0.08	0.93	0.11	0.14
CONV	Chisamba	0-15	6.17	0.72	0.05	17.92	1.04	10.9	5.48	0.28
CONV	Chisamba	15-30	6.2	2.72	0.09	17.86	0.78	10.92	5.76	0.12
CF	Chisamba	0-15	5.49	3.2	0.05	18.86	1.11	8.59	4.4	0.28
CF	Chisamba	15-30	5.58	2.72	0.08	13.15	0.83	8.98	5.01	0.20

Table 2. Soil physical properties of the sites

Farming Systems	Site	Bulk Density	FC θv	PWP θv	PAW θv	Sand	Clay	Silt	Texture
		g/cm3	%	%	%	%	%	%	
CONV	Batoka	1.37	29.04	6.03	23.01	82	6.8	11.2	Loamy Sand
CONV	Batoka	1.4	29.08	4.43	24.66	82	6.8	11.2	Loamy Sand
CF	Batoka	1.37	35.73	5.22	30.51	82	6.8	11.2	Loamy Sand
CF	Batoka	1.36	43.16	14.74	28.42	82	6.8	11.2	Loamy Sand
CONV	Chisamba	1.12	27.93	10.77	17.16	46	24.8	29.2	Loam
CONV	Chisamba	1.1	18.68	4.96	13.72	42	30.8	27.2	Clay Loam
CF	Chisamba	1.14	18	6.28	11.72	42	30.8	27.2	Clay Loam
CF	Chisamba	1.11	15.86	4.41	11.45	40	34.8	25.2	Clay Loam

3.2 Cowpea Dry Biomass Yield

Performance of cowpea genotypes on the dry biomass and grain yield varied between sites and among genotypes. Chisamba site (CHBIO) produced 2802 kg ha^{-1} of cowpea dry biomass which was significantly ($P<0.05$) higher than the dry biomass at Batoka site (BK BIO) with 1188kg ha^{-1} during 2014/15 growing season (Figure 1). Similar trend of dry biomass yield was observed in the second growing season (2015/2016) where the yield of cowpea dry biomass was 4897 kg ha^{-1} at Chisamba and 1753 kg ha^{-1} at Batoka. The cowpea genotypes C1 (Lutembwe) and C3 (LT 11-3-3-12, produced an average of 3650kg ha^{-1} dry biomass yield and was significantly ($P<0.001$) more than yield of cowpea genotypes C2 (Bubebe) and C4 (BB 14-16-2-2) by 49% at Chisamba. However, at Batoka, cowpea C1 and C3 had an advantage over C2 on dry biomass yield. The higher cowpea dry biomass yield obtained at Chisamba could be attributed to relatively good soil physical and chemical properties as compared to loamy sand soils of Batoka. Cowpea dry biomass is important for improving soil fertility when the crop residue decompose (Verhulst et al., 2010).

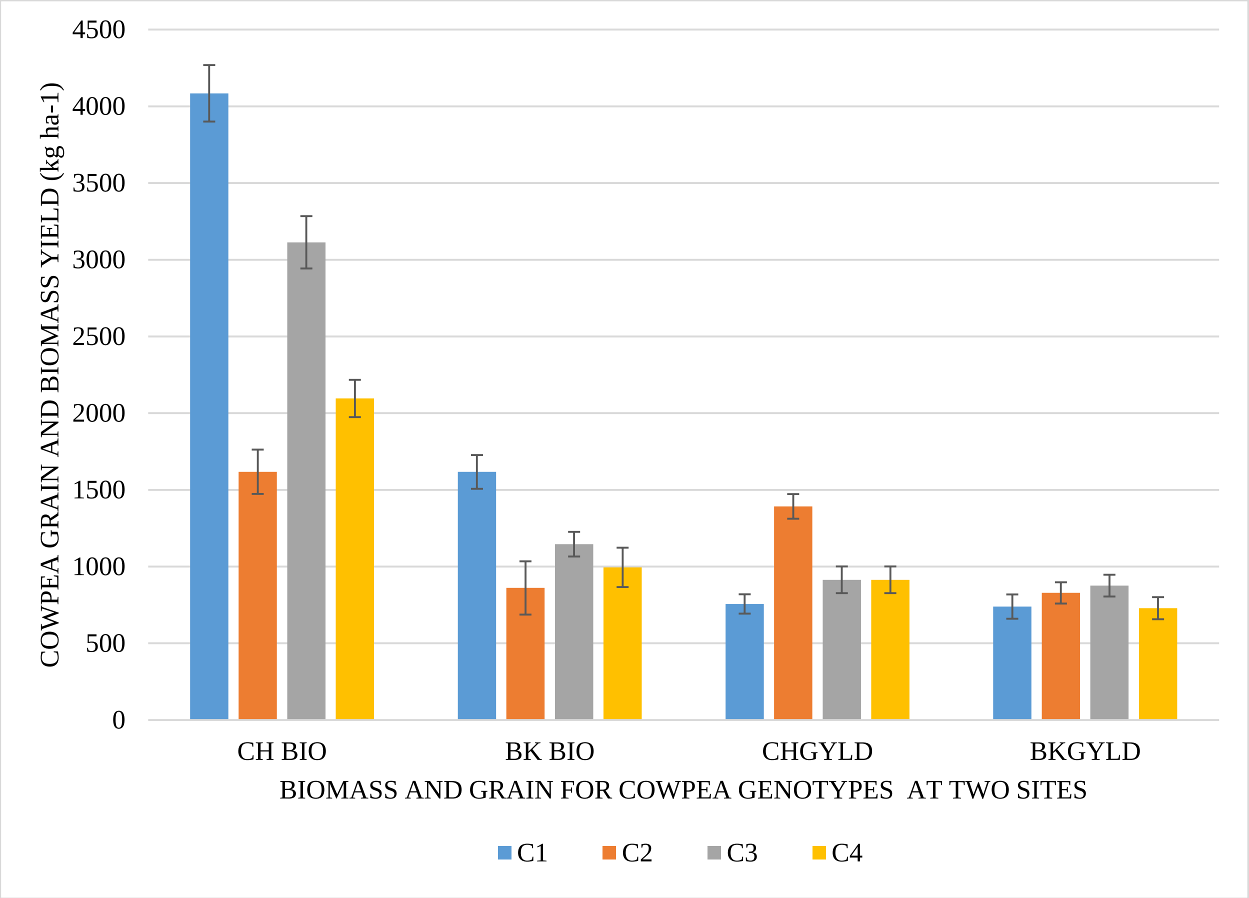

Figure 1. Cowpea dry biomass and grain yield at Chisamba and Batoka sites

Table 3. Cowpea dry biomass nutrient content

	Cowpea dry biomass nutrient content						
Cowpea Genotypes	Ca%	K%	Mg%	N%	P%	Zn ppm	Mn ppm
Lutembwe	0.127	3.057	0.283	0.63	0.290	217	1011
Bubebe	0.130	1.673	0.333	2.14	0.277	300	790
LT 11-3-3-12	0.123	3.100	0.247	2.59	0.283	250	857
BB 14-16-2-2)	0.163	3.183	0.243	4.53	0.253	306	970
LSD (0.05)	0.0988	0.6744	0.789	0.954	0.0821	117.3	264.5
Pr	0.745	0.004	0.095	<0.001	0.725	0.793	0.252
CV	36.4	12.3	14.3	19.3	14.9	21.9	14.6

3.3 Nitrogen Use Efficiency

Nitrogen Use Efficiency (NUE) by maize genotypes was measured as a percentage ratio of nitrogen uptake in maize grain to the amount of nitrogen applied as ^{15}N label. The NUE was significantly (P <0.05) found higher in CF than CONV system. High NUE in CF system could be as a result of crop rotation of maize and cowpeas that contributed to soil physical and chemical properties improvement. The results are in agreement with Verhulst, François, Grahmann, Govaerts and Cox (2014) who stated that crop monoculture has negative effects on yield and NUE and positive effects if legumes are included in the rotation. Nitrogen uptake in the CF was more compared to CONV and Maize genotype ZMS 606 (M1) expressed highest NUE at both sites GV 635 at Chisamba (Figure 2). This implies that there is genetic variation for nitrogen use efficiency among the maize genotypes used in the study. Therefore, development of new cultivars with higher NUE, coupled with best management practices such as conservation farming will contribute to sustainable agricultural systems that protect and promote soil, water and air quality(Baligar, Fageria, & He, 2007).

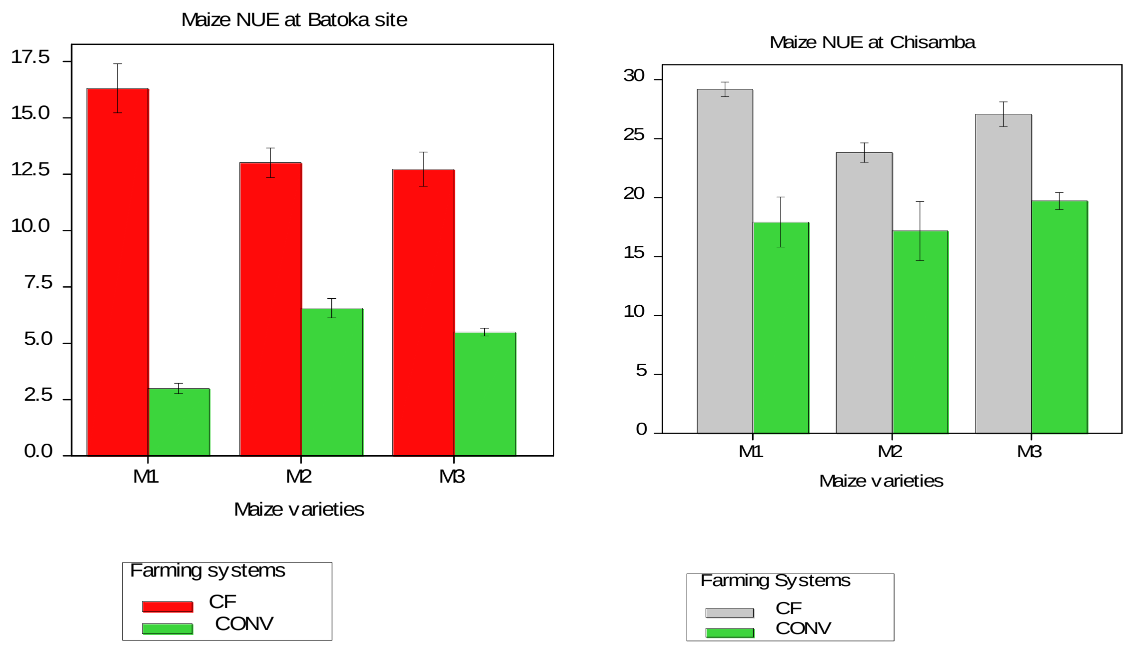

Figure 2. Nitrogen Use Efficiency in maize grain production under conservation and conventional farming systems at Chisamba (left) and Batoka (right) sites

3.4 Soil Moisture Utilization

The soil moisture content during the crop growth showed variations between CF and CONV farming systems. Batoka site which has loamy sand soils recorded higher water content in CF with 11.9% than in CONV which was 9.1% at 40cm depth 8 weeks after planting. Neither maize nor cowpea genotypes had influence on the availability of moisture at Batoka. Chisamba site, however had more moisture content in CONV (56.2%) compared to CF (46.1%). Chisamba site showed significant interaction (P =0.005) between farming systems and maize genotypes. ZMS 640 (M2) significantly conserved more water than ZMS 606 (M1) and GV 635(M3) in

CF system. The results have indicated that amount of water uptake by maize plant depends not only on farming system but also on the genotype (Hansakar, 1996). Considering the high maize grain yield produced by GV 640 in the CF, it means that water use efficiency (WUE) could be highest for GV 640 compared to other two maize genotypes (Tahar, 2010). The lower moisture content in the CF could have been attributed to high water uptake by vigorous growing maize crop (Figure 3 and 4). These results were in agreement with Esser, 2017, who stated that moisture content in the CF maize crop was less as compared to CONV.

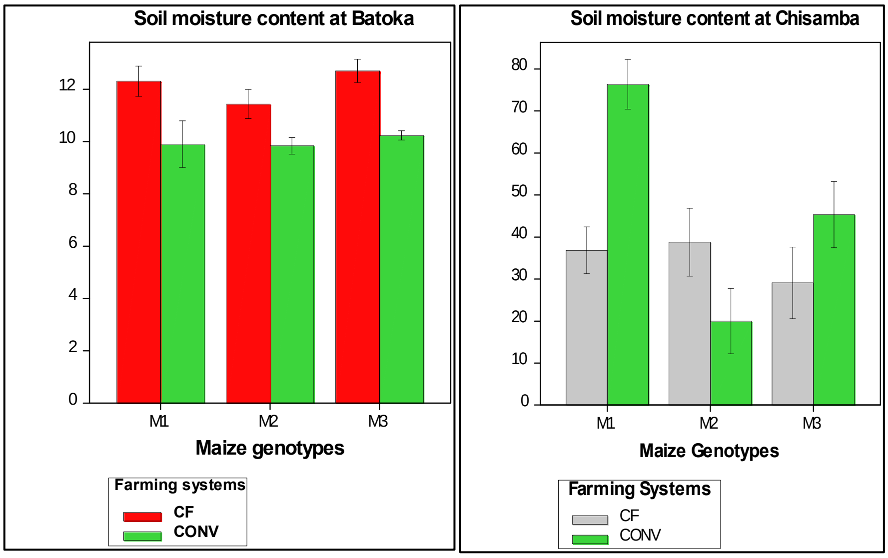

Figure 3. Effect of farming systems on soil moisture content at Batoka (40cm) and Chisamba (40cm) 8 weeks after planting

Cowpea genotypes used in the experiment for rotation with maize significantly ($P<0.05$) contributed to the uptake of moisture in the CF plots. Significant interaction between cowpea and maize genotypes was observed at $P<0.001$). The cowpea genotypes Lutembwe and its mutant LT conserved highest moisture content with average of 61.8% and 57.0% respectively in the CF system mainly due to high dry biomass yield produced by the two genotypes. The dry biomass acted as mulch to prevent excessive loss of water in the plot before planting and during part of the growing season (Richard & Marietha, 2007).

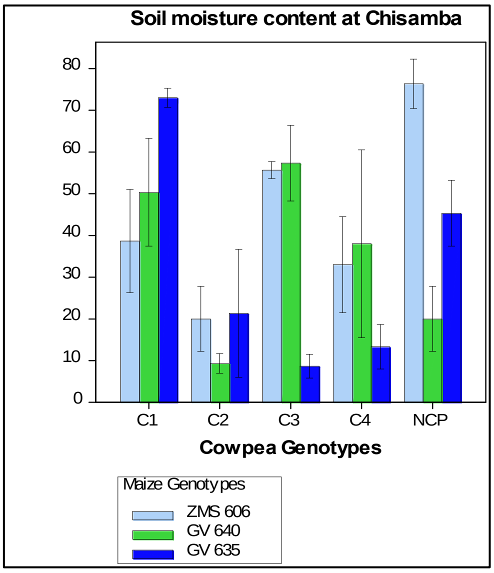

Figure 4. Effect of cowpea genotypes on soil moisture content

3.5 Maize Grain Yield (Kg. ha^{-1})

On average, between the two sites, Chisamba produced higher maize grain yield (7960kgha^{-1}) than Batoka (4453kgha^{-1}). The differences in maize grain yield between Chisamba and Batoka was as a result of variations in soil quality status. Batoka site is loamy sand soils with low levels of plant nutrients. Maize grain yield in conservation farming (CF) system was 6600kgha^{-1} and was significantly higher at P<0.05 by 30% than in conventional farming (CONV) system (Figure 5 and 6). ZMS 606 and GV 640 which yielded 6668kgha^{-1} and 12000kgha^{-1} were significantly superior over GV 635 in conservation farming during the 2015/2016 and 2016/2017 growing season respectively. The good performance of maize under CF was attributed to improved soil fertility status that enhanced increased water and nitrogen use efficiency by the crop. Similar results were reported by Sumanta et al. (2013) that maize grain yield increased in the conservation agriculture field after two growing seasons. Golden valley Agricultural Research Trust [GART] (2011) also reported that maize grain yield increased when maize was rotated with a legume crop *(mucuna pruriens)* in the CF system. Cowpea genotype C4 (BB 14-16-2-2) significantly(P<0.05) contributed to high yields of maize in the maize – cowpea rotation as compared to other genotypes (Figure 6) mostly due to high Biological Nitrogen Fixation (IAEA, 2008).

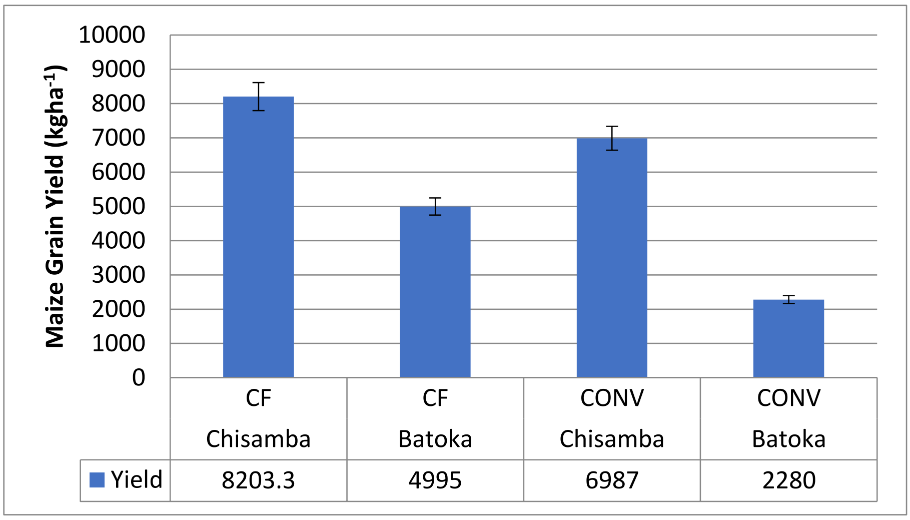

Figure 5. Effect of sites and farming systems (Conservation farming- CF and conventional CONV) on maize grain yield

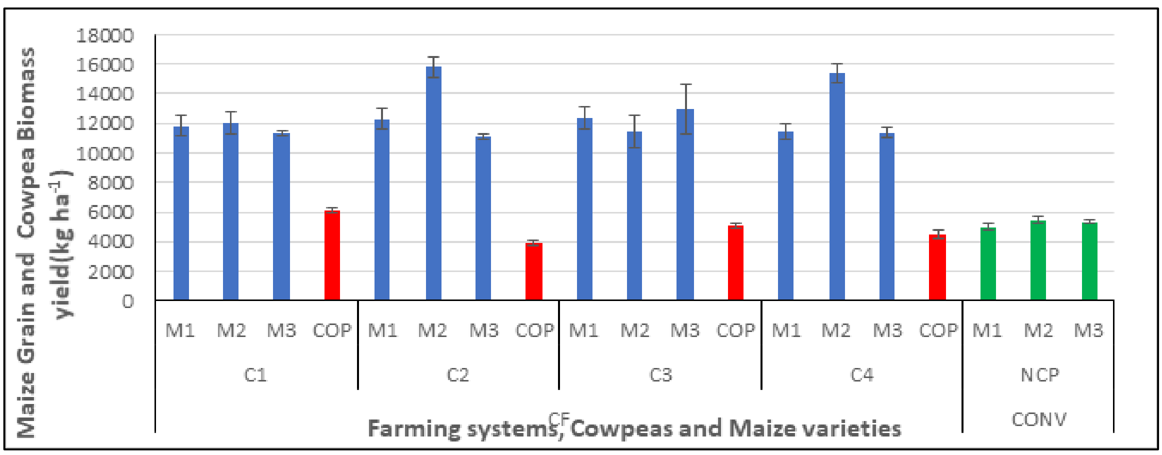

Figure 6. Effect of farming systems and cowpea genotypes on the performance of maize varieties

4. Conclusion and Recommendations

Maize grain yields varied according to sites of different soil types. Loamy sandy soils of Batoka produced lower yields than Chisamba with heavy clay loam soils. Conservation Farming system (CF) significantly out yielded conventional farming system (CONV) in maize grain yield for two seasons by 30% and 60% due to improved soil properties, high nitrogen use efficiency and high moisture utilisation in the CF. Cowpea genotype (Bubebe mutant) BB 14-16-2-2 increased maize yield of ZMS 606 and GV 640 in 2015/16 and 2061/17 growing season under conservation farming system respectively. Cowpea genotype BB 14-16-2-2 can therefore be considered in the maize-cowpea rotation system to improve productivity of ZMS 606 and GV 640 maize varieties for enhanced food security among smallholder farmers in Zambia.

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Policy Integration and Coherence for Conservation Agriculture Initiatives in Malawi

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Abstract

In sub-Saharan Africa, development and dissemination of perceived new agricultural innovations dominate the development agenda yet hunger and poverty remain widespread. A conducive policy environment is essential to support these efforts. Despite that national policies are a critical component in the functioning of an agricultural innovation system, studies have often overlooked their relevance in farmers' adoption of agricultural innovations. There is an urgent need to enhance understanding of how policies affect long-term adoption of agricultural innovations aimed at increasing productivity and incomes of smallholder farmers. This study utilises thematic content analysis to examine the extent of integration of Conservation Agriculture (CA) and coherence in Malawi's national agricultural policies, and their implication for CA adoption among smallholder farmers.

Results indicate that inadequate integration of CA in the National Agricultural Policy (NAP), coupled with a lack of coherence of agricultural department policies, undermines farmers' CA adoption. While inadequate integration constrains resource allocation for supporting CA activities, lack of coherence of agricultural policies radiates conflicting and confusing agricultural extension messages to smallholder farmers. We argue that inadequate CA integration and incoherence of policies are institutional constraints which prevent farmers' sustained adoption. To facilitate long-term adoption of CA among smallholders, there is need to: (1) strengthen CA integration in agricultural policies; (2) improve departmental coordination to enhance coherence of agricultural strategies and extension messages disseminated to farmers; and (3) strengthen government's role in supporting multi-disciplinary research to generate and disseminate best practices capable of sustaining CA adoption.

Keywords: climate smart agriculture, governance, institutional analysis, policy interplay, sub-Saharan Africa, sustainability

1. Background

Hunger and poverty are pressing concerns of development agents and national governments worldwide. A report issued by the United Nations Food and Agriculture Organisation estimates that 815 million people are currently experiencing hunger globally (Food and Agriculture Organisation [FAO], 2017), despite agriculture being a key economic sector and main source of employment in many countries (Lipper et al., 2014). Generation and dissemination of new agricultural innovations has traditionally driven the national development and policy agenda in the sub-Saharan region (Teklewold, Kassie, & Shiferaw, 2012) as attempts have continued to address these concerns. One such innovation is conservation agriculture (CA), defined as a sustainable farming system anchored on three fundamental principles: minimal soil disturbance (reduced tillage), permanent soil cover and crop associations (Kaluzi, Thierfelder, & Hopkins, 2017). According to FAO (2015), the three principles need to be practised simultaneously, in addition to other good agricultural practices, for optimal results. CA is widely advocated as a promising technology for improving agricultural productivity, food security, sustainable land management, and smallholder farmers' resilience to climate change impacts (FAO, 2018).

While current innovation systems approaches suggest that policies are an important component in the functioning of an innovation system (Hall, Mytelka, & Oyeyinka, 2006; Spielman & Birner, 2008), farming systems studies often overlook policies (Feder, Just, & Zilberman, 1985; Doss, 2006); hence empirical evidence of linkages between policies and challenges in sustaining adoption of agricultural innovations is lacking. Despite that policies are central in guiding national priorities (Kalaba, Quinn, & Dougill, 2014), their role in shaping the context in which smallholder farmers operate and adopt innovations remains poorly understood. It is thus imperative to generate in-depth understanding of how national policies shape smallholders' adoption of agricultural development interventions, where livelihoods largely depend on agriculture.

The aim of this article is to analyse the role of national policies in smallholder farmers' adoption of CA in Malawi. The paper focuses on analysis of policy documents from across the Ministry of Agriculture, Irrigation and Water Development [MoAIWD], which has the mandate to implement all agriculture related activities in the country. Specific objectives are: (1) to analyse the extent of integration of CA in the relevant policy documents of the MoAIWD; (2) to analyse coherence of departmental strategies and guidelines for CA implementation; and (3) to examine implications of policy integration and coherence for smallholders' adoption of CA.

1.1 Theoretical Framework

Policy integration refers to the extent to which a social, economic or environmental objective or consideration is embedded into (national) policy (Oberthur, 2009). Research on policy integration has mostly been devoted to assessing the extent of integration of international agreements into national policies (Stringer et al., 2009; Nilsson et al., 2012; England, Stringer, Dougill, & Afionis, 2018; Atela, Quinn, Minang, Duguma, & Houdet, 2016), while globally, integration of sectoral and departmental policies remains a common challenge (Oberthur, 2009). There is a critical lack of knowledge on the integration of agricultural considerations and issues at sectoral/sub-sectoral levels (Gomar, Stringer, & Paavola, 2014). Analysing integration of policies at lower governance levels is important to understand how policies at national level can affect adoption of agricultural interventions at the grassroots, since this is where policy intent translates into action.

Policy coherence relates to how two or more policies and/or their implementation arrangements interact in achieving their objectives (May, Sapotichne, & Workman, 2006). The effectiveness of policies (e.g. at national, sectoral or departmental level) may be either reinforced or undermined by other policies, producing either mutually-supporting or adverse outcomes (Dixon & Stringer, 2015; Lasco, Cruz, R. Pulhin, & J. Puhlin 2006; Soderberg, 2008). Coherence has become a crucial variable in policy analysis considering its importance in determining policy effectiveness (Atela et al., 2016). As national implementation arrangements often involve multiple sectors and stakeholders (Chandra & Idrisova, 2011), outcomes of one policy (e.g. sustainable food production) are often a sum of all decisions, policies and actions from more than one government agency (Glasbergen, 1996). However, research into coherence has mostly focussed on examining policies at ministerial governance levels (e.g. Kalaba et al., 2014; Atela et al., 2016) with little scholarly attention focusing on sub-sectoral/departmental policies at lower governance levels. Exploring coherence is necessary to identify where policy statements or actions in different departments are supporting or conflicting with each other in the context of CA, particularly given that CA is a multi-sectoral technology (Chinsinga & Chasukwa, 2015).

Cejudo and Michel (2017) argue that policy integration, and coherence are interrelated; such that poor integration, often emanating from poor coordination, culminates in incoherent policies. Similarly, Soderberg (2008), Stringer et al. (2012) and Kalaba et al. (2014) observed that different government sectors or agencies tend to work in isolation, and may produce antagonistic relationships which do not facilitate joint problem solving. When departments work independently, there is a lack of joint learning and long-term alignment of over-arching objectives across departments, resulting in contradictory messages and wastage of resources (England et al., 2018). Coherence in policies can be undermined when interests and policy issues pull in different directions, or they can be reinforced when they are in harmony (May et al., 2006). Stringer et al. (2009) noted that in Southern Africa, mutually supportive links between policy strategies are often poorly developed; such that even if overlaps exist, opportunities usually remain unexploited. For Malawian agriculture, Dougill et al. (2017) contend that multilevel institutional inefficiencies, policy conflicts and gaps limit the effectiveness of CA and sustainable land management agenda. Considering that policy integration and coherence are interlinked (Cejudo & Michel, 2017), simultaneous examination of integration and coherence of policies is necessary to generate insights to improve the policy environment in which smallholder farmers adopt and/or implement agricultural development interventions.

2. Research Design and Methods

2.1 Case Study

Malawi provided an appropriate case for this study because despite CA being incorporated in Malawi's agricultural policies, as a strategy for improving agricultural production and resilience in smallholder farming systems (Mloza-Banda & Nanthambwe, 2010), adoption levels remain meagre with only 2% of the country's smallholders practicing some form of CA (Kaluzi et al., 2017). This signals potential shortcomings in relevant policies *vis-a-vis* CA, considering that policies shape what gets prioritised and implemented. Additionally, organisational complexity of the Ministry of Agriculture, Irrigation and Water Development and its policy mechanisms (Chinsinga & Chasukwa, 2015) necessitate a better understanding of the agricultural policy environment. Improving the policy context for CA is important for Malawi's predominantly agrarian economy, with over 80% of the population relying on rain fed agriculture for their livelihoods (Malawi Government, 2016).

2.2 Methods and Data Analysis

Purposive sampling was used to select documentary materials for in-depth analysis, since what matters most in the choice and sample size of text for document analysis is the "richness of textual detail" (Waitt, 2010, pp 222), and its usefulness and relevance to the research objectives (Baxter & Eyles, 1997). The documents analysed were Malawi government sectoral policies as published by the different Departments across the Ministry of Agriculture, Irrigation and Water Development. To ensure document authenticity (Scott, 1990), selected policy documents were physically obtained from the relevant Ministry headquarters (Table 1).

Table 1. Description of Malawi national policy documents analysed

Policy document	Responsible sector	Description	Analysis focus
National Agriculture Policy (NAP)	MoAIWD	National policy on agriculture (Malawi Government, 2016)	integration
Agriculture Sector-wide Approach (ASWAp) (under review)	MoAIWD	Programme-based agriculture investment plan outlining the national agriculture development agenda (Malawi Government, 2010)	integration
Guide to Agricultural Production and Natural Resources Management in Malawi (GAPNRM)	MoAIWD (all Departments in the Ministry)	Departmental guidelines on good agriculture practices in Malawi (Malawi Government, 2012)	coherence
Guideline for implementation of conservation agriculture in Malawi	MoAIWD (Department of Land Resources and Conservation)	Malawi national conservation agriculture guidelines (National Conservation Agriculture Task Force [NCATF], 2016)	coherence

Note. MoAIWD= Ministry of Agriculture, Irrigation and Water Development.

Policy documents were analysed using thematic content analysis (Bryman, 2016), which is a commonly used method for analysing textual data (Hay, 2010). Analysis of CA integration entailed systematically examining dominant narratives in the policy documents to establish the presence, prominence and context in which CA appears in the text. Criteria for assessing the extent of CA integration into policy documents were adapted from Mwase et al. (2014) (Table 2).

Table 2. CA integration assessment criteria adapted from Mwase et al. (2014)

Rating	Description
Very weak	CA completely absent in the policy document
Weak	The policy does not explicitly mention CA but some aspects related to CA are specified
Moderate	CA explicitly specified only in policy strategies and/or implementation plan
Strong	CA explicitly specified in policy objectives, strategies and monitoring and evaluation framework
Very strong	CA explicitly specified in policy objectives, strategies, monitoring and evaluation framework and funding mechanism

Policy coherence was analysed through the perspective of policy interaction (Nilsson et al., 2012; Young, 2002). This entailed analysing implementation strategies derived from the Guide to Agricultural Production and Natural Resources Management, which contains the 'how-to' technical knowledge from all Departments in the MoAIWD and is the reference manual for agricultural extension officers (Malawi Government, 2012). Interactions between the strategies were examined to determine their relationship with CA adoption. This entailed first compiling an inventory of strategies, from which a screening matrix (Soderberg, 2008) was developed. The next step was to isolate strategies relevant to CA, and to examine key interactions. Coherence with CA adoption was illustrated using criteria adapted from Nilsson et al. (2012) and Oberthur and Gehring (2006) denoted as: (1) positive - where Departmental activities support CA adoption (2) negative - where activities undermine or conflict with CA adoption or (3) neutral - where no clear effect on CA adoption was established. Data on key outcomes was displayed qualitatively to elucidate whether or not the policy implementation arrangements were mutually reinforcing, impeding or contradicting adoption of CA in Malawi.

3. Results

3.1 Extent of CA Integration in National Agriculture Policy (NAP) and Agriculture Sector-wide Approach (ASWAP)

Although the NAP is the key policy document for agricultural development in Malawi, CA integration is moderate; it only appears at the lower level of the policy, in implementation plans, under "*promoting investments in climate smart agriculture and sustainable land and water management including integrated soil fertility management and conservation and utilisation of Malawi's rich agrobiodiversity"* (Malawi Government, 2016). Similarly, integration of CA in the ASWAp policy document is moderate. Absence of CA in broader policy statements (goals, objectives and priority areas) demonstrates that CA is insufficiently embeded as a priority national strategy for achieving agricultural goals and objectives. This suggests that CA lacks political recognition and support at the national governance level. Considering that no funding mechanisms are outlined in the NAP, availability of finances and other resources for implementing CA activities on the ground is uncertain.

Results show that failure to embrace CA more broadly underlies insufficient integration of CA in the agricultural policy documents, and is manifested by CA gaps and/or missed opportunities in relevant thematic policy areas (Table 3).

Table 3. CA missed opportunities and gaps in key thematic policy areas

	Policy	
Key thematic policy area	NAP	ASWAP
Food security	X	X
Agricultural risk management	X	X
Catchment restoration and conservation	X	X
Irrigation and rainwater harvesting	X	X
Research and technology transfer	X	X
Soil health	O	O

Note. x = gap identified; o = no gap identified.

The food security policy area of the NAP emphasises use of inorganic fertilisers, improved crop varieties, herbicides and pesticides. As a result, national priorities and resources have been biased towards these strategies (Chinsinga, 2011), at the expense of sustainable land and water management (SLWM) which includes CA. Considering that SLWM strategies are pre-requisite to any sustainable agricultural production system (Mwase et al., 2014), there is a case for stronger CA integration in agricultural policies. The current NAP was launched in 2016 with the overall goal "*to achieve sustainable agricultural transformation that will result in significant growth of the agriculture sector, increased incomes for farming households, improved food and nutrition security for all Malawians and increased agricultural exports"* (Malawi Government, 2016). CA has potential to improve yields especially in areas with sandy soils (Steward et al., 2018) and contribute to food security (FAO, 2018; Thierfelder et al., 2016). However, failure to recognise broader potential of CA undermines its incorporation in strategies for achieving food security goals in Malawi's agricultural policies.

Findings show that CA is mainly included in the NAP and ASWAP as a farm-level intervention under rain-fed agriculture, hence a gap exists under the policy thematic area of irrigation and rain water harvesting (Table 4). While the ASWAP articulates its purpose to: *"increase soil water and nutrient buffer capacity to ensure higher productivity of rain-fed crops"* (Malawi Government, 2010), the policy noticeably overlooks application of CA in irrigation farming. Similarly, the NAP overlooks CA in the sustainable irrigation development priority area; yet application of CA practices has potential to reduce problems of siltation of rivers/streams, reduced river flows, and moisture stress in crops constantly reported as major challenges in most irrigation schemes in Malawi (Department of Irrigation Services, 2015). Since implementation of CA principles of permanent soil cover and minimum soil disturbance improves water infiltration and water holding capacity of soil while reducing surface runoff and soil erosion (Njira & Nabwami, 2013), there is scope for stronger CA integration in sustainable irrigation development and catchment restoration and conservation thematic areas of NAP and ASWAp.

Though development partners such as FAO and other donors regard CA as an adaptation strategy to prolonged dry spells, CA is conspicuously missing in the NAP's agricultural risk management priority area, and ASWAp's climate change sub-component. For managing agricultural risk, the two policies have prioritised strategies such as: increasing adoption of drought tolerant crop varieties; promoting weather-index crop and livestock insurance and early warning systems; strengthening commodity exchange systems; and rainwater harvesting. Although CA is applicable for water harvesting strategies, it has not been explicitly included under the climate change sub-component. Lack of explicit mention of CA under the rainwater harvesting strategy practically excludes it from resources allocated for rainwater harvesting; in Malawi, rainwater harvesting is synonymous with construction of physical structures such as dams and underground or above-ground water tanks (Rainwater Harvesting Association of Malawi [RHAM], 2013). When used in conjunction with other agricultural risk-combating interventions, CA has the potential to capture and conserve rainfall *in-situ*, recharge ground water, thereby maintaining the water table within the root zone. Thus, CA may help prevent total crop failure especially in drought prone areas (NCATF, 2016; Thierfelder et al., 2016).

Despite the need to generate more knowledge due to challenges and controversies associated with CA (Kirkegaard et al., 2014; Andersson & D'Souza, 2014; Glover, Sumberg, & Andersson, 2016), CA is not specifically mentioned among the policy priority research areas of the NAP. Evidence in the literature shows that there is growing need for adaptive research aimed at enhancing the performance of, and contextualising of, CA to different agro-ecological and social contexts (Whitfield et al., 2015). Nevertheless, the NAP's research mainly focuses on developing new, high yielding, disease-resistant, and drought-tolerant crop varieties. Thus, a gap exists for incorporating CA in the agricultural research agenda, including adaptive research and performance evaluation of technologies already developed and disseminated to smallholder farmers to enhance understanding of interactions among technological, social, political and environmental factors in adoption and dis-adoption decision processes. This would enable researchers and practitioners to obtain valuable evidence required to customise technologies to local contexts, necessary for enhanced and sustained adoption of agricultural innovations among smallholder farmers.

While broader engagement of relevant stakeholders in the CA innovation system is essential, implementation arrangements of the NAP have overlooked the role of several key stakeholders. Only a few organisations have been mentioned as having a role in CA: the MoAIWD's three Departments of Land Resources and Conservation, Agricultural Extension Services and Agricultural Research Services, Non-Governmental Organisations (NGOs) and farmers' organisations. Other organisations and institutions have not been specifically included such as Departments of Crop Production, Animal Health and Livestock Development, Irrigation Services and Environmental Affairs; academic experts, International Agricultural Research institutions, Civil Society organisations (policy advocates) and the private sector (e.g. seed companies and agro-dealers). This questions the level of inclusiveness and involvement of stakeholders in the formulation of the policies. Excluding such important stakeholders is likely to lead to disjointed efforts in CA and raises the likelihood of both political and practical contradictions in policy, dissemination and/or agricultural extension, unfavourably affecting the operating environment of farmers. The following sections elucidate incoherencies in agricultural policies and their implication for CA.

3.2 Incoherencies in Departmental Strategies of the MoAIWD

Results of the analysis of coherence of departmental strategies of the MoAIWD unveiled both positive and negative interactions with CA (Table 4).

Table 4. Key interactions between MoAIWD Departmental strategies and CA

Department	Strategy being promoted	Interaction with CA
DCP	Tractor hire ploughs, ridgers & cultivators	-ve
	Oxen hire ploughs & ridgers	-ve
	Herbicides and pesticides	+ve/-ve
	Chemical fertilisers & hybrid seed	+ve/-ve
	Crop diversification	+ve
	Sasakawa planting method	-ve
	Deep ploughing & ridges	-ve
DAHLD	Crop residues for livestock feed	-ve
	Improved pastures	+ve
	Off-pasture grazing	-ve
	Stall feeding	+ve/-ve
DLRC	Planting ridges (tied/box ridges, ridge alignment contour ridging)	-ve
	Crop residue incorporation	-ve
	Minimum tillage	+ve
	Cover crops & mulching	+ve
	Compost manure	+ve/-ve
	Agroforestry	+ve
	Planting basins	+ve
	Vetiver hedgerows	+ve/-ve
	Herbicides	+ve/-ve
DAES	Lead farmer approach	+ve/-ve

Note. DCP= Department of Crop Production; DAHLD= Department of Animal Health and Livestock Development; DLRC= Department of Land Resources and Conservation (host department for CA); DAES= Department of Agricultural Extension Services; +ve= positive interaction; -ve= negative and/or conflicting interaction

Table 4 illustrates that numerous strategies exist across key departments of the MoAIWD that are incoherent with CA due to their negative interaction with CA principles and/or social-economic aspects of CA adoption. In addition, some strategies though apparently positive, have the potential to exert negative impacts on CA if poorly designed and executed, thus carrying a risk of undermining CA promotion efforts and/or adoption.

Promotion of conventional tillage strategies by the DCP and DLRC (Table 4) stands in conflict with the minimum soil disturbance pillar of CA. One of the national priority areas, to facilitate agricultural development as stated in the NAP, is to intensify farm mechanisation hence the promotion of tractor and animal-drawn ploughs, ridgers and cultivators by the DCP, being the host department of tractor and oxen hire programmes (Malawi Government, 2016). Also, the DLRC is self-conflicting as it simultaneously promotes tillage practices such as contour, marker and tied/box ridges as soil and water conservation measures, and CA (Table 4). Ploughing and ridging involve turning the soil every season and have been the benchmark of agriculture policy since the colonial era (Nanthambwe & Mulenga, 1999). While promotion of farm machinery is well intended to reduce the labour burden on farmers (Friedrich & Kassam, 2009), exclusion of CA compatible equipment such as soil rippers and specialised planting equipment in the NAP mechanisation strategy, in addition to the department's promotion of conventional tillage practices, promulgate conflicting signals to extension agents and farmers, thereby undermining CA promotion efforts.

The DAHLD strategy of emphasising preservation of crop residues for livestock feed: "*collect, stack crop residues and protect them by thorn bush barriers"* (Malawi Government, 2012), constrains crop residue supply for CA farmers particularly in mixed crop-livestock systems. Although planting of vetiver grass is promoted for soil and water conservation purposes (Malawi Government, 2012), it is unsuitable for livestock feeding as compared to alternatives such as Rhodes grass (*Chloris gayana*) or Napier grass *(Pennisetum purpureum)* (Gondwe, 2015). Thus, emphasis on promoting vetiver grass by the DLRC intensifies conflicts over crop residues between livestock and CA. The DLRC also exacerbates competition for crop residues by promoting residue incorporation (to make compost *in-situ*), limiting the availability of mulch materials and undermining CA's principle of continuous soil cover as farmers resort to applying very thin mulch (Chinseu, 2018). While compost manure is useful in improving soil health (Mereu et al., 2018), the strategy can reduce the availability of crop residues for CA mulching especially under smallholder farming conditions which typically produce insufficient biomass (Andersson & D'Souza, 2014; Baudron, Andersson, Corbeels, & Giller, 2011). Negative interactions of applying compost manure and crop residue mulch highlight the need to explore alternative strategies (such as liquid manure or cover crops) capable of minimising (unintended) negative consequences while enhancing CA synergistic interactions in the smallholder farming system.

While the sasakawa planting method is promoted by the DCP to optimise plant population and increase crop yield per unit area (Sasakawa Africa Association, 2007), the strategy contradicts the crop association pillar of CA, because it encourages maize monocropping. Locally known as the 'one-one' planting method (Malawi Government, 2012), the sasakawa method of planting sends conflicting signals to CA farmers who are simultaneously advised by the DLRC to adopt intercropping in CA systems. This suggests that coordination between the DCP and DLRC is deficient, hence the propagation of inconsistent and incoherent strategies. Under such circumstances, extension messages disseminated to farmers are conflicting as departments push their agendas without synchronising with each other's strategies. Similarly, incoherencies sowing confusion among smallholder farmers are also evident in Malawi's CA guidelines, shown in the next section.

3.3 Incoherence of Malawi's CA Guidelines

Although the CA guidelines are meant to "harmonise extension messages and minimise confusion and controversy over the definition and practice of CA in Malawi" (NCATF, 2016), inconsistencies and contradictions exist (Table 5).

Table 5. Incoherencies, controversy and contradictions in Malawi's CA guidelines (NCATF, 2016)

Extract from the CA manual (NCATF, 2016)	Elucidation/Remarks
"CA produces higher and more stable yields under variable rainfall" (p3)	Yield increases under CA take time (>5 years). This may raise false expectations particularly among smallholder farmers who largely expect immediate benefits.
"Achieving the benefits of CA necessitates the adoption of practices that require a break in cultural norms such as ploughing, ridging and keeping the fields completely clean" (p3)	Inconsistent with other pronouncement in the same document stating that "*one of the attractive features of CA is…. compatibility with common methods of planting"* (p8)
"Minimum soil disturbance is fundamental and non-negotiable" p9	Minimum soil disturbance refers to no-till system. Inconsistent with document sentiments of the need for flexibility to adapt CA to local circumstances and farmer preferences: *"adapt CA with farmer-specific circumstances"* p29, and *"adapting a technology to their specific needs and circumstances is crucial to attract interest in adoption"* (p28)
CA's effectiveness, simplicity and affordability without explicit needs for inputs and tools is a key feature to attract adoption" (p8)	Conflicts with another section of the same guidelines which has included inorganic fertilisers, hybrid varieties, herbicides, jab planters and soil rippers in "*Malawi's system of CA"* (p9); these inputs are deemed expensive by smallholder farmers who also perceive CA to be complex

Although the NCATF guidelines acknowledge that "*CA is a soil and water conservation practice rather than a soil fertility practice per se*" (p14), they simultaneously offer contradicting sentiments which seem to discourage the use of planting basins, the most appropriate *in-situ* water conservation practice for the Malawi context. While emphasising no-till systems, the guidelines have amplified negative aspects of planting basins while down-playing their benefits: *"Digging planting basins involves significant soil disturbance and labour for digging"*(p 15), and "*In Malawi...the added value of water conservation in basins has not been established against the high labour cost of digging basins" (p55).* Consequently, planting basins have been excluded from the frame of "*Malawi's system of CA*" (p9), yet the need to harvest rainwater *in-situ* is often a primary motivation for many CA farmers in Malawi, more importantly in the wake of frequent dry spells regularly experienced in Malawi in recent years and projected into the future (Sutcliffe, Dougill, & Quinn, 2016). In addition, research needs identified in the CA manual have only specified economic and biophysical studies "*to provide evidence of its [CA] performance*" (p29), and have overlooked social-cultural and institutional analyses that can broaden understanding of farmers' adoption, up-scaling or dis-adoption decisions. Multidisciplinary analyses would be more useful in generating relevant knowledge to inform policy and aid modification and/or tailoring CA projects to farmers' unique conditions, necessary for achieving more sustained adoption/up-scaling of CA.

4. Discussion

Although CA is a dominant rhetoric in agricultural development arena in Malawi, its integration in national agricultural policies remains inadequate to support its effective uptake. Findings in this article reveal poor integration of CA in the country's dominant agricultural policies, despite stated intentions of promoting SLWM as a means of achieving sustainable agriculture production and resilient socio-economic development. Inadequate integration of CA in the NAP diminishes chances of CA benefiting from national priority funding; considering that Malawi government annual budgets are finalised at the national level at the Ministry headquarters, where national objectives and strategies get re-prioritised following numerous prioritisations at lower levels of government. Therefore, even though CA features at lower policy levels in implementation plans, poor allocation of human and financial resources is inevitable, and this undermines implementation of CA activities on the ground (Lasco et al., 2006). As argued by Kalaba et al. (2014), policy strategies and actions that are prioritised at national level stand a better chance of being implemented because sufficient financial as well as technical resources are allocated due to strong support at the top level of governance. Since CA support at the top governance level is weak, financial and human resources for carrying out CA activities feature as one of the commonly cited institutional constraints in CA implementation (Dougill et al., 2017).

Narrow perspectives on CA in the agricultural policy documents, where CA is mainly viewed as a farm level technology for rain-fed agricultural production, have restricted inclusion of CA in other relevant policy areas. The limited awareness of CA and its broader applicability in achieving broader agricultural policy objectives signifies weak collaboration among researchers, practitioners and policy makers within the CA innovation system. This has hindered broader integration of CA in key policies and undermined potential to demonstrate multi-functionality of CA, thereby diminishing its stature in the policy arena. Strengthening stakeholder collaboration within the CA innovation system and greater advocacy in policy are thus paramount in deepening CA awareness and integration (Dougill et al., 2017).

Inadequate incorporation of CA in the government's research agenda of key policies has led to NGOs dominating CA research, with arguably limited and potentially biased research agendas (Wood, Dougill, Quinn, & Stringer, 2016). As evidence from independent local research is sparse, key policy documents are disproportionately informed by evidence generated by NGOs with funding from international donor agencies. For instance, the CA guidelines for Malawi, endorsed and adopted by the national conservation agriculture task force (NCATF) and the MoAIWD, are a mirror image of Total Land Care's CA implementation guidelines and approach (see Total Land Care [TLC], 2015 and NCATF, 2016). Overreliance on NGOs' evidence, which is primarily generated to serve international donor interests (Escobar, 1995), potentially undermines stakeholder consensus in development of a robust and widely acceptable national CA policy.

Without highlighting CA research in the NAP and ASWAp, resource mobilisation for local CA research becomes challenging; since the government's research agenda emphasises development of new varieties that are drought tolerant, disease resistant and high yielding in response to challenges of declining agricultural productivity and weather-related risks (Malawi Government, 2016). However, the literature widely acknowledges the need for more research to adapt and contextualise CA to achieve sustained adoption (Twomlow & Delve, 2016; Baudron, Thierfelder, Nyagumbo, & Gerard, 2015; Andersson & D'Souza, 2014). In the Malawi CA guidelines, a narrow research agenda, focused on biophysical and economic analyses to support the efficacy of CA, has overlooked the important role of participatory and interdisciplinary social and political-institutional aspects of CA, which are crucial for sustaining adoption among smallholder farmers (Friedrich, Kassam, & Taher, 2009). Lack of a robust CA research programme has led to paucity of local evidence pertaining to social, political, and institutional features which shape the environment and experiences of farmers implementing CA.

This article reveals that insufficient CA integration in agricultural policies contributes to incoherencies of agricultural department policies. For instance, while the DLRC is the lead department for promoting CA, collaborative linkages with other departments are not well defined, therefore CA is not broadly embedded in other departmental strategies. As a result, the strategies are not well synchronised for coherence with CA, leading to conflicts with CA (Table 4). While the Crops Department is rationally mandated to modernise and mechanise agriculture by promoting tractor-drawn or oxen-drawn ploughs, cultivators and ridgers, exclusion of specialised CA equipment puts the strategy in conflict with CA's minimum soil disturbance principle, which discourages ploughing or ridging (Derpsch, Friedrich, Kassam, & Hongwen, 2010; African Conservation Tillage Network, 2016). Similarly, promotion of residue incorporation by the DLRC and DAHLD's crop residue livestock strategies have negative impacts on CA's pillar of continuous soil cover, as they limit availability of mulch materials in smallholder communities and thus negatively affect CA adoption. While concurring with Cejudo and Michel (2017) in observing interconnectedness of policy integration and coherence, this study emphasises that stronger CA integration into agricultural policies, coupled with strong collaboration among relevant stakeholders, is necessary to improve the policy environment in which smallholders operate. This may facilitate sustained implementation of CA leading to durable impacts of agricultural innovations more broadly.

Though aimed at being the handbook for CA implementation, the CA guidelines contain inconsistencies and controversies capable of undermining CA. Notably, despite calling for flexibility in CA dissemination to adapt CA to local contexts, the CA guidelines demonstrate rigidities in dissemination approaches exemplified by declaring that no-till system is '*non-negotiable'* (NCATF, 2016; TLC, 2015). Rigidity in CA projects may fuel farmers' perceptions of being 'forced' to adopt CA configurations pre-determined by promoters as reported in the literature, disregarding local needs and aspirations, thereby jeopardising local project ownership (Wood et al., 2016). In addition, rigid farming regimes are unable to effectively cope with current and future stresses therefore limit their adaptive capacity and growth (Dixon & Stringer, 2015). Similarly, Dyer et al. (2014) emphasise flexibility and two-way communication as essential in CA project design. As "*one size does not fit all*" in project or programme design (Young, 2003 p390), Giller et al. (2015); Twomlow and Delve (2016) recommend a flexible CA package and a non-purist approach, to fit CA with farmers' unique situations and motivations for sustained adoption to occur. While the CA guidelines are meant to act as main tool for promoting CA, rigidities and inconsistent statements therein reinforce organisational practices that ignore farmers' aspirations, motivations and/or local context, which constrain adoption.

5. Conclusion

This article has examined CA integration and coherence of agricultural policies, and their possible implications for CA adoption. Findings indicate that integration of CA in the NAP is insufficient, and coherence of agricultural departmental strategies, in the context of CA in Malawi, is lacking. These policy deficiencies are mainly propelled by narrow focus of CA in the sectoral policies; weak political support for CA; poor sub-sectoral collaboration and coordination; poor knowledge-exchange in planning and implementation; and un-harmonised departmental strategies. Deficient CA integration and lack of coherence for CA in agricultural department strategies engender institutional constraints which potentially impinge adoption. These findings show that there is need to strengthen multidisciplinary research and engagement with policy makers and processes and raise awareness of the potential of CA, with a view to enhancing CA integration in relevant national policy objectives. Improved collaboration among relevant agricultural stakeholders is needed to enhance CA-coherence of agricultural strategies. This could be achieved through the new National Agricultural Investment Plan and National Resilience Strategy being developed, which present opportunities for greater coherence in policy planning in Malawi.

Our article makes an important contribution to a body of literature on agriculture and sustainability in sub-Saharan Africa through critical policy analysis to demonstrate how policies at national level may influence adoption of agricultural innovations at the grassroots. By analysing the extent of integration of CA and coherence of policies, the article has unveiled policy narratives capable of undermining adoption. The study provides empirically grounded knowledge vital for improved decision-making and project design of agricultural interventions, applicable to similar situations in sub-Saharan Africa. This knowledge may facilitate shifts in farming system practices towards sustainable agricultural development in the region.

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Sunn Hemp: A Legume Cover Crop with Potential for the Midwest?

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Abstract

Crops like corn and soybean occupy vast area in the Midwest, USA. When land is left fallow after the harvest of these crops, a number of degradation factors operate and bring about soil erosion, nutrient loss, decreased soil organic carbon, reduced biological activity and increase in weed biomass. Integrating cover crops (CCs) into this system would build benefits that the very system lacks. There are various CCs available, but leguminous CCs allows for reduced application of fertilizer nitrogen and builds the soil fixed atmospheric nitrogen. Winter CCs are restricted in the Midwest because of the short planting window which greatly minimizes the biomass accumulation. Warm season CCs would serve well here. Sunn hemp is one such tropical CC that grows well in temperate conditions too, without producing seeds. It comes with many benefits - including decreased soil erosion, improved soil organic carbon, increase in soil fixed nitrogen, higher biomass that adds organic matter and N to the soil, reduced weed density and weed biomass. The timing and method of termination influences the residue management. Going by the benefits it adds, sunn hemp is a viable warm season CC that can be grown in the Midwest and has great potential in fallows, prevented plant acres, areas of crop failure (planted and failed) and also in areas after the harvest of the short season small grains or processing crops. However, intensive research on sunn hemp is needed in the Midwest which is discussed.

Keywords: biomass, cover crop, CC termination, Midwest, nitrogen, sunn hemp, weed density

1. Introduction

Large stretches of land area in the upper Midwest, USA are dedicated to corn and soybean. These crops occupy the land for a short growing season and then the land remains fallow for the rest of the year, which opens it up for a number of degradation factors like loss of fertile topsoil through soil erosion, reduction in nitrogen due to leaching, decreases in the accumulation of soil organic carbon (SOC), decreased biological activity, and increased weed density and biomass. A more diversified rotation of additional crops including cover crops (CCs) could reduce these impacts.

2. Why Cover Crops?

Integrating CCs into such a system (corn – soybean) would build benefits that the very system lacks - improved soil organic matter, nitrogen fixation, increased nutrient cycling, improved biological diversity, reduced weed density and most of all, reduced soil erosion (Teasdale et al., 2007; Kaspar & Singer, 2011). Apart from the environmental/ ecosystem services they provide (Blanco-Canqui et al., 2015), CCs are also now viewed as possible sources of agronomic service to the ecosystem - if they can enhance the performance and yield of the succeeding crop (Wortman et al., 2012a). Though various studies have demonstrated this, deriving maximum agronomic benefits with CCs will depend on the choice of the species and the management of residues (Wortman et al., 2012b). CCs grown as single species has an advantage over that of a mixture for ease of operations and termination (Mirsky et al., 2009). However, some farmers still choose CC mixtures to harvest the multi- various advantages of N fixation, differential harvesting of nutrients due to varied rooting systems and the soil layer depths they occupy, creation of a varied influence on soil porosity and infiltration, and the type of residue they leave on the surface leading to no-till, or the forage they can provide for the animals on the farm.

3. Cover crop options

Various CC options are available: cereals like winter rye, wheat, oat, sudan-sorghum grass, legumes like hairy vetch, red clover, crimson clover, cowpea, brassicas like rapeseed, white mustard, forage, either grown as single species or as mixtures. However, while most CCs are able to establish and grow well in tropical areas, some of these would not survive the harsh winters of the Midwest. Many of these would be less productive here than in other areas of the country, with late planting dates, shorter growing season and lower heat unit accumulation from harvest to planting and a very short growing season (Appelgate et al., 2017). It is a challenge to have successful establishment and growth of CCs in these regions.

Integrating legume CCs in these systems reduces the total dependence on fertilizer N and improves the environment by decreasing N losses (Reinbott et al., 2004). Winter legume CCs help improve soil physical properties, reduce soil erosion, conserve soil water, recycle nutrients and increase crop yield potential (Veenstra et al., 2007). However, the lack of favorable planting window and weather conditions means that the winter legume CCs often accumulate limited biomass. Warm season legumes may then be a desirable option.

Research on a few CCs that fit the corn - soybean system has been extensive. Although Natural Resource Conservation Service (NRCS) has listed some new CCs for this region, research has been limited in its ability to test effectiveness and scope of these new CCs. One such crop that deserves attention is sunn hemp. This is touted as one of the most efficient and effective CC for the Midwest, yet is largely untested.

4. Sunn Hemp

Sunn hemp (*Crotolaria juncea L.*) is a warm season legume that is grown for its ability to produce large biomass amounts and fix atmospheric nitrogen, thus improving the nutrient cycling of the soil while preventing soil erosion. It can also suppress weed density and biomass during the fallow period. By using this adapted tropical legume, the challenges of the use of winter cover crops can also be overcome. Though it grows all year round in Hawaii and is able to produce seeds there, it does not produce seeds in the Midwest. Sunn hemp is adapted to a wide range of soils and hence has attracted attention. It performs on poor sandy soils and also on soils with low fertility; however, it grows best on well-drained soils with a pH of 5 to 7.5, and is resistant to nematodes (NRCS, 1999).

Sunn hemp is grown more in the southern states where there is warm temperatures, and cultivars being photoperiod sensitive, have a higher productivity there compared to other regions of the country. As a tropical legume, sunn hemp is able to produce larger quantities of biomass in a shorter time period than winter legumes from temperate zones while still providing agronomically important amounts of fixed nitrogen (Price et al., 2012). Sunn hemp is a legume that grows rapidly and can produce 5.6 t biomass ha^{-1} and 122 kg N ha^{-1} in as little as 60 to 90 days. Close to 8 t ha^{-1} of biomass with 145 kg of N ha^{1} has been recorded in the south (Balkcom & Reeves, 2005; Cherr et al., 2006), and an average of 9.6 t biomass ha^{-1} at 45 to 60 days after planting in a 2-year study near Stillwater, Oklahoma (Warren et al., 2017).

Planting of sunn hemp is usually undertaken when the soil temperature is more than 50^{o} F, and this makes it an ideal cover crop to follow wheat harvest or after short-season summer crops harvested in August or early September. Being a photosensitive crop, it is killed by temperatures less than 28^{0} F, and any delay in planting shortens the growing season and leads to a reduction in biomass yield. Therefore it is important to plant sunn hemp atleast 45 days before the first killing freeze in fall (Warren et al., 2017). It cannot produce viable seed in continental United States except for extreme southern locations of Florida and Texas; thus, eliminating its potential to be a weed (NRCS, 1999), but this elevates seed prices for the Midwest. Sunn hemp cultivar, “AU Golden” is suitable for production in temperate environments (Balkcom et al., 2011).

Sunn hemp as a CC has been consistently tested in the south, but has lacked the same intensity of research in the Midwest. Hence, it is of interest to the authors to build the case for sunn hemp as a CC. There are very few warm season legumes available as CCs; Sunn hemp can fill that void and fit in the cropping systems of the upper Midwest with benefits as indicated below.

4.1 Potential Benefits

4.1.1 Nitrogen and Carbon

Research has proved that SOC and crop yields are positively correlated, and therefore an increase in SOC through the addition of CC residues help increase crop yields (Blanco-Canqui et al., 2012). The SOC concentration was 1.25 times greater with sunn hemp on average than in non-CC plots in the top soil layer (Blanco-Canqui et al., 2011). Any increase in SOC improves the soil physical properties, increases water retention and infiltration, improves nutrient cycling and thereby stimulates crop growth. SOC also absorbs and filters nutrient loss in runoff (Rawls et al., 2003). Stallings et al. (2017) reported higher C:N ratio that led to greater immobilization with June and July planting of sunn hemp, and lower C:N ratio with May planting. At the

0 to 5-cm layer, increased soil nitrogen was recorded with cover grasses and sunn hemp compared to fallow (Garcia et al., 2013).

Sunn hemp added nitrogen to the soil as a legume crop, resulting in higher nitrogen uptake and yield of corn in CC plots compared to no cover plots. However, there was net increases of soil N that resulted in increased nitrate leaching. Muneoz- Carpena et al. (2008) recommended that when sunn hemp was used as CC, there should be reduction in the N fertilizer applied. In Kansas, averaged across four N application rates, soil total N concentration increased by 125 kg ha^{-1} under sunn hemp compared with non-CC plots (Blanco-Canqui et al., 2012). Even though sunn hemp fixed N in the soil in significant amounts, in places of low rainfall, the beneficial effects of summer CCs may be limited. Sunn hemp contributed the equivalent of 58 kg ha^{-1} of N fertilizer for corn planted the following spring (Balkcom & Reeves, 2005), but N losses (most likely due to leaching) during the winter greatly reduced availability. Sunn hemp in combination with rye is able to scavenge residual N and could improve N use efficiency in organic systems and increase mineralizable N (Dabney et al., 2001).

The assumption that winterkilled CCs released N very fast is supported by Weinert et al. (2002), who documented that CCs which winterkill release and leach N more quickly than CCs which overwinter. Such experiments need to be evaluated in the upper Midwest too, to quantify the addition of N and increase in yield with sunn hemp as cover crop.

4.1.2 Weed Suppression

Compared to mowing CCs, termination with a roller-crimper results in uniform distribution of residues leading to improved weed suppression, prolonged residue decomposition and reduced fuel and labor inputs (Creamer & Dabney, 2002). For organic farmers, alternating this practice with crops that are established with tillage avoids selection for perennial weeds (Rasmussen et al., 2014; Smith et al., 2011). Volunteer CCs resulting from incomplete termination with mechanical rolling can be problematic in subsequent crops and may impact the benefits of organic rotational no-till. But with sunn hemp, since the potential to seed is next to nonexistent, there is no problem of the CC becoming a weed (NRCS, 1999). CCs need to produce a biomass in the range of 5 to 8 t ha^{-1} in order to form an effective layer of mulch to prevent weeds from establishing (Mohler & Teasdale, 1993). Sunn hemp has been recorded to produce nearly 7 to 8 t ha^{-1} of biomass in the Midwest regions. That makes it a potential CC capable of weed control after the cash crop either in the summer or fall. In Georgia, Bradley et al. (2015) reported lower grass weed biomass with sunn hemp, which also needs to be studied in the Midwest.

4.1.3 Biomass N

Nitrogen fixing summer or tropical legume CCs such as sunn hemp that produce high biomass may improve soil properties more rapidly and have a greater effect on increasing crop yields. Planting CCs early, such as after corn silage or wheat or into standing crops just before it reaches maturity (Ruis & Blanco-Canqui, 2017) is one way of CC management. For example, when leguminous CC followed wheat in Kansas, biomass levels were 7 t ha^{-1} for sunn hemp and 5.3 t ha^{-1} for late maturing soybean (Blanco-Canqui et al., 2011). Results of the experiments conducted by Blanco-Canqui et al. (2012) indicated that summer CCs, particularly sunn hemp, can return significant amounts of residues in a short period of about 12 wks. The increased height of sunn hemp may also be beneficial for shading and smothering weeds. Such higher residue input from sunn hemp has been reported from other regions as well (Mansoer et al., 1997; Balkcom & Reeves, 2005; Schomberg et al., 2007).

Cultivar "Tropic Sun", which has been most extensively studied, has been shown to produce 5.8 t ha^{-1} biomass and contribute 135-145 kg ha^{-1} N in a 9-12-week period (Mansoer et al., 1997). High biomass production within a short period enables sunn hemp to serve as a summer CC between warm-season harvest and cool-season planting (Mosjidis & Rehtji, 2011), with the added benefit of reduced fallow weed population and density. A winter CC such as rye, could sequester N produced from decomposing sunn hemp biomass (Balcom & Reeves, 2005), making this system a profitable one. Three year mean biomass added to the soil from sunn hemp in a study in Georgia ranged from 6.9 to 9.8 t ha^{-1} while that of crimson clover ranged from 3.5 to 4.9 t ha^{-1}. This increased biomass contributed to improvement in soil structure and fertility (Hubbard et al., 2013). In a planting date study at Wisconsin, a maximum biomass of 5.7 to 7.4 t ha^{-1} was obtained (Stute, 2017). Repeated use of sunn hemp as a CC in conservation tillage systems could be expected to improve soils in the region due to the large amount of residue produced in a short growing period (Schomberg et al., 2007), and thus leads to the argument for sequential CCs.

4.1.4 Crop Yield

Legume CCs like sunn hemp are the most reliable means to enhance cash crop yields compared with fallows or other CC species (Snapp et al., 2005). Sunn hemp when used as summer CC brought about changes in soil properties which increased the yield of crops that followed (Blanco-Canqui et al., 2011 & 2012). This is in conformity with the results of Balkcom and Reeves (2005). Increase in crop yields due to the beneficial effects of CCs like sunn hemp can be particularly greater at or below 66 kg ha^{-1} of N application, which suggests that CCs may be supplementing extra N to the crop for higher gains in yield while also removing competition from weeds, reducing input costs of herbicides and fertilizers, and gainfully using soil moisture. Results from Kansas showed that the mean increase in grain yield of corn as a result of including cowpea, pigeonpea, sunn hemp, double cropped soybean, and double cropped sorghum in the rotation over fallow system with 0 kg N ha^{-1} was 78, 91, 66, 72 and 12% respectively (Mahama et al., 2016). Fertilizer N replacement values for cowpea, pigeonpea, sunn hemp, double-cropped soybean, and double-cropped grain sorghum were 53, 64, 43, 47, and -5 kg N ha^{-1}, respectively.

When sunn hemp was grown as summer CC, particularly at N application rates that were low, Blanco-Canqui et al. (2012) reported an increase in crop yields. When no nitrogen was applied, sunn hemp increased sorghum yield by 1.18 times in 2003, 1.54 times in 2005, 1.32 in 2007, and 1.43 in 2009 as compared to non-CC plots. This difference in sorghum yield between sunn hemp and non-CC plots at 0 kg N ha^{-1} tended to increase gradually with time after summer CC establishment. However, CCs may or may not increase yields of subsequent crops (Andraski & Bundy, 2005).

4.2 Termination

Termination method and residue management can influence N mineralization, soil nutrient loss and availability, crop N uptake, weed communities and soil moisture availability (Mirsky et al., 2009; Parr et al., 2011; Wortman et al., 2012b). Yield is typically expected to improve with legume CCs, and when loss occurs, it is attributed to incomplete cover crop termination, increased moisture utilization by CCs leading to moisture deficit, or nutrient immobilization (Mischler et al., 2010a). Liebl et al. (1992) found that transpiration reduced available soil moisture during dry periods, but following no-till termination, CC residue conserved soil moisture relative to a no-till system without CCs. Given that the driest portion of the growing season in the western Corn Belt typically occurs after CC growth (i.e., June-August), potential soil moisture savings offered by the residue (post-termination) throughout the growing season may negate moisture deficits observed during CC growth (Wortman et al., 2012b).

Delaying termination until approximate planting of the following crop creates a more synchronous relationship between the sunn hemp residue mineralization and crop demand (Stallings et al., 2017). Starting with a CC and then switching from conventional till to no till is more likely to ensure success and to maintain economic crop yields (Islam & Reeder, 2014). One method of reducing tillage frequency in organic grain production is CC based rotational no-till (Mirsky et al., 2012), which involves growing high-biomass CCs, terminating them with a roller-crimper, and no-till planting cash crops into the weed-suppressive mulch (Keene et al., 2017). It is also necessary to make sure that the CC is susceptible to control with a roller-crimper so that it does not compete with the cash crop (Bernstein et al., 2011; Mischler et al., 2010b). Blanco-Canqui et al. (2012) concluded that inclusion of summer legume CCs like sunn hemp in no-till systems brings about many benefits like improved soil physical properties, increased SOC and N, and also reduced application of fertilizer N.

Sunn hemp planted in August or September following an early season summer cash crop would be best served by allowing freezing temperatures to terminate it. Mowing and crimping are other non-chemical methods of termination and many farmers have reported good success with it. Growing sunn hemp as CC and roller crimping it would therefore lead to no till corn, with additional benefits of improved N status of the soil. This usually may require multiple passes with roller/crimper to sufficiently kill the cover crop. This system can greatly benefit organic no-till corn while conventional farmers can also be benefitted by growing sunn hemp. When CC and manure additions are coupled, an organic reduced tillage system can sequester increased SOC over a no-till system after several years (Teasdale et al., 2007).

4.3 Potential Applications

There are few good warm season legume CC options for the upper mid-west, yet several applications where it could be used. Applications include summer fallow, prevented plant acres, cases of crop loss, and after harvest of short season crops such as small grains and processing crops.

Land is often left fallow in organic production systems, either as a planned soil building strategy or to remediate soils from physical degradation caused by excessive tillage or to reduce weed populations (Clark et al., 2017). Large areas of the upper Midwest are also unplanted annually due to the stringent cut-off dates associated with federally supported crop insurance (United States Department of Agriculture (USDA) Handbook, 2018). Wisconsin, for example, has averaged 76,142 acres annually in the past 10 years for prevented plant acres, and

6,132,295 acres for planted and failed (USDA, 2018).

We can anticipate increases in prevented plant acres and storm damaged crops as storm intensity and frequency increase. More extreme temperatures and precipitation can prevent crops from growing. Extreme events, especially floods and droughts, can harm crops and reduce yields. High nighttime temperatures affected corn yields across the U.S. Corn Belt in 2010 and 2012 (Environment Protection Agency (EPA), 2017, Iizumi & Ramankutty, 2015). Sunn hemp would be a right fit under such situations. It can be either grown as a single crop or in sequential cover cropping.

Finally, harvest of short season crops such as small grains and processing idle cropland for a significant portion of the growing season with cover crops has beneficial effects. Planting a warm season legume like sunn hemp to capture unused solar radiation could provide many associated benefits as described earlier.

5. Conclusion

Though there is potential in using sunn hemp in the organic no till corn production, its performance depends heavily on the production of biomass, and formation of a mulch layer to effectively control weeds. Sunn hemp as a legume CC fixes atmospheric N, increases the soil nutrient availability, improves the SOC, reduces soil erosion and serves the ecosystem. It can be either cultivated as a warm season CC or a component of sequential cover cropping in organic transitions or no till corn. In all this, the proper stage of crimping is very important. There has not been much studies in that direction on sunn hemp, especially in the upper Midwest of USA, and therefore, needs research and documentation.

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Ancient Agropastoral System of the Bolivian Altiplano: a Robust Ecosystem Endangered from Changes in Land-use

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Abstract

The current study examines the challenges and constraints faced by rural, small-herd, llama (*Lama glama*) agropastoralists of the Bolivian *Altiplano*. Three different study sites with various degrees of agropastoralism were examined in order to describe the relationship between quinoa (*Chenopodium quinoa*) and llama production and the implications of land use competition between these two livelihoods. In order to document the impact of land use change, the study also examined the native forage species available to free grazing llamas and their relative importance. Llama pastoralists were interviewed and completed a survey on the perceived importance of native forage plants in grazing llama diets as well as the perceived constraints to llama husbandry. The relative frequency of citation (RFC) index was employed as a measure of relative importance of different native forage plant species. This data was supplemented with further primary data collected from the field using mixed methods involving participatory rural appraisal techniques (PRA), interviews and focus groups. Secondary data was collected from an in-depth literature review, government offices and other relevant institutions. The study presents a detailed list of all cited native forage species and their perceived importance as a forage crop and any ethnoveterinary uses. The results reveal that challenges and constraints can often be site-specific, and a lack of forage throughout the dry season (May to November) was a general constraint among study sites. Quinoa production was found to be in direct competition with llama husbandry, with many sites demonstrating s shift away from llama pastoralism.

Keywords: llama husbandry, land-use conflict, sustainable livestock, Bolivia

1. Introduction

The United Nations Human Development Index ranks Bolivia 118th out of 188 countries, with 45% of the population living below the poverty line (UNHDI, 2016). Llama husbandry is recognized as an important element of the *Altiplano* ecosystem (Barreta et al., 2013; Treydte, Salvatierra, Sauerborn, & Lamers, 2011; Postigo, Young, & Crews, 2008; Fairfield, 2004) as it ensures soil fertility and seed dispersal while providing a livelihood and a source of many goods and services for rural communities. Small ruminant (llama and sheep) husbandry is the principal economic activity for more than 54 000 rural poor families in Bolivia, while 3 000 families pursue llama husbandry as their primary source of income (Barreta et al., 2013; Vera, 2006). Llama husbandry in the Bolivian *Altiplano* involves traditional agro-pastoral herding in natural pastures. Agropastoralists are defined as people who derive less than 50% of their income from animals and animal products, and the remainder of their income is predominately derived from the cultivation of crops (Jenet et al., 2016). In the Bolivian Altiplano, community pastures are managed collectively by local peoples (Jenet et al., 2016). Traditionally, communities of the Altiplano would self-govern access and use of community pastures depending on population density, the environment and available resources. Up to 90% of pasture land in the Altiplano is still managed communally (Coppock et al., 2017).

1.1 Background on Native Forage Species of the Bolivian Altiplano

Under current management practices, the herds of the poorest pastoralists are observed to be experience an accelerated productivity decline (Alcazar, Morales Sanchez, & Rojas, 2003). The Food and Agriculture Organization of the United Nations [FAO] (FAO, 2005; Vera, 2006) reported birth rates of 50-60% and death rates of 35-55% in Bolivian rural llama populations.

Low forage availability, particularly during the dry season (from May to November) is a recognized challenge for rural llama husbandry in Bolivia (Barreta et al., 2013; Fugal, Anderson, & Roundy, 2010; Van Saun, 2006; Genin, Villca, & Abasto, 1994; San Martin & Bryant, 1989; Reiner, Bryant, Farfan, & Craddock, 1987). Animals are more susceptible to parasitic infections during the dry season (Fugal et al., 2010) when forage availability is low, and the animals' immune system and overall health is weakened (Alandia, 2003). Alzérreca (1992) states that native Bolivian vegetation accounts for 98% of the llama diet, while the remaining 2% is sourced from cultivated fodder crops and crop residues. Ordonez (1994) found that llamas grazing in natural pastures in Ecuador consumed approximately 1.7 kg of dry matter (DM) daily per head. Stölzl, Lambertz and Gauly, (2015) noted that llamas raised in Central European grazing conditions had a DMI of 0.85% of BW. Alzérreca (1985) states that Bolivian Altiplano grazing lands produce an average DM yield of 400-800 kg/ha/year and estimates that the central Altiplano could support a carrying capacity of 7-21 ha/AU/year (Note 1. AU = 1 llama. Source: Alzérreca (1985)).

1.2 Land-Use Pressure in the Bolivian Altiplano

Agricultural land intensification is one of the most significant factors for land-cover change (Kim et al., 2014; Lambin et al., 2001). In the Bolivian Altiplano, the trend is agricultural intensification and expansion of quinoa cultivation (*Chenopodium quinoa* Willd.) (Felix & Villca, 2009; Postigo et al., 2008). The Altiplano region of the Potosi Department is Bolivia's main quinoa producing area and also the area with the highest concentration of llamas, i.e. 762 793 heads according to Fundación de Estudios Sociológicos [FUNDES] (2009). Between 2000 and 2013, quinoa production in Bolivia more than tripled in area under cultivation (Blajos, Ojeda, Gandarillas, & Gandarillas, 2014). Despite this increase, the average yield per hectare has decreased (Blajos et al., 2014; Jacobsen, 2011) - cf. Figure 1. Quinoa parcels are often sporadically distributed and, increasing, natural pastures are put under quinoa cultivation. (Bonifacio et al., 2014; Martinez, 2014). Free grazing llamas will graze on quinoa plants as the fields do not have delimitated areas. This can result in disputes between quinoa producers and llameros, with the llamas being called 'thieves' and the pastors held accountable for the economic losses of the quinoa producers (Bonifacio et al., 2014). The expansion of the area under quinoa production in the Altiplano has seen acceleration with the increased mechanization and use of tractors by quinoa farmers (Healy, 2001). When natural pastures are converted to quinoa parcels, soil degradation is accelerated through erosion and the destruction of the native vegetation. The destruction of natural vegetation greatly undermines llama productivity, as the availability of already scarce forage plants is decreased. Pastoralists are forced to pasture their animals in further marginalized areas, further from the corrals and home (Blajos et al., 2014). Quinoa was traditionally cultivated alongside llama husbandry, with a long crop rotation and llama manure used as fertilizer and to conserve soil humidity - but this has changed drastically in the last decade (Fonte et al., 2014; Jacobsen, 2011). With the quinoa 'boom' in full swing, llama husbandry has lost its attractiveness to rural agropastoralists. Traditional agropastoralists are abandoning llama husbandry in favour of exclusively growing quinoa as a cash crop (Martinez, 2014). This has upset the equilibrium between crop and animal production in the delicate Altiplano ecosystem (Chura, 2009). The increase in conversion of natural pastures into cropland puts the availability of native forage plants and the traditional ecological knowledge (TEK) associated with llama husbandry and forage plants at risk, which can result in the disappearance of this knowledge (Signorini, Piredda, & Bruschi, 2009; Martin, 1995). The current literature surrounding native forage plant species of the Bolivian Altiplano contains little ethnobotanical knowledge of these plant species. Moreover, Vidaurre, Paniagua and Moraes (2006) estimated that only 3% of ethnobotanical studies carried out in Bolivia concerned the ethnobotany of forage species.

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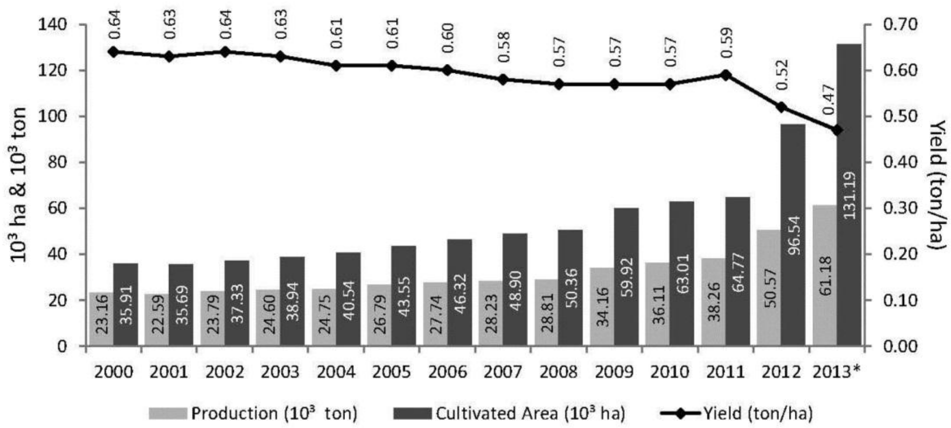

Figure 1. Quinoa production and expansion in Bolivia. Source: redrawn from Blajos et al., 2014

2. Study Objective

The study addresses the challenges and constraints of agropastoralism, and the associated traditional ecological knowledge (TEK) of native forage species in the Bolivian Altiplano. The study addresses the knowledge gap in llama husbandry in the Bolivian Altiplano, specifically the identification and perceived importance of native forage plants in natural pastures. The TEK of native plants for ethno-veterinarian controls was also studied.

3. Methods

3.1 Study Area

The study area encompassed three communities in the Province of Antonio Quijarro, Department of Potosi, Bolivia (Figure 2). Communities were chosen to have a similar population size and residents of all three communities derived their income from various degrees of agropastoralism. The Province accounts for 35% of the entire Bolivian llama population (Instituto Nacional de Estatistica [INE], 2014). The study sites are characterised by an extremely low average annual rainfall (277 mm) and located at an average altitude of 4120 m a.s.l. (Table 1).

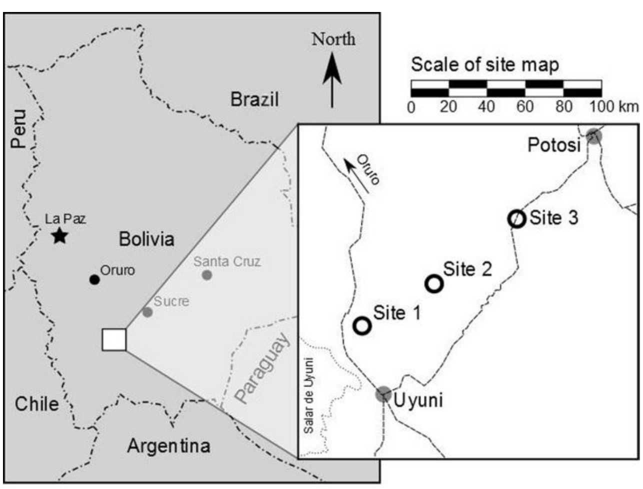

Figure 2. Map of the study area

Table 1. Climatic and descriptive characteristics of study sites. Sources: adapted from personal correspondences (2014); SENAMHI (2014); and ZONISIG (2000)

		Site 1 (Chacala)	**Site 2** (Tomave)	**Site 3** (Chaquilla)
Altitude (m a.s.l.)		3828	3918	3764
Average Annual Precipitation (mm)		200	291	340
Average Annual	High	15.8	14.9	16.2
Temperature (℃)	Low	-1.2	-6.9	-8.6
Population (latest census)		97	41	40
Farming systems		High commercial production of quinoa for 40 years, mixed with llama and sheep husbandry	Small commercial quinoa production in last 5 years. Llama husbandry with support from local association.	Exclusive llama and livestock husbandry with no commercial quinoa production.
Local Geography		Mountains and Grasslands	Foothills and Wetland Plains	Wetland Plains
Geographical Coordinates		20°10’25S, 66°51’48W	20°03’45S, 66°31’49W	19°51’22S, 66°08’40W

The climatic conditions and limited rainfall of the Department permit a vegetative growth period less than three months (Zonificacion Agroecologica y Socioeconomica, Departamento de Potosi, Bolivia [ZONISIG], 2000). The different United Nations Educational, Scientific and Cultural Organization [UNESCO] classes of native vegetation found in the Department are shown in Figure 3. The majority of the landscape is dominated by short, woody shrubs, tall bunchgrasses and perennial rhizomatous grasses and slow-growing perennials. UNESCO (1973, cited from ZONISIG, 2000) identified 409 plant species from 70 families in the Potosi Department (ZONISIG, 2000). The native vegetation consists primarily of species from the following families: Asteraceae (23%), Poaceae (19%), Fabaceae (5%), Verbenaceae (3%), Cactaceae (3%), Mimosaceae (2%), Solanaceae (2%), the remaining 43% in other plant families (ZONISIG, 2000).

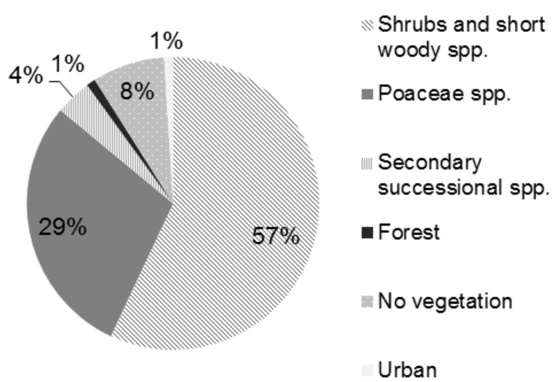

Figure 3. UNESCO classes of vegetation cover in Potosi Department. Source: ZONISIG, 2000

3.2 Data Collection

Data collection was carried out January to April 2014, during the wet season. Primary data was collected through an analytical survey developed *in-situ*. Following the first contact with study participants, the survey was developed with the help of three key informants from Site 1 whom also served as respondents for pilot testing the survey. The survey aimed to sample all llama-owning individuals at each of the three study sites to achieve maximum variation in the sample. In total, 41 respondents participated in the survey (Site 1: 12; Site 2: 15; Site 3: 14). After completing the survey with each respondent, a short interview on native forage plants was conducted - each respondent was asked purposeful questions to consider their knowledge on native forage plants. The interviews were followed by a free listing exercise, where respondents were asked to name all known forage plants. Each time a respondent mentioned a plant during the survey, the interview and in the free listing exercise, the local plant names were recorded and noted as a citation to calculate the Relative Frequency of Citation (RFC) index.

3.3 Relative Frequency Citation (RFC) and Data Analysis

The demographics and descriptive variables of the management practices of the study sites were recorded, and significant differences were measured between sites using a one-way analysis of variance (ANOVA). The Levene's test was performed to test for equal variances. When equal variances were assumed, the Scheffe post-hoc test was used, and when equal variances were not assumed, the Games-Howell post-hoc test was used to determine which sites differed significantly from one another.

To determine the subjective importance of forage species, the Relative Frequency of Citation (RFC) index was used (Ahmad et al., 2014; Signorini et al., 2009). The number of species cited by each respondent and the frequencies at which they were cited at each study site gives an idea of the TEK of forage plants in the area. By identifying the most frequently cited plants, it can be inferred that these species are indeed the most well-known and probably also the most important species (Ahmad et al., 2014; Estomba, Ladio, & Lozada, 2006) for pastoral use.

As the RFC of a group does not take into consideration the frequency with which a respondent has cited a given plant, nor the total number of species cited by an individual, an adapted version of the RFC (per individual, RFCi) was also calculated to compare results.

In order to gain an understanding of the diversity of the forage plant community between sites, the Simpson Diversity Index (D) and Equitability (H) were calculated. The diversity indices and associated evenness were calculated for each individual, and then the average was taken to give a total diversity index for each site. The total and mean citations for each species at all three study sites were also calculated. By using quantitative measures in conjunction with qualitative measure and the context of the study sites, a useful picture of the ecology and ethnobotany at each site is produced.

The ethnobotanical datasets of native forage plants were analysed according to the statistical methods presented in Table 2 to obtain a measure of individual and local importance - i.e. site-specific - for each species to also elucidate the inter-site diversity of forage plants.

Table 2. Methods of statistical analyses applied

	Application	Specification	Explanation
Relative Frequency of Citation (RFC) index	To identify the most frequently cited plants for each study site	$RFC = \frac{\mathrm{FC}}{\mathrm{N}}$	FC is the number of respondents who mentioned a given species and N is the total number of respondents from the site.
	To identify the most frequently cited plants for each respondent/informant	$RFC_i = \frac{\mathrm{FC_i}}{\mathrm{n_i}}$	FC_i is the number of times an individual (i) mentioned a given species and n_i is the total number of species citations recorded for this respondent.
Indices of diversity and evenness	To gain an understanding of the inter-site diversity of the forage plant community: 1. the Simpson Diversity Index (D) and 2. the Shannon Equitability Index (H)	$D_i = \frac{\sum_j m_{ij}(m_{ij}-1)}{M_i(M_i-1)}$	m_{ij} is the total number of times that an individual cited a given species (*j*) and M_i is the total number of species cited by this respondent. Afterwards, the average was taken of the calculated D_i values to give a species diversity for the entire site, where N is the total number of respondents for the site.
		$D = \frac{\sum D_i}{N}$	
		$H_i = \frac{\sum_j \left(\frac{m_{ij}}{M_i}\right) \times \ln\left(\frac{m_{ij}}{M_i}\right)}{\ln(M_i)}$	Symbols are identical to those used in the calculation of D_i. The equitability indicates how even the distribution of species is for each respondent (H_i)
		$H = \frac{\sum H_i}{N}$	H_i was averaged to get an equitability measure (H) for the entire site.
Statistical tests	To analyse the inter-site differences with regard to known forage species, a one-way analysis of variance (ANOVA) was carried out	ANOVA	

	To identify sites significantly different from each other with regard to knowledge of forage plants: 1. post-hoc Scheffe tests (assuming equal variances) and 2. Games-Howell tests (assuming unequal variances). Nb. Outliers, defined as a species mentioned by a sole individual and only on one occasion, were not included in the analysis of variance, but are presented in the base inventory list (see Appendix I)	Scheffe test
		Games-Howell test
	The use of plants for ethno-veterinarian purposes was analysed using X^2 tests of independence.	X^2 test

4. Results

4.1 Site Differences

Income derived from llama husbandry was reported at 17.91% on average from Site 1, 24.67% from Site 2, and 36.07% from Site 3 – no statistical differences between sites was observed. As per the definition of agropastoralism (Jenet et al., 2016), all three sites fall into agropastoral systems as the inhabitants derive less than 50% of their income from animals and animal products.

Site 1 had the highest reported area of planted quinoa (μ=10.33 ha), while Site 2 reported an average of 1.35 ha, and Site 3 had the lowest area of quinoa planted (μ=0.2 ha). Llama populations were reported to be decreasing at a significantly higher rate (p-value 0.001) at Site 1 than at Site 2 and Site 3 (p-value 0.007). Herd sizes reported from respondents were higher than those reported in previous studies. Livestock owners were asked what would be an ideal number of llamas in a herd in order to maintain a satisfactory livelihood. Mean ideal herd sizes of llamas per person were reported as 37.5 heads, 50.1 heads, and 40.9 heads at Sites 1, 2, and 3, respectively - Table 3.

Table 3. Average herd size of llamas in Potosi Department and Ayopaya region, Bolivia

	From study survey	**Markemann & Valle Zarate (2010)**	**Markemann (2007)**	**Delgado (2003)**	**Nurnberg (2005)**	**FIDA et al. (1999)**
Mean	82.2	45.6	43.7	52.0	50.0	46.0
SD	79.2	34.2	25.3	37.9	38.4	-
Range	10 – 400	5 – 153	13 – 95	6 – 254	9 – 218	-
Number of herds/ respondents	41*	47	21**	65	43	51,997***

*derived from 41 herds, with a total of 947 animals from 3 communities in Potosi Department;

**derived from 21 registered herds in August 2007, with a total of 918 animals from 3 communities in Cochabama Department;

***derived from the national census of 2,398,572 llamas and 51,997 families

The number of citations of different ethnobotanical ecosystem categories varied among study sites. Post-hoc Scheffe tests revealed that the ecosystem of *bofedales* (wetlands); F (2, 38) = 13.79, p-value=0.00, was cited a significantly greater number of times at Sites 2 (μ=2.00, σ=1.134), and 3 (μ=1.57, σ=0.756) than at Site 1 (μ=0.25, σ=0.622). Post-hoc Scheffe tests revealed that *espinas* (spinose plants); F (2, 38) = 10.448, p-value=0.00, were cited significantly more often at Site 1 (M=3.33, SD=1.073) than at Sites 2 (μ=1.80, σ=1.373) and 3 (μ=1.21, σ=1.122). Similarly, post-hoc Scheffe tests revealed that herbaceous plants (*pastos verdes*); (2, 38) = 9.544, p-value = 0.00, were cited a significantly higher number of times at Site 1 (μ=1.25, σ=0.965) than at Site 2 (μ=0.27, σ=0.458) and Site 3 (μ=0.29, σ=0.469).

4.2 Time Inputs

Livestock owners at Site 1 dedicated significantly more time to their animals than at Site 2 (p-value 0.000) and at Site 3 (p-value 0.000) in the wet season which runs from November - May. This is the same time that quinoa is planted, and the quinoa is harvested in April or May. During the wet season at site 1, the llamas need to be brought out to pasture and kept the entire day so as to make sure they do not enter quinoa plots and graze on the plants. The pastors employed were always family members at Sites 2 and 3, while at Site 1, 75% of the respondents used family members as pastors; 16% hired salaried pastors, and 8% employed the *Partida* system, where the livestock owner and the hired pastor split the llama products as a form of payment. The amount of time input required was stated as a limiting factor by 59% of the respondents at Site 1, while it was not mentioned as a problem at Sites 2 and 3, as the animals are allowed to graze freely throughout the year.

4.3 Native Pasture Access & Use

Respondents across all three study sites stated that a single llama needs, on average 4.4 ha of natural pasture land in order to ensure the animal's wellbeing. There were some variations among sites, but no statistically significant differences. Most of the respondents in all three study sites stated that they had access to natural pasture lands for their animals to graze (Table 4); however, reported access to natural pastures was slightly lower at Site 1. The most common limitation to ensuring sufficient pasture land at Site 1 was that there was no land available for the animals' to graze upon, as it was in use for quinoa production. At Site 3, respondents also reported a low level of perceived sufficient pasture land available (μ=0.414). However, respondents stated overstocking of animals and overgrazing of the available pasture lands as reasoning to their answers. Respondents at Site 1 reported the significantly lower perception of secure, long-term access to pasture lands.

Table 4. Native Pasture Use & Access

		Mean Site 1	Mean Site 2	Mean Site 3
Access to pasture land	0=NO, 1=YES	0.75	1.00	1.00
Secure, long-term access	0=NO, 1=YES	**0.08	0.80	0.85
Sufficient pasture land	0=NO, 1=YES	**0.00	0.80	0.42
Pasture Requirement	ha required for a single llama	5.40	4.25	3.19

* p value < 0.05, ** p value < 0.001

4.4 Manure

All respondents at the three study sites used llama manure as an agricultural fertilizer. All respondents were aware of the agricultural benefits of manure applications, i.e. that it is rich in nutrients and enhances water-holding capacity and soil aeration. Manure was generally harvested from corrals or communal latrines latrines and applied every 2 years when the soil was tilled, prior to planting. A metric ton of fresh llama manure is sold for on average BOB 193.95. Manure is sold to neighbours in the same community, or to nearby communities. According to the United States Department of Agriculture [USDA], llamas generate an average of 150 kg of manure a month (USDA, 2008). This results in a potential profit of BOB 32 per llama per month. With an average herd size of 82.2 heads (from current study), a theoretical monthly profit of BOB 2630.40 (equivalent to USD 380.97 on 5th May 2018) can be generated solely from the sale of llama manure. The results from the study showed that the amount of manure sold (intra and inter-communities) was found to differ significantly among study sites; $F (2, 38) = 17.78$, p-value = 0.00. Post-hoc Games-Howell tests revealed that Site 3 (μ=1.00, σ=0) sold significantly higher amounts of manure than Site 1 (μ=0.17, σ=0.389) and Site 2 (μ=0.4, σ=0.508) with a p-value of 0.000 and 0.001, respectively.

4.5 Future Outlook of Llama Husbandry

Livestock owners were asked if they would like to continue with llama husbandry as a livelihood. Respondents at Site 1 showed a significantly lower interest in continuing with llama husbandry than at Sites 2 and 3 (p-value 0.013, and p-value 0.017 respectively). At the time of the study, 33% of respondents at Site 1 were planning on slaughtering their entire herd at the beginning of the dry season (May) because the work involved was too demanding for the amount of income it generated, and the dwindling amount of natural pastures in the area.

4.6 Ethnobotany of Native Forage Plants

A total of 59 different plants (including ethnobotanical groups) were cited by respondents from all study sites. Based on the botanical identification, a total of 54 individual species (in some cases sub-species) were identified, belonging to 44 genera and 18 families. When it was impossible to identify the exact species the annotation 'cf.' was used. The five main ethnobotanical groups of plants stated by respondents were: *espinas* (spinose plants), *leñas/tolas* (shrubs), *pastos verdes* (herbaceous plants), *bofedal* (wetland plants), and *pajas/ichu* (grasses). Some informants recognized each of these groups as a single species (ethno-species), while others further defined specific vernacular names within each classification. Vernacular names are sometimes given to an entire class of plants, rather than a specific species (Villagrán & Castro, 2004). See the base inventory list in Appendix I for a complete description of all cited forage plants and classes of plants. The plant families most frequently mentioned by informants were: Poaceae (22.2%; 9 species, 123 citations), Fabaceae (20.9%; 7, 116), Asteraceae (20.4%; 13, 113) and Malvaceae (8.7%; 2, 48) — Table 5).

Table 5. Botanical families most frequently mentioned by respondents across all sites of this study compared to findings in ZONISIG (2000). Values listed in percent of all responses

Botanical Family	**Current Study (%)**	**ZONISIG Study (%)**
Asteraceae	12.4	23
Poaceae	13.7	19
Fabaceae	12.8	5
Amaranthaceae	2.8	-
Malvaceae	5.3	-
Lamiaceae	2.4	-
Solanaceae	2.1	-
Verbenaceae	1.5	-
Cactaceae	<1	-
Apiaceae	<1	-
Campanulaceae	2.6	-
Pteridaceae	1.9	-
Juncaceae	1.2	-
Rosaceae	<1	-
Loasaceae	<1	-
Linaceae	<1	-
Ephedraceae	<1	-
Amaryllidaceae	<1	-

A total of 909 citations were recorded from interviews with a total of 41 respondents across all three study sites. Four of the mentioned forage plants (Tables 5) were cultivated crops: *mint, barley, alfalfa* and *flax*. Crop residues of *broad beans* from home-gardens and quinoa residues were also used as fodder. Quinoa crop residues (*hipi de quinoa*) were most often used as fodder by respondents at Site 1 (75% of respondents). The remaining 48 plants are all wild, native plant species.

A total of 25 plants were reported to be of additional medicinal value, while 9 were cited to be used for ethno-veterinarian purposes (See Appendix I and Table 6). Some species were reported to be toxic to livestock (6 species) - Appendix I.

The forage plants mentioned by respondents were distributed across local ecosystems — Figure 4. A total of seven ecosystem classes were mentioned in the local language. Translated, a *bofedal* is a type of seasonal wetland where hydrophilic plants can be found year round. The local ecosystem classification of *pampa* was reported to contain the highest concentration of forage plants. *Pampa* can be translated from Quechua to English as plains, or grasslands.

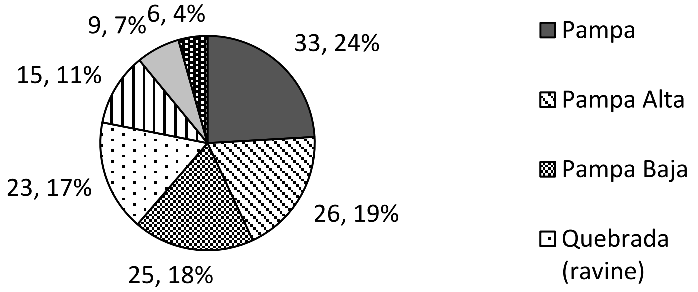

Figure 4. Local distribution of forage plants (per cent of species) to ecosystem classes according to respondents

4.7 Relative Frequency Citation of Forage Species

The RFC and RFC_i were calculated as a basis for a comparative ranking of forage species (Table 6), in order to identify the most important species at each study site. A complete table of the RFC and RFC_i indices can be found in Appendix II. Sites 2 and 3 had similar rankings of RFC and RFC_i, while Site 1 differed more from the other two study sites (Figure 5; Table 7). The ethnobotanical groups of spinose plants (*espinas*), shrubs (*leñas/tolas*) and grasses (*paja/ichu*) were ranked among the top five categories of forage species across all three study sites. Sites 2 and 3 ranked the ethnobotanical group of wetland species (*bofedales*) much higher than Site 1. Sites 2 and 3 also ranked cultivated crops, such as *mint* and *barley*, higher than Site 1. However, Site 1 ranked crop residues of *quinoa* among the top 10 forage plants, whereas Sites 2 and 3 did not. Significant differences in the number of times a specific ethno-species was mentioned as a forage plant were found between sites (see Table 8).

Figure 5. A herd of llamas grazing on natural vegetation with quinoa plots (chacras) in the background at Site 1. Photo: M. Sørensen (2014)

Table 6. Comparative ranking of forage plants based on mean Relative Frequency Citation, RFC and RFC_i (see text). Only the two highest ranks of vegetation categories and the four highest ranks of individual species are shown. Estimated values of RFC and RFC_i are shown in square brackets

Rank	**Site 1**		**Site 2**		**Site 3**		**PRA Ranking**
	RFC	**RFC_i**	**RFC**	**RFC_i**	**RFC**	**RFC_i**	
Ranking of vegetation categories							
1	*Spinose (Espinas) *Shrubs (Leñas/Tolas) [1.0]	*Spinose (Espinas) [0.115]	*Wetlands (Bofedal) [1.0]	*Shrubs (Leñas/Tolas) [0.123]	*Grasses (Ichu/Paja) [1.0]	*Grasses (Ichu/Paja) [0.158]	
2	*Herbaceous Plants (Pastos verdes), *Grasses (Ichu/Paja) [0.83]	*Shrubs (Leñas/Tolas) [0.084]	*Shrubs (Leñas/Tolas) *Grasses (Ichu/Paja) [0.93]	*Wetlands (Bofedal) [0.113]	*Wetlands (Bofedal) *Shrubs (Leñas/Tolas) [0.93]	*Shrubs (Leñas/Tolas) [0.143]	
Ranking of individual species							
1	*Tarasa tenella* (Cav.) Krapov. [1.0]	*Tarasa tenella* (Cav.) Krapov. [0.111]	***Medicago sativa* L. *Festuca orthophylla* Pilg [0.67]	**Medicago sativa* L. [0.072]	*Lobelia oligophylla* (Wedd.) Lammers *Astragalus garbancillo* Cav. [0.64]	*Lobelia oligophylla* (Wedd.) Lammers [0.069]	*Festuca orthophylla* Pilg.
2	*Tagetes multiflora* Kunth [0.92]	*Chondrosum* cf. *simplex* (Lag.) Kunth [0.069]	***Hordeum vulgare* L. *Parastrephia lepidophylla* (Wedd.) Cabrera [0.53]	***Hordeum vulgare* L. [0.064]	*Parastrephia lepidophylla Clinopodium bolivianum* (Benth.) Kunth	***Medicago sativa* L. [0.045]	*Parastrephia lepidophylla* (Wedd.) Cabrera

3	*Adesmia* spp *Chondrosum* cf. *simplex* (Lag.) Kunth [0.67]	*Tagetes multiflora* Kunth [0.053]	*Adesmia* spp. [0.47]	*Parastrephia lepidophylla* (Wedd.) Cabrera [0.049]	*Cheilianthes pruinata* Kaulf. *Parastrephia quadrangularis* (Meyen) Cabrera [0.50] *Festuca orthophylla* Pilg **Medicago sativa L. **Hordeum vulgare L. *Oxychloe* cf. *andina* Phil. *Lampaya medicinalis* Phil. *Tagetes multiflora* Kunth [0.43]	**Hordeum vulgare L. [0.036]	*Adesmia* spp.
4	*Tetraglochin cristatum* (Britton) Rothm. *Fabiana* cf. *denudata* Miers *Parastrephia lepidophylla* *Astragalus garbancillo* Cav. [0.58]	*Bromus* cf. *catharticus* Vahl. [0.034]	*Astragalus garbancillo* Cav. [0.40]	*Adesmia* spp. [0.048]	*Baccharis tola* Phil. subsp. *tola* *[0.36]*	*Astragalus garbancillo* Cav. [0.033]	*Adesmia* cf. *miraflorensis* J.Remy

*ethnobotanical group, **cultivated crop

Table 7. Reported ethno-veterinarian plant species and use at the three sites (% of respondents who report use)

Plant Species	**Vernacular name**	**Percentage of Respondents who Reported Use (%)**			**Average (%)**	**Use**
		Site 1	**Site 2**	**Site 3**		
Tagetes multiflora Kunth	Suico	83.3	26.7	42.9	48.8	Herbal infusion used to treat diarrhea, constipation, and bloating
Clinopodium bolivianum (Benth.) Kunth	Muña	33.3	33.3	50	39	Herbal infusion used to treat diarrhea, constipation, and bloating
Mentha spp.	Hierbabuena	0	26.7	14.3	14.6	Herbal infusion used to treat diarrhea, constipation, and bloating
Senecio cf. *nutans* Sch.Bip.	Chachacoma	25.0	0	0	7.3	Herbal infusion used to treat bloating
Spinose plants	Espinas	0	6.7	0	2.4	Herbal infusion of 7 different spinose plants to cure all illness
Linum usitatissimum L.	Linaza	0	6.7	0	2.4	Herbal infusion for purgative effects
Xenophyllum cf. *popusum* (Phil.) V.A. Funk	Pupusa	0	6.7	0	2.4	Herbal infusion to treat diarrhea
Fabiana cf. *denudata* Miers	Tara tara	2.4	0	0	2.4	Pomace made with leaves to treat fractures/broken bones

4.8 Inter-Site Diversity of Forage Plants

No significant differences were found between sites for the calculated Simpson index of diversity for plant citations (Table 8). A one-way ANOVA of equitability (H_i) in citations between the sites did reveal significant differences; with $P<0.05$. Post-hoc Scheffe tests revealed that Site 1 (H=0.9379, SD=0.01034) had significantly lower equitability than Site 3 (H=0.9522, SD=0.01877). These results show that respondents at Site 1 mentioned a significantly wider variety of species than at Sites 2 and 3; with the citations from respondents at site 3 being the less varied.

4.9 Inter-Site Variation of Native Forage Plant Use

The variation with respect to the number of citations of native forage plant species and categories between sites is shown in Table 8. The number of citations of different ethnobotanical ecosystem categories as apparent from the average FCi-values varied among study sites. Post-hoc Scheffe test for the *bofedal* ecosystem ($P<0.001$) was cited a greater number of times at Sites 2 and 3 than at Site 1. Post-hoc Scheffe tests revealed that *espinas* ($P<0.001$), were cited more often at Site 1 than at Sites 2 and 3. Similarly, post-hoc Scheffe tests divulged that *pastos verdes* ($P<0.001$), were cited more at Site 1 (Figure 6) than at Sites 2 and 3.

Figure 6. View of quinoa and llama grazing areas at study site 1: Chacala, Potosi Region, Bolivia.

Photo: S.J. D'Apollonia (2014)

Significant differences in the number of times a specific ethno-species was mentioned as a forage plant were also found between sites (Table 5). Post-hoc Games-Howell tests were used to analyse for the following species to determine where exactly the differences between sites lie. Respondents at Site 3 did not mention *Adesmia* spp. as forage species while mentioned at Site 1 (mean=0.92, SD=0.900) (Figure 7) and Site 2 (mean=1.07, SD=1.486). Upon observation *Adesmia* spp. were found to be present at Site 3, although the plants were mainly found in the foothills (*quebradas*) and not the principal grazing area of the wetlands (*bofedal*). *Lobelia oligophylla* (Wedd.) Lammers, $F(2, 38) = 5.426$, p-value=0.008, was mentioned more often at Site 3 (mean=1.14, SD=1.099) than at Sites 1 (mean=0.25, SD=0.452) and 2 (mean=0.33, SD=0.617*). Lampaya medicinalis* Phil., $F(2, 38) = 4.22$, p-value=0.022, was cited as a forage plant a greater number of times at Site 3 (mean=0.57, SD=0.852) than at Sites 1 (mean=0.17, SD=0.389) and 2 (mean=0.00, SD=0.00). *Bromus* cf. *catharticus* Vahl., $F(2, 38) = 3.912$, p-value=0.029, was cited significantly less frequently as a forage species at Site 3 (mean=0.07, SD=0.267) than at Sites 1 (mean=0.92, SD=1.165) and 2 (mean=0.33, SD=0.724). While species such as; *Chondrosum* cf. *simplex* (Lag.) Kunth, *Opuntia* cf. *soehrensii* Britton & Rose, *Tarasa tenella* (Cav.) Krapov. and *Tagetes multiflora* Kunth were all mentioned a significantly greater number of times at Site 1 than at Sites 2 and 3.

Figure 7. Native forage plant at study site 1; añawaya (*Adesmia* sp.). Photo: S.J. D'Apollonia (2014)

Table 8. Ethnobotanical citations and associated diversity indices for each of the three sites. Pairwise comparisons between sites were done for the diversity and equitability measures using post hoc Scheffe tests. Within each row, estimates marked with the same letter (a, b) are not significantly different at the 5 % probability level

	Site 1	**Site 2**	**Site 3**
Total number of citations	352	304	253
Total number of different species cited	41	39	33
Mean number of citations (per respondent)	29	20	18
Median number of citations	26	20	18
Simpson Index of Diversity (D)	0.109^{a}	0.139^{a}	0.127^{a}
Equitability (H)	0.937^{a}	0.945^{ab}	0.952^{b}

5. Discussion

5.1 Future Outlook of Llama Husbandry in the Bolivian Altiplano

The study sites were chosen to include agropastoralists pursuing different livelihood strategies involving livestock (llama) husbandry and quinoa production (Figure 8). Site 1 was chosen as a representation of a village with a high degree of quinoa production and a low degree of llama husbandry. Site 2 was chosen to represent a village with a balance of both llama and quinoa production, and Site 3 was chosen as a community that exclusively practised llama husbandry. The results of the socioeconomic descriptions from the survey confirm these general village characterisations. Respondents at Site 1 planted a significantly greater area of quinoa in the community (μ=10.33 ha) in comparison to Sites 2 (μ=1.35 ha) and 3 (μ=0.2 ha). Respondents at Site 1 also placed significantly higher importance on quinoa production than livestock husbandry. It was observed that Site 3 rated livestock husbandry as being of significantly higher importance than the other two study sites. Furthermore, the reported income derived from llama husbandry across study areas reflects the accurate description of the study sites, with Site 3 deriving the most income from llama husbandry (μ=36.07%), and Site

1 deriving the least (μ=17.91%). The rejection of the null hypothesis that all study sites are equal in their livelihood pursuits is of crucial importance in order to compare the impact of land-use pressure on rural llama husbandry.

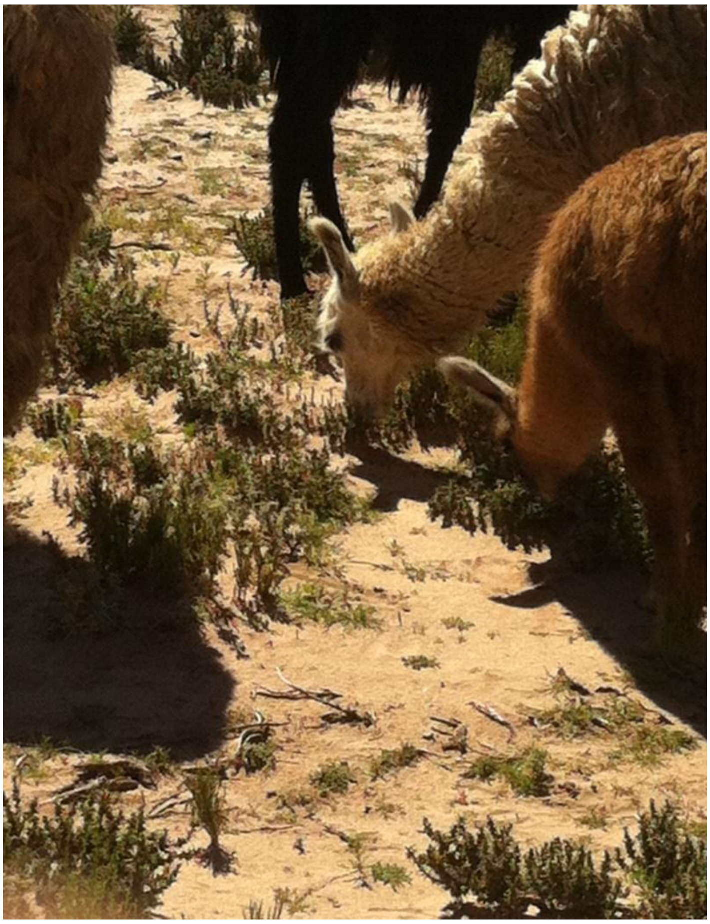

Figure 8. Llamas grazing on native forage plants. Study Site 1: Chacala, Potosi Region, Bolivia.

Photo: S.J. D'Apollonia (2014)

Respondents at Site 1 stated that their llama populations were, on average, in decline. This contrasts findings at Sites 2 and 3, where respondents stated that their llama populations were stable or increasing. This is a very important finding, in that it confirms that the future of llama husbandry is at risk in areas where there is a perceived lack of pasture. Responses from the analytical survey on the future forecasts for llama husbandry at Site 1 show that only four of the pastoralists interviewed said they would continue with llama husbandry the following year. From surveys, interviews and focus groups with llameros at Site 1, the greatest constraint in llama husbandry was a lack of pasture caused by land-use competition with quinoa producers. As quinoa production increases, through expanding cropland, native pastures are disappearing (according to pers. comm. with local villagers, 2014; Bonifacio, 2014; Jacobsen, 2011). This trend is slowly being recognized by altiplano residents as an impending threat to traditional livelihoods such as llama husbandry.

5.2 Forage Plants in Natural Pastures

The present study offers a good basis for further investigation of the native forage plant community in the Bolivian *Altiplano*. Most of the plants (84.58%) reported as forage species were found in the *pampa* ecosystem (including *pampa alta* and *pampa baja*). However, the *bofedal* ecosystem was mentioned a significantly greater number of times at Sites 2 and 3. This could signify that respondents at Sites 2 and 3 placed higher importance on the forage plant species sustained in a *bofedal* ecosystem. All study sites mentioned shrubs (*leñas/tolas*) with a high RFC ranking. This shows that these native shrubs species are considered a vital component of *L. glama* diets in natural pastures, which is also in agreement with previous studies (Fugal et al., 2010; Bryant & Farfan, 1984).

5.3 Ethnobotany and TEK of Native Forage Plants

The RFC_i takes into consideration the frequency of citations for each individual respondent rather than the citations across an entire group of respondents; we therefore consider RFC_i a more useful index. We did not perform any analysis of correlations to determine why there were variances between RFCi, and the frequency of citations was only analysed on an inter-site level. Further analysis to determine factors such as age, gender, time at a pasture that may correlate with TEK could be carried out.

The ethnobotanical importance of forage species must not be neglected when developing management plans for natural pastures. Many forage species cited by respondents are very slow-growing and, for example, *Yareda* (*Azorella compacta* Phil.), found in *bofedales*, is estimated to grow 1.5 cm per year (Kleier & Rundel, 2004), while *tola* (shrub) species are known to be of particularly slow growth (ZONISIG, 2000). Management plans of natural pastures should incorporate the slow growth rates of these native forage species, especially if they are rated with a high RFC.

6. Conclusion

Management of natural pastures must incorporate results from studies which detail the most important forage species from an ethnobotanical perspective and consider findings from studies which employ PRA methods. These results can also be applied to more quantitative studies with detailed counts of the abundances and availability of native forage species in natural pastures by performing controlled plot sampling of the natural landscape in order to determine native forage species abundances and availability. The conflict between llameros and quinoa producers arises because of the direct competition for land use. This case study reveals that the expected costs of time and labour investment outweigh the expected benefits of llama husbandry. The current market price of llama products is too low for rural llama husbandry to remain competitive with other rural livelihood options. Secondary, value-added llama products such as manure may provide an added economic incentive for rural peoples to pursue llama husbandry. Challenges are sometimes case-specific, as in the case of Site 1 which mentioned access to pasture land as the greatest challenge, while access to quality forage plants throughout the year (specific deficits reported from June - August) was a common constraint across all study sites. Parallel livestock and crop systems in areas where llama and quinoa production are in direct competition were observed and explored in this study. Both livelihoods have the ability to be mutually beneficial if land-use conflicts are addressed. The need for re-establishing a balanced and integrated quinoa-llama production system with adequate forage availability in the Bolivian Altiplano is of crucial importance for ensuring long-term sustainability for rural livelihoods and the environment.

Conflict of interest statement

None.

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Appendix 1: Base inventory plant list

Plant Classifications	Botanical Species	Vernacular Name	Botanical Family	Local Distribution *(see below)*	Other Uses
Plant Habitat/ Ethnogroup		Espinas		1, 2, 3, 4	
		Leñas/Tolas		1, 2, 3, 4	
		Pastos verdes		1, 4 & 5	
		Bofedal		3	
		Ichu/Paja		1, 2, 3	
Crop Residues	*Vicia faba* L.	Hipis de haba	Fabaceae	7	
	Chenopodium quinoa Willd.	Hipis de Quinoa	Amaranthaceae	7	
Cultivate Crops	*Mentha* spp.	Hierbabuena	Lamiaceae	7	**Medicinal:** used to treat stomach pain, diarrhoea, colds and coughs. Preparation: herbal infusion with leaves.
	Hordeum vulgare L.	Cebada	Poaceae	7	
	Medicago sativa L.	Alfalfa	Fabaceae	7	
	Linum usitatissimum L.	Linaza	Linaceae	7	**Medicinal:** used for stomach pain and fevers. Preparation: toast and boil seeds. Drink as a tea.
Native Forage Species					
Grasses (*Paja / Ichu*)					
	Festuca orthophylla Pilg.	Paja brava	Poaceae	1,2,3	
	Stipa cf. *chrysopylla* E. Desv.	Sikuya	Poaceae	1,3	
	Bromus cf. *catharticus* Vahl.	Cedabilla	Poaceae	1,3	**Medicinal:** used to treat rheumatism and body aches. Said to provide energy when consume a herbal infusion of the vegetative parts.
	Festuca dolichophylla J. Presl.	Chillihua	Poaceae	1,2,3	
	Deyeuxia cf. *curvula* Wedd.	Chiqu chiqu	Poaceae	1, 3	
	Deyeuxia sp.	Caorayo	Poaceae	6	
	Chondrosum cf. *simplex* (Lag.) Kunth	Llapa	Poaceae	1,3,5	
	Chondrosum sp.	Llapa roja	Poaceae	1,2,3,5	
Spinose (*Espinas*)					
	Adesmia cf. *miraflorensi* Remy	Churky	Fabaceae	2, 4	**Medicinal:** used to treat colds and coughs. Preparation: herbal infusion with leaves and flowers. **Also used as firewood.**
	Adesmia spp.	*Añawaya	Fabaceae	2, 4	**Medicinal:** used to treat colds and coughs. Preparation: herbal infusion with leaves and flowers. **Also used as firewood.**
	Tetraglochin cristatum (Britton) Rothm.	Llucho	Rosaceae	2, 4	**Medicinal:** used to treat colds and coughs. Preparation: herbal infusion with leaves and flowers. **Also used as firewood.**
	Junellia seriphioides (Gillies & Hook.) Moldenke	Haraquiska (Largarta espinosa)	Verbenaceae	1,2,4	**Medicinal:** used to treat stomach pain, coughs, colds, and body aches. Preparation: flowers prepared into a herbal tea. **Also used as firewood.**
	Ephedra cf. *breana* Phil.	Cola de Caballo Pinkopinko	Ephedraceae	4	**Medicinal:** roots, stem, leaves, flowers, & fruits consumed to treat stomach pain, colds, and bone pain. Also used to treat bladder and urinary infections. Purgative. Preparation: herbal infusion of leaves and stem.
	Chuquiraga atacamensis Kuntze	Hakataka Chio'kiska	Asteraceae	2, 4	Good forage plant, animals consume young shoots. **Medicinal:** used for stomach pain, body pain, colds, and dry cough. Cleanse the body after birth and has abortive effects. **Also used as firewood sometimes, but not often.**
	Opuntia cf. *soehrensii* Britton & Rose	Leko Airampu Ayrampu	Cactaceae	1,2, 4	**Edible fruits. Fruits used to dye fabric.** **Medicinal:** used to treat liver and kidney infections. Vermicide. Preparation: fruit boiled into herbal infusion or made into fresh juice. **Toxic:** some claim that it is toxic when animals consume vegetative parts.
	Corryocactus brevistylus (K. Schum.) Britton & Rose	Tayakchi Tacaysiña	Cactaceae	4	**Medicinal:** fruit consumed to treat stomach, gallbladder, liver, and kidney infections. Laxative. **Edible fruits.** Fruit consumed fresh.
Shrubs (*Tolas*)					
	Baccharis tola Phil. subsp. *Tola*	Ñaka	Asteraceae	1,2, 4	**Medicinal:** used to treat cold, coughs, and stomach pain. Preparation: toast leaves and serve as an herbal infusion. Forage plant when young (tender). Good forage plant overwinter, when forages are limited. **Also used as firewood.** **Ceremonial** uses as incense.
	Parastrephia quadrangularis (Meyen) Cabrera	T'iti	Asteraceae	1,2,4	**Medicinal:** antibiotic properties Preparation: herbal infusion from leaves **Also used as firewood**

Fabiana cf. *denudata* Miers	Tara tara	Solanaceae	1,2, 4	**Ceremonial** use as incense; in funerals and purification ceremonies. **Medicinal:** used to treat broken bones and cuts. Preparation: grind green parts of plant into pomace mixed with wheat flour and placed over wound. Can also be mixed with bird (*Agriornis*) guano and egg yolks, or urine to make a plaster. Also used for coughs and colds. **Also used as firewood.**
Parastrephia lepidophylla (Wedd.) Cabrera	Quiruta Suputola	Asteraceae	1,2,4	**Medicinal:** used to treat fevers, cough, and stomach and bile infections. Preparation: herbal infusion with leaves. **Ceremonial** uses as incense. **Also used as firewood.**
Lampaya medicinalis Phil.	Lampaya	Verbenaceae	1, 3	**Medicinal:** used to treat cough and colds. Reported use of treating skin infections (scabies). Preparation: herbal infusion from stems leaves and flowers. Toast the leaves and stem and make a tea mixed with lemon. Apply as a pomace to skin infections. **Also used as firewood.**
Baccharis cf. *acaulis* (Wedd. ex R.E. Fries)	K'nya	Asteraceae	1,2,3	
Parastrephia lucida (Meyen) Cabrera	Umatola	Asteraceae	1, 2, 4	**Medicinal:** used to treat fractures and broken bones. Preparation: grind leaves and apply as pomace. Also used as an herbal infusion of leaves to treat lung infections, fevers, and tooth pain. **Also used as firewood.**
Chersodoma jodopappa (Sch.Bip. ex Wedd.) Cabrera	Oqetola	Asteraceae	1, 4	**Medicinal:** used to treat headaches, colds, coughs, and stomach pain. Preparation: boil leaves in an herbal infusion.
Herbaceous Plants (*Pastos Verdes*)				
Tarasa tenella (Cav.) Krapov.	*Malva	Malvaceae	1,2,3,5	
Schkuhria sp.	Hamacura Pasto del campo	Asteraceae	1, 5	
Tagetes multiflora Kunth	Suico	Asteraceae	1,2,3, 5	**Medicinal:** used to treat stomach pains, bloating, gastrointestinal problems and produces soothing effects. Preparation: herbal infusion with flowers and leaves.
Northoscordum andicola Kunth	Muchuguna Cebollin	Amaryllidaceae	1,2,3,5	**Edible tuber**
Hoffmannseggia doellii Phil. subsp. *doellii*	Mutucura Mutucuru	Fabaceae	1,2,3,5	**Edible tuber**
Senecio mathewssi Wedd.	Pasto lloron	Asteraceae	1, 3, 6	
Nototriche longirostris (Wedd.) A.W. Hill	Tuluma pasto	Malvaceae	1,3,5	
Chenopodium ambrosioides L.	Quinoa de paloma Payko	Amaranthaceae	5	**Medicinal:** used to treat stomach pain and diaahrea. Preparation: herbal infusion with vegetative parts.
Oxychloe cf. *andina* Phil.	*Paco Pacoya	Juncaceae	3, 6	Paco = any edible grass in Quechua
Xenophyllum cf. *popusum* (Phil.) V.A. Funk	Pupusa	Asteraceae	6	**Medicinal:** antibiotic properties. Preparation: herbal infusion with leaves **Ceremonial** uses as incense.
Atriplex cf. *imbricata* (Moq.) D. Dietr.	Piñaya Piyaya	Amaranthaceae	1,3, 4, 5	Good forage plant, animals gain weight from eating this plant. Maintains during dry season. **Edible leaves.**
Wetland (*Bofedal*)				
Azorella compacta Phil.	Yareda	Apiaceae	6	**Medicinal:** Roots, flower, seeds, & resin consumed to treat liver & gall bladder infections, cough, diabetes, pain (tooth), and purify the blood. Infusion of the root used to treat 'women's pain' and gastrointestinal problems. Preparation: herbal infusion from all parts.
Sarcocornia pulvinata (R.E. Fries) A.J. Scott	Yankiyanki Anke Janke	Amaranthaceae	3, 6	Janke/Janki/Anke/Anki = alludes to the action of ingesting forage in Quechua (Chile flora, pg. 171)
Gomphrena pumila Gillies ex Moq.	Alchi alchi	Amaranthaceae	3, 5, 6	
Lobelia oligophylla (Wedd.) Lammers	Begal *Vega *Cienigo	Campanulaceae	6	
Azorella cf. *biloba* (Schltdl.) Wedd	Cangiui	Apiaceae	6	
Non-Categorized				
Graephalium spp.	Vira Vira Wira Wira	Asteraceae	4	**Medicinal:** used to treat headaches, colds and coughs. Preparation: use leaves as a herbal infusion
Solanum sarrachoides Sendtn.	azul tika papa silvestre	Solanaceae	1,2,3,5	

Astragalus garbancillo Cav.	Garboncillo	Fabaceae	1,2,3,5	**Toxic:** causes bloating and constipation in animals.
Loasa grandiflora Desr.	Itapayo Ortiga macho Itapallo	Loasaceae	4	**Toxic:** harmful when consumed as forage.
Cheilianthes pruinata Kaulf.	Chujchu	Pteridaceae	1,2,4	**Toxic:** provokes fever and rigors in animals when consumed
Clinopodium bolivianum (Benth.) Kunth	Muña	Lamiaceae	4	**Medicinal:** used to treat stomach and intestinal pains as well as antibiotic properties Preparation: herbal infusion with leaves and flowers
Senecio cf. *nutans* Sch.Bip.	Chakacoma	Asteraceae	4	**Medicinal:** used to treat altitude sickness, stomach pain, body aches, fever, coughs, colds, and flatulence. Preparation: herbal infusion with leaves. Inhale smoke of leaves to cure rhinorrhea. Pomace made from grinding leaves and applied to soothe pain. **Edible leaves used in cooking as spice.**
Lupinus oreophilus Phil.	Kela	Fabaceae	1,2,3,5	**Toxic:** can be toxic when consumed as fresh forage. Needs to be cut and dried if using as forage for animals.

*sub-ethno group

1 = *pampa* (plains/grasslands)
2 = *pampa alta* (high plains/grasslands)
3 = *pampa baja* (low plains/grassland)
4 = *quebrada* (ravine, mountain)
5 = *chacras* en descansa (fallow fields)
6 = *bofedal* (wetlands)
7 = *chacras* (home garden/plots)

Appendix II: Relative frequency citation (RFC) results

Botanical Species	Vernaculare Name	Site 1 N	Site 1 F	Site 1 Indices RFC	Site 1 Indices Average RFCi	Site 1 Ranking RFC	Site 1 Ranking RFCi	Site 2 N	Site 2 F	Site 2 Indices RFC	Site 2 Indices Average RFCi	Site 2 Ranking RFC	Site 2 Ranking RFCi	Site 3 N	Site 3 F	Site 3 Indices RFC	Site 3 Indices Average RFCi	Site 3 Ranking RFC	Site 3 Ranking RFCi
	Espinas	12	40	1.00	0.1147	1	1	11	47	0.73	0.0891	3	4	10	17	0.71	0.0701	3	4
	Leñas/Tolas	12	31	1.00	0.0840	1	3	14	38	0.93	0.1226	2	1	13	38	0.93	0.1433	2	2
	Pastos verdes	10	15	0.83	0.0426	3	7	4	4	0.27	0.0173	9	15	4	4	0.29	0.0180	8	19
	Bofedal	2	3	0.17	0.0058	10	29	15	30	1.00	0.1134	1	2	13	22	0.93	0.0887	2	3
	Ichu/Paja	10	25	0.83	0.0721	3	4	14	29	0.93	0.0980	2	3	14	36	1.00	0.1576	1	1
Vicia faba L.	Hipis de haba	6	7	0.50	0.0220	6	13	5	6	0.33	0.0253	8	11	4	6	0.29	0.0238	8	15
Chenopodium quinoa Willd.	Hipis de Quinoa	6	8	0.50	0.0228	6	11	3	5	0.20	0.0163	10	17	1	1	0.07	0.0036	11	29
Mentha spp.	Hierbabuena	0	0	0	0	-	-	4	4	0.27	0.0157	9	18	2	2	0.14	0.0074	10	24
Hordeum vulgare L.	Cebada	4	5	0.33	0.0178	8	17	8	15	0.53	0.0635	5	6	6	8	0.43	0.0363	6	7
Medicago sativa L.	Alfalfa	5	6	0.42	0.0137	7	20	10	23	0.67	0.0724	4	5	6	9	0.43	0.0448	6	6
Linum usitatissimum L.	Linaza	0	0	0	0	-	-	1	1	0.07	0.0027	12	32	0	0	0	0	-	-
Grasses (*Paja / Ichu*)																			
Festuca orthophylla Pilg.	Paja brava	5	6	0.42	0.0170	7	18	10	13	0.67	0.0392	4	9	6	8	0.43	0.0278	6	11
Stipa cf. *chrysopylla* E. Desv.	Sikuya	3	4	0.25	0.0116	9	22	0	0	0	0	-	-	0	0	0	0	-	-
Bromus cf. *catharticus* Vahl.	Cedabilla	6	11	0.50	0.0341	6	8	3	5	0.20	0.0121	10	22	1	1	0.07	0.0032	11	30
Festuca dolichophylla J. Presl.	Chillihua	0	0	0	0	-	-	0	0	0	0	-	-	1	2	0.07	0.0068	11	25
Deyeuxia cf. *curvula* Wedd.	Chiqu Chiqu	5	9	0.42	0.0241	7	10	2	3	0.13	0.0066	11	26	2	4	0.14	0.0151	10	20
Deyeuxia sp.	Caorayo	0	0	0	0	-	-	0	0	0	0	-	-	1	2	0.07	0.0062	11	26
Chondrosum cf. *simplex* (Lag.) Kunth	Llapa	8	24	0.67	0.0690	4	5	2	2	0.13	0.0082	11	24	0	0	0	0	-	-
Chondrosum sp.	Llapa roja	1	1	0.08	0.0017	11	35	0	0	0	0	-	-	0	0	0	0	-	-
Spinose (*Espinas*)																			
Adesmia cf. *miraflorensi* Remy	Churky	5	7	0.42	0.0153	7	19	0	0	0	0	-	-	0	0	0	0	-	-
Adesmia spp.	*Añawaya	8	11	0.67	0.0319	4	9	7	16	0.47	0.0477	6	8	0	0	0	0	-	-
Tetraglochin cristatum (Britton) Rothm.	Llucho	7	8	0.58	0.0206	5	15	0	0	0	0	-	-	0	0	0	0	-	-
Junellia seriphioides (Gillies & Hook.) Moldenke	Haraquiska (Largarta espinosa)	4	4	0.33	0.0087	8	28	0	0	0	0	-	-	0	0	0	0	-	-
Ephedra cf. *breana* Phil.	Cola de Caballo Pingo pingo Pinko pinko Hakataka	1	1	0.08	0.0017	11	35	0	0	0	0	-	-	0	0	0	0	-	-
Chuquiraga atacamensis Kuntze	Chio'kiska Leko	3	4	0.25	0.0104	9	23	0	0	0	0	-	-	0	0	0	0	-	-
Opuntia cf. *soehrensii* Britton & Rose	Airampu Ayrampu	5	5	0.42	0.0128	7	21	1	1	0.07	0.0020	12	34	0	0	0	0	-	-
Corryocactus brevistylus (K. Schum.) Britton & Rose	Tayakchi Tacaysiña	0	0	0	0	-	-	0	0	0	0	-	-	1	1	0.07	0.0032	11	30
Shrubs (*Tolas*)																			
Baccharis tola Phil. subsp. *tola*	Ñaka	4	4	0.33	0.0089	8	25	5	8	0.33	0.0209	8	12	5	6	0.36	0.0211	7	17
Parastrephia quadrangularis (Meyen) Cabrera	T'iti	4	4	0.33	0.0089	8	25	1	2	0.07	0.0053	12	27	7	7	0.50	0.0252	5	13
Fabiana cf. *denudata* Miers	Tara tara	7	8	0.58	0.0207	5	14	5	7	0.33	0.0202	8	13	3	3	0.21	0.0103	9	22
Parastrephia lepidophylla (Wedd.) Cabrera	Quiruta Suputola	7	7	0.58	0.0183	5	16	8	17	0.53	0.0488	5	7	7	8	0.50	0.0273	5	12
Lampaya medicinalis Phil.	Lampaya	2	2	0.17	0.0053	10	30	0	0	0	0	-	-	6	8	0.43	0.0286	6	9
Baccharis cf. *acaulis* (Wedd. ex R.E. Fries)	K'nya	0	0	0	0	-	-	3	3	0.20	0.0092	10	23	2	2	0.14	0.0104	10	21
Parastrephia lucida (Meyen) Cabrera	Umatola	0	0	0	0	-	-	1	1	0.07	0.0030	12	31	0	0	0	0	-	-

Chersodoma jodopappa (Sch.Bip. ex Wedd.) Cabrera	Oqetola	1	1	0.08	0.0017	11	35	0	0	0	0	-	-	0	0	0	0	-	-
Herbaceous Plants (*Pastos Verdes*)																			
Tarasa tenella (Cav.) Krapov.	Malva Hamacura	12	39	1.00	0.1113	1	2	4	5	0.27	0.0145	9	19	1	1	0.07	0.0031	11	31
Schkuhria sp.	Pasto del campo	1	1	0.08	0.0033	11	33	0	0	0	0	-	-	0	0	0	0	-	-
Tagetes multiflora Kunth	Suico Muchuguna	11	21	0.92	0.0526	2	6	4	4	0.27	0.0121	9	21	6	6	0.43	0.0209	6	18
Northoscordum andicola Kunth	Cebollin	1	1	0.08	0.0017	11	35	0	0	0	0	-	-	0	0	0	0	-	-
Hoffmannseggia doellii Phil. subsp. *doellii*	Mutucura Mutucuru	1	1	0.08	0.0017	11	35	0	0	0	0	-	-	0	0	0	0	-	-
Senecio mathewssi Wedd.	Pasto lloron	1	1	0.08	0.0017	11	35	0	0	0	0	-	-	1	1	0.07	0.0045	11	27
Nototriche longirostris (Wedd.) A.W. Hill	Tuluma pasto	1	1	0.08	0.0017	11	35	0	0	0	0	-	-	2	2	0.14	0.0077	10	23
Chenopodium ambrosioides L.	Quinoa de paloma Payko *Paco	4	5	0.25	0.0178	8	17	1	1	0.07	0.0030	12	34	0	0	0	0	-	-
Oxychloe cf. *andina* Phil.	Pacoya	2	2	0.17	0.0040	10	31	2	2	0.13	0.0071	11	25	6	7	0.43	0.0233	6	16
Xenophyllum cf. *popusum* (Phil.) V.A. Funk	Pupusa	0	0	0	0	-	-	1	1	0.07	0.0026	12	33	0	0	0	0	-	-
Atriplex cf. *imbricata* (Moq.) D. Dietr.	Piñaya Piyaya	0	0	0	0	-	-	1	1	0.07	0.0026	12	33	0	0	0	0	-	-
Wetland (*Bofedal*)																			
Azorella compacta Phil.	Yareda Yankiyanki	0	0	0	0	-	-	1	1	0.07	0.0035	12	30	0	0	0	0	-	-
Sarcocornia pulvinata (R.E. Fries) A.J. Scott	Anke Janke	1	1	0.08	0.0017	11	35	1	1	0.07	0.0035	12	30	0	0	0	0	-	-
Gomphrena pumila Gillies ex Moq.	Alchi alchi	1	1	0.08	0.0017	11	35	1	1	0.07	0.0037	12	29	0	0	0	0	-	-
Lobelia oligophylla (Wedd.) Lammers	Begal *Vega *Cienigo	3	3	0.25	0.0087	9	27	4	5	0.27	0.0130	9	20	9	16	0.64	0.0689	4	5
Azorella cf. *biloba* (Schltdl.) Wedd	Cangiui	0	0	0	0	-	-	0	0	0	0	-	-	1	1	0.07	0.0040	11	28
Non-Categorized																			
Graephalium spp.	Vira Vira Wira Wira Azul tika	1	1	0.08	0.0017	11	35	0	0	0	0	-	-	0	0	0	0	-	-
Solanum sarrachoides Sendtn.	Papa silvestre	1	1	0.08	0.0017	11	35	0	0	0	0	-	-	0	0	0	0	-	-
Astragalus garbancillo Cav.	Garboncillo Itapayo	7	7	0.58	0.0221	5	12	6	6	0.40	0.0260	7	10	9	9	0.64	0.0327	4	8
Loasa grandiflora Desr.	Ortiga macho Itapallo	2	2	0.17	0.0040	10	31	1	1	0.07	0.0042	12	28	0	0	0	0	-	-
Cheilianthes pruinata Kaulf.	Chujchu	5	5	0.42	0.0128	7	21	5	5	0.33	0.0187	8	14	7	7	0.50	0.0282	5	10
Clinopodium bolivianum (Benth.) Kunth	Muña	4	4	0.33	0.0094	8	24	5	5	0.33	0.0172	8	16	7	7	0.50	0.0248	5	14
Senecio cf. *nutans* Sch.Bip.	Chakacoma	3	3	0.25	0.0089	9	26	0	0	0	0	-	-	0	0	0	0.0000	-	-
Lupinus oreophilus Phil.	Kela	0	0	0	0	-	-	1	1	0.07	0.0026	12	33	1	1	0.07	0.0031	11	31

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Choices of Research Methodologies on Climate Change Adaptation Especially Focusing on Agriculture Sector: A Systematic Review

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Abstract

A rapid increase in climate researches by applying diverse methodologies and approaches in recent decades. These researches have directly or indirectly contributed in better understanding of climate issues, risks and vulnerabilities. It has improved awareness and capacities of the public and communities to adapt to the vulnerabilities and impacts. It, further, contributes in formulation of climate policies and plans to address climate risks and vulnerabilities at the local and national levels. Appropriate methodologies lead to better results in the researches. This paper has applied systematic review of the published papers (2010 -2017) to understand the general and specific research methodologies in climate discourse especially in Web of Science (WS), Springer Link (SL) and Science Direct (SD). Altogether, 37 journal papers (10 WS, 13 SL and 14 SD) were selected for the detail analysis based on the assessment of abstracts, which was mainly concentrated on research methodologies specializing in agriculture. In the process, the authors have analyzed the contents, research methodologies, data analysis, and geographical coverages. The analysis, further, concentrated on the scope and limitations of the research methodologies used. Wide-ranging research methodologies are found that are applied by the researchers in the climate change discourse. Some researchers have applied general research methodologies whereas others have used specific research methodologies and model analysis. Furthermore, it is comprehended that the combination of research methodologies and approaches through focus group discussion together with household survey and model analysis is the effective way for the research by using quantitative and qualitative data.

Keywords: adaptation, agriculture, climate change, participatory approaches, research methodologies

1. Introduction

The researches on climate change discourse are rapidly increasing in recent years because of increased climatic risks, vulnerabilities and impacts in all sectors at all levels (Lwasa, 2014). These researches and assessments are focused at different levels and scales (from the global to the national and also to the local level) and sectors (such as agriculture, forestry, health and medicine, water, education etc.). Diverse methodologies have been applied in the researches and assessments that directly or indirectly contribute to the policy, awareness and identifying key issues relating to climate change and environment. Different research approaches (both qualitative and quantitative), frameworks, methodologies and tools/models have been applied to assess and analyze the climatic risks, vulnerabilities, impacts and also adaptations based on specific research issues and focuses (UNFCCC, 2004; Winkel et al., 2013). Many of such researches have emphasized on adaptation to address the issues of climate change (Locatelli et al., 2008). Berrange-Ford et al., (2015) further emphasized on importance of comprehensive syntheses of existing research methods and tools to evaluate process on adaptation and climate policies.

As defined by Intergovernmental Panel on Climate Change (IPCC), vulnerability is the degree of susceptibility of an environmental or social system to cope with adverse effects of climate change, variabilities and extremes. It requires integrated assessment across the range of disciplinary spheres and scales with assessment tools and frameworks (Antwi-Agyei et al., (2012). Mostly top-down or scenario driven researches and approaches are prominent as compared to bottom up or vulnerability driven approaches, which is also taking momentum in climate change discourse in recent years (Locatelli et al., 2008). It is more effective to combine top-down and bottom up approaches with scientific data, information and local knowledge, practices for detail assessment of the entire process. Devkota (2014) emphasized on the importance of scientific knowledge of changing climate as well as the perception, knowledge and practices of local people. Most of the researches are concentrated on assessments of the climatic risks, vulnerabilities and adaptations to address the short and long-term impacts. Furthermore, the researches on the adaptive capacity, institutional capacities, climate policies, research methodologies and approaches are quite common concentrating at the different levels and sectors (Lockwood et al., 2015).

Appropriate methodologies and tools are the key for the success of any research. These researches, either at the community level or at the national level, use diverse methodologies, which provide the opportunities in sharing of knowledge, experiences and dialogues among the communities, researchers and other stakeholders based on set of guiding questions for analysis of data and information at different levels. Basically, these guiding questions help to examine the factors at the multiple levels using a variety of tools to gather information through a participatory process and collaborative learning. These researches contribute in designing effective climate change adaptation as well as integrating climate adaptation into livelihoods and natural resource management and overall development. This paper aims to review and analyze the research methodologies including participatory approaches and statistical/econometric models to guide the researches on climate change adaptation in agriculture in Nepal. It further analyzes the scope and limitations of these methodologies from academic point of view and unveils the research methodologies and tools for the research in adaptation in agriculture based on the research issues and questions.

2. Methodological Framework

The specific research framework is planned for this paper focusing on the methodologies commonly used in climate change researches mainly based on the papers published in Web of Science (WS), Springer Link (SL) and Science Direct (SD). The process ultimately help the fellow researchers to select the appropriate methodologies in the climate change researches with their specific research objectives and focuses. The specific research objectives and focuses could be related to climate change policies at the national and local level or assessment and analysis of climate risks, vulnerabilities and adaptation initiatives/interventions including needs and priorities of the communities at local level. The literature review, defining the research theme and inclusion/exclusion criteria are the initial steps of the systematic review followed by the systematic review of the published papers based on titles, contents and abstracts that leads to evaluation and analysis of selected papers and results interpretation and discussion (Figure 1).

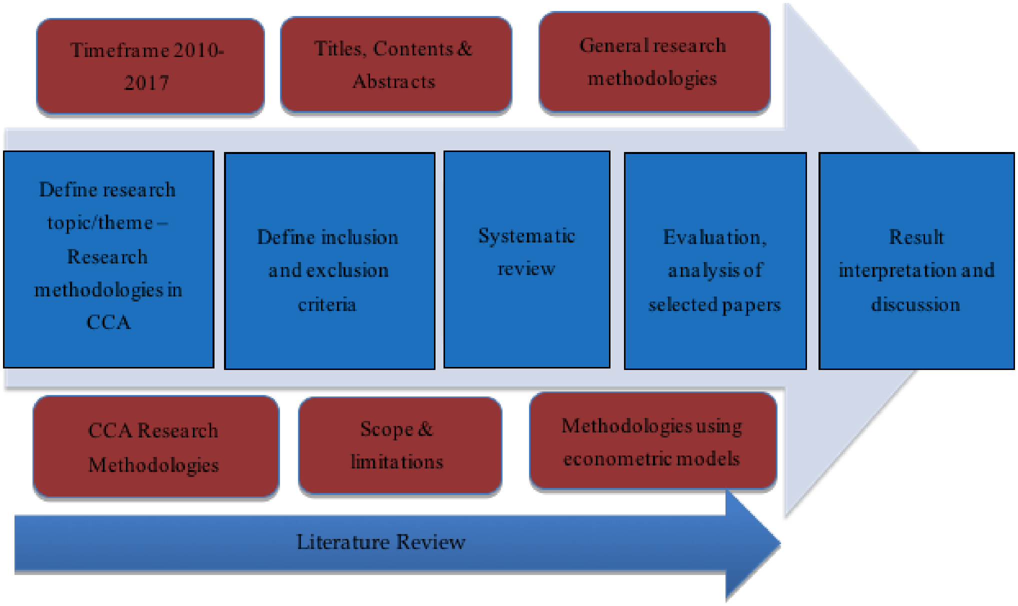

Figure 1. Methodological framework (Author's own creation)

3. Research Methodology

This study is based on the systematic review and assessment of the research methodologies particularly concentrating on climate change adaptation in agriculture in the published papers in Web of Science (WS), Springer Link (SL) and Science Direct (SD). The open accessed research papers were searched specifically in the WS, SL and SD respectively for systematic review. Prior to search the papers in the databases, the inclusion and exclusion criteria were defined considering the research focus and interest (Table 1). These databases were chosen based on the popularity among the researchers and practitioners for the research on multiple issues and themes. The keywords "Research methodologies on climate change adaptation in agriculture" were used for the search and access the relevant papers in the selected database. The inclusion criteria for systematic search and review of the papers on these databases were open accessed journal papers in English on research methodologies concentrated in climate change adaptation in agriculture from the period of 2010 to 2017.

Table 1. The inclusion and exclusion criteria for systematic review of the papers

Inclusion Criteria	Exclusion Criteria
• Research methodologies in climate change adaptation (CCA) in agriculture • Open access journal papers published in Science Direct (SD), Springer Link (SL) and Web of Science (WS) • Original research papers • Papers in English Language • Published in between 2010-2017	Papers related to • Mitigation • Fisheries and winery, viticulture • Energy and livestock • Ecosystem services • Water reservoirs • Rural transportation • Review papers, book chapters and short communications are not included

The total numbers of papers found in the first search were 58, 544, and 562 in the WS, SL and SD respectively based on the inclusion criteria. The second search was more concentrated to climate change in agriculture within the selected papers, which reduced the number of papers to 41, 269 and 134 respectively. However, the papers related to mitigation, fisheries, winery, viticulture, energy and livestock, ecosystem services, water reservoirs and rural transportation were also found within the list. Thus, those papers were excluded from the list by reviewing the title of the papers. The review papers, book chapters, short communications are also excluded as well. Some of the review papers, abstracts and conference papers were also found during the detail review of the titles, thus discarded from the list as well. By clearance of the papers based on exclusion criteria, the number of papers has been reduced to 15, 30, and 25 respectively (Table 2). The abstracts of these papers were reviewed to finalize the total number of papers for the detail systematic review and assessment of research methodologies on climate change adaptation in agriculture.

Table 2. Number of papers selected through the process of systematic review

Search Databases	First search with keywords research methodologies in CCA in agriculture	Second search with the keywords climate change adaptation in agriculture	Third Search with exclusion criteria	Final Selection based on Abstracts
Web of Science (WS)	58	41	15	10
Springer Link (SL)	544	269	30	13
Science Direct (SD)	562	134	25	14
Total	1164	444	71	37

Finally, 37 journal papers (10 from WS, 13 from SL and 14 from SD respectively) were selected for detail review and analysis based on the assessment of the abstracts, which was mainly concentrated on research methodologies specializing climate change adaptation in agriculture. In the process, the authors have analyzed the contents, research methodologies and tools adopted, data analysis, geographical coverages in the selected papers. The analysis further concentrated on the scope and limitations of the research methodologies in the research on climate change adaptation in agriculture.

4. Key Results and Discussion

4.1 Quantitative vs Qualitative Researches

The study found application of different research methods and tools in climate change in agriculture specific to the research focus and research interest. The results have shown that the researchers are highly motivated to quantitative data and model analysis than the qualitative analysis. Among the total research papers identified, 48.64% researches have focused on quantitative analysis. Only 27.02% have concentrated on qualitative research and rest (24.32%) have concerted on combination of quantitative and qualitative research. In terms of geographical coverage, 56.75% papers were concentrated at the national level whereas 24.32% were focused at the regional and sub-regional levels. Diverse methodologies, methods, tools and models have been used to analyze the climate data, trend and information for both quantitative and qualitative researches. It is complicated and challenging to understand and exchange the coherent arguments particularly on research methods used in climate change adaptation research. Hinkel and Bisaro (2015) also supported the complex and complications of the climate change researches with the multiple research methods and tools being used by the researchers. The arguments and debates on climate researches are centered on issues of quantitative versus qualitative data and research over the years. Some argued quantitative research is better and more scientific than qualitative research, whereas others believed that quantitative and qualitative researches are just different methodologies - neither is better than each other (Dawson, 2009).

Based on the research objectives and focuses, the researchers have focused different methodologies. For instance, some of the researches emphasized on general trend analysis, focus group discussion (FGD), household (HH) survey, assessment of seasonal variation, vulnerability and adaptive capacity assessment (VACA). Likewise, other researchers have applied the network analysis and farming system approach, spatial distribution, participatory and rapid rural appraisal tools. Some of the researchers have applied specific methodologies such as economic and bio-climate models, hydro-economic modeling, agriculture production systems simulation, land use allocation model, econometric and regression analysis (multinomial logit, ordinary least square (OLS) method, binary logistic regression model). Furthermore, other researches have concentrated on specific models and software for analysis such as simpson index of diversification & cropping intensity index, vegetation interface processes (VIP) based ecosystem model and weather research forecasting, decision support system for agro-technology (DSSAT) software, stochastic rainfall model combined with weather generator etc. There are some researches that have focused on agro-ecological zones, multi-criteria scoring methods, decision making models, and marginal rate of return (MRR) and willingness to pay, cost-benefit analysis (CBA), principal component analysis (PCA), expert opinion survey (EOS). Detail of the these research methods is available in Annex 1.

Mostly qualitative researches have applied comparatively general methodologies, conceptualization, case studies and integrated approaches whereas quantitative researches have applied specific tools and software such as STATISTICA, STATA and decision support software. Wenkel et al. (2013) emphasized on the progresses in the field of climate discourse with the use of geographical information systems (GIS), computer science, climate modeling and new data acquisition technologies. Mostly these simulations and modeling require up-to-date scientific knowledge and climate information from regional and global climate scenarios. However, these scientific models and analyses are complex and difficult for general public and communities to understand. The communities have own understanding and experiences of changing climate based on local knowledge and practices. Thus, combination of scientific and local knowledge on climate change minimizes gaps in model analyses and perceptions and experiences of the communities. Some of the researchers (such as Devkota 2014; Lockwood et al., 2015) have emphasized on the combination of local knowledge with scientific data to build and enhance the people's understanding on climate risks and adaptation strategies.

4.2 Scope, Limitations and Gaps

Each research methodology focuses on specific tools, procedures and combination of tools/procedures considering the research focus, interest and questions as well as the issues, available resources, time and sectors. Each of these research methodologies has its specific scope and limitations. Dawson (2009) also agreed on specific strengths and weaknesses of each methodology. Many researchers apply the methodologies for the participatory action research and analysis, especially in the field of natural sciences such as agriculture, forestry, biodiversity mainly at local/community level (Ahmed et al., 2014 & Saccheli et al., 2016). IUCN, IISD, SEI & Inter-cooperation (2007) and CARE (2009) also emphasized on participatory action research and analysis by developing the tools such as Community based Risk Screening – Adaptation and Livelihoods Tool (CRiSTAL) and Climate Vulnerability and Capacity Assessment (CVCA), respectively. Whereas, many other agencies such as Livelihood Forestry Programme (LFP) (2010) with the support of UKaid also developed and implemented participatory tools such as vulnerability matrices, timeline, hazard mapping among others for understanding and documenting the risks, vulnerabilities and implications of climate change in the peoples' livelihoods.

For academic research, several other tools and computer-based models have been applied by the researchers to understand and predict the climate systems and its behaviors at the global to the national and also at the local levels such as general circulation models including statistical models. Mostly these models incorporate the statistical software that analyzes the atmosphere and ocean circulations to address the climate questions and assumptions. Many researchers use computer-based models of climate system to better understand the future climate issues and projections. They also use range of scenarios using various assumptions based on future economic, social, technological and environmental conditions (EPA, 2016). It also focuses on frameworks for analyzing vulnerability and capacity to adapt at the community, households and individual level.

The gaps between research on climate change adaptation and policy still exist including the gaps in building capacities on climate forecasting, risk assessment, adaptive capacities of the farmers even conducting research on adaptation to deal with harsh climate (Ngeve et al., 2014). Sterrett (2011) identified the gaps on additional information and statistical analysis related to climate and hydro-geological changes in the South Asian region. She further reported the necessity of better communication between decision makers and scientific community. Hinkel and Bisaro (2015) argued on complication of climate change research because of diverse analytical methods applied from natural and social sciences by using abstract and ambiguous terms such as vulnerability and adaptive capacity without considering wider array of social science. There are quite a large number of research papers on climate change adaptation with use of diverse research methodologies. These researches are multidimensional and multi-scalar in nature with integrated tools for analysis of climate change impacts and adaptation (Esteve et al., 2015).

4.3 Discussion on Appropriate Research Methodologies for Climate Change Adaptation in Agriculture: A Case in Nepalese Context

Climate change impacts vary spatially and temporarily. In Nepalese context, the climate change impacts vary with the altitudinal, geographical and climatic variations. Further investigations are required to understand the complexity of climate change through detailed assessments (Antwi-Agyei et al., 2012). Since diverse research methodologies, approaches and tools are available, it is possible to apply appropriate research methodologies in the climate change researches even in Nepalese context. However, the reliable climatic data and data sources of multiple years at least for 30 years are crucial in the research, which is difficult in Nepalese context due to limited meteorological stations and geographical and climatic variations in the country. Karki et al. (2009) also affirmed that the researchers in Nepal have to still rely on literature review and scattered climatic information due to lack of long term high quality data for reliable analysis and predictions of climate change. The additional time, efforts, investments and capacities are required to gather and analyze climatic data because of challenge of extreme topography, thus, necessary to choose the appropriate and comprehensive methodology or approach for the adaptation research in Nepal. Not a single method or model has all the answers relating to climate change research. Thus, it is highly recommended to use different approaches and methodologies that complement each other (Sterrett 2011).

Climate change impacts are increasing over the years, which indicated climate crisis is real that needs urgent attention, short-term and long-term adaptation through joint, concerted efforts and interventions (Karki et al., 2009). Numbers of researches conducted by researchers and development agencies have also contributed in understanding and minimizing the climate crisis and impacts. It is found the specific research methodologies and/or combinations of methodologies are applied in climate change researches. Both qualitative and quantitative data and methods are utilized in these researches with specific research issues, problems and purposes. IUCN (2015) has emphasized on the combination of qualitative and quantitative methods in climate change research to understand and gather reliable data & information. Berrange-Ford et al. (2015) has also given importance on comprehensive research methods and tools in climate change adaptation and policy research.

Review of the literature and state of climate change adaptation policies and practices in agriculture is crucial to understand prior to plan for the research. Systematic review is a newly emerged review method in climate change discourse by defining research questions, inclusion and exclusion criteria including in depth review and analysis of the content and context in the research and literature. Berrang-Ford et al. (2015) and Sud et al. (2015) has also emphasized on research syntheses of climate adaptation focusing on review of adaptation policies and practices and frameworks. The formal systematic review was started in health sciences, but widely adapted in other sectors including climate change adaptation (Berrang-Ford et al., 2015). It follows the combination of quantitative and qualitative analyses and complex iterative literature searches. Additionally, forward and backward citation tracking, snowballing method, personal communication and review of grey literatures will be integrated into the search methods.

Assessment of vulnerabilities, CC impacts and adaptation in agriculture has significant importance in climate change research in Nepal. National and regional scale multi-indicator vulnerability assessments are vital in assessing vulnerability across a large area (Antwi-Agyei et al., 2012). The IPCC third Assessment Report has defined CC impacts, vulnerability and adaptation assessment (UNFCCC, 2004). Vulnerability is associated with natural hazards like flood, droughts and social hazards like poverty etc. It is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity. The quantitative assessment of vulnerability is usually carried out by constructing a 'vulnerability index' that depends on several set of indicators in a sector and also in a region. Furthermore, the vulnerability also depends on frequency of occurrence of extreme events such as flood, drought and landslide in the region. Basically, it is a numerical scale calculated from a set of variables selected by the researcher for the regions/districts, used to compare with one another or with some reference. Participatory approaches such as hazard mapping, seasonal calendar, historical timeline and vulnerability matrix are important in the community through focus group discussions. These assessments support in understanding the community, locality, climate change impacts, vulnerabilities, and adaptation strategies.

Sterrett (2011) also emphasized on these analytical tools for better understanding the context including secondary research, institutional mapping, policy analysis and additional participatory tools. It is also important to quantify and analyse the direct and indirect cost associated with adaptation (UNFCCC 2011). Cost benefit analysis (CBA) is an established economic tool for determining the economic efficiency of adaptation/development interventions (Mechler & The Risk to Resilience Study Team, 2008). The CBA adds evidence base value for money of climate change adaptation and it is also used as a forecasting tool. The CBA also supports social accountability by engaging community in a concrete way (Oxfam 2013). Furthermore, a number of econometric models have been applied for detail econometric analysis of different factors of climate change in Nepalese context. A binary probit model is effective to analyse the factors affecting farmers' decisions on adaptation to climate change. Whereas multi-nominal model is suitable for analyzing factors affecting farmers' choices of specific adaptation methods (Komba & Muchapondwa 2015).

Yegbemey et al. (2014) also applied Heckman selection and SUR models to analyze the differential effects of farmers' behaviours such as age, gender, level of education, experience in agriculture, access to credit, membership to the organization, farm size, contact with extension and perception of adaptation to climate change. Likewise, Quang Ngo (2016) revealed that SUR Model the best option to overcome the gaps and weaknesses of univariate and multi-nominal discrete choice models. It further converges the unique maximum likelihood parameter estimates. This model is efficient than other estimation methods as it utilizes the present information in the cross-regression error correlation. Mandleni & Anim (2011) also revealed the application of Heckman selection model to estimate the determinants of an individual farmer's decision to select adaptation.

5. Conclusion

Several research methodologies are available in climate change science concentrating diverse sectors (agriculture, forestry, livestock, water, health etc.) and at different levels (local to national and regional). Based on the research focuses and interests, the researchers have applied general and specific research methodologies as appropriate. Comparatively quantitative data analysis and appropriate tools and model analysis has dominated the climate change research than qualitative data. Combination of participatory research methodologies and model analysis utilizing primary and secondary sources of data is effective for the climate change research since climate change have multiple impacts at all levels. Literature review needs to be continuous throughout the research period starting from designing of the research plan to data analysis and finalization of the research outcomes.

The selection of appropriate research methodologies, methods, tools and approaches will depend on the research interests and local contexts. In Nepalese context, it is difficult to gather the climatic data because of existence of limited meteorological stations and reliable climatic data and diverse micro-climatic variations within small geographical areas. It is very crucial to carry out much of the researches on it since it has affected almost all livelihood sectors. Thus, combination of multiple research methodologies and tools including the literature review is recommended for the detail research on climate change adaptation in Nepalese context. The review and analysis of climate data and information through the use of participatory tools, econometric analysis with the use of qualitative and quantitative data are recommended in research on climate change adaptation in agriculture.

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Annex 1. Review of research and data analysis methods in climate change adaptation research

S.N.	*Author (s)*	*Title of the paper*	*Research methods*	*Data analysis*	*Country/region*
WS9	Varadan & Kumar, 2015	Mapping agricultural vulnerability of Tamil Nadu, India to climate change: A dynamic approach to take forward the vulnerability assessment	Vulnerability indicators approach – Simpson index of diversification (SID), Cropping intensity index	Qualitative & Quantitative	India
WS8	Mo et al., 2012	Impacts of climate change on crop evapotranspiration with ensemble GCM projections in the North China Plain	Vegetation Interface Processes (VIP) process-based ecosystem model and Weather Research Forecasting (WRF) modelling system	Quantitative	China
WS7	Ebi et al., 2011	Smallholders adaptation to climate change in Mali	Stakeholder workshops & analysis	Qualitative	Mali
WS6	Seo, 2014	Evaluation of the Agro-Ecological Zone methods for the study of climate change with micro farming decisions in sub-Saharan Africa	Agro-Ecological zone (AEZ) methods including Arc GIS	Quantitative	Sub-Saharan Africa
WS5	Lee et al., 2014	Developing local adaptation strategies for climate change in agriculture: A priority-setting approach with application to Latin America	Multi-criteria scoring methods	Qualitative	Latin America
WS4	Feola et al., 2015	Researching farmer behaviour in climate change adaptation and sustainable agriculture: Lessons learned from five case studies	Decision making model, cross-scale and cross-level pressures, temporal dynamics	Qualitative	-

WS3	Wenkel et al., 2013	LandCaRe DSS – An interactive decision support system for climate change impact assessment and the analysis of potential agricultural land use adaptation strategies	Interactive Land CaRe DSS system	Qualitative & Quantitative	-
WS2	Antwi-Agyei et al., 2012	Mapping the vulnerability of crop production to drought in Ghana using rainfall, yield and socio-economic data	Crop drought sensitivity and vulnerability assessment & Cluster Analysis using STATISTICA software	Qualitative & Quantitative	Ghana
WS10	Chagumaira et al., 2015	Use patterns of natural resources supporting livelihoods of smallholder communities and implications for climate change adaptation in Zimbabwe	Participatory approaches combined with remote sensing and GIS	Qualitative & Quantitative	Zimbabwe
WS1	Gohar & Cashman, 2016	A methodology to assess the impact of climate variability and change on water resources, food security and economic welfare	Mathematical Programming Approach	Quantitative	-
SL9	Bene et al., 2016	Is resilience a useful concept in the context of food security and nutrition programmes? Some conceptual and practical considerations	Conceptualizing resilience	Qualitative	-
SL8	Yang et al., 2015	Responses of rice yields in different rice-cropping systems to climate variables in the middle and lower reaches of the Yangtze River, China	Gene expression programming (GEP) algorithm	Quantitative	China
SL7	Murage et al., 2015	Determinants of adoption of climate smart push-pull technology for enhanced food security through integrated pest management in eastern Africa	Multinomial logit and marginal rate of return (MRR)	Quantitative	Eastern Africa
SL6	Therfelder et al., 2015	Where is the limit? Lessons learned from long-term conservation agriculture research in Zimuto Communal Area, Zimbabwe	Probability of a failed season (PFS) & A conventional control plot (CP)	Quantitative	Zimbabwe
SL5	Ginkel et al., 2013	An integrated agro-ecosystem and livelihood systems approach for the poor and vulnerable in dry areas	Integrated system approaches & Case studies	Qualitative	-
SL4	Cairns et al., 2013	Adapting maize production to climate change in sub-Saharan Africa	Arc GIS software	Quantitative	Sub Saharan Africa Africa
SL3	Bogale, A. 2012	Vulnerability of smallholder rural households to food insecurity in Eastern Ethiopia	Ordinary Least Square (OLS) method	Quantitative	Ethiopia
SL2	Cedamon et al., 2017	Adaptation factors and futures of agroforestry systems in Nepal	Multinomial logistic regression model	Quantitative	Nepal
SL13	John & Fielding, 2014	Rice production constraints and 'new' challenges for South Asian smallholders: Insights into de facto research priorities	Network analysis & farming systems approach	Qualitative	South Asia
SL12	Hussain et al., 2016	Household food security in the face of climate change in the Hindu-Kush Himalayan region	Vulnerability and Adaptive Capacity Assessment (VACA)	Qualitative & Quantitative	Hindu-Kush Himalayan region
SL11	Sherman et al., 2016	Food system vulnerability amidst the extreme 2010-2011 flooding in the Peruvian Amazon: A case study from the Ucayali region	Participatory research methods & Semi-structured interviews	Qualitative	Peruvian region
SL10	Asfaw et al., 2016	What determines farmer's adaptive capacity? Empirical evidence from Malawi	Multivariate probit (MVP) and Multinominal treatment effect (MTE) techniques	Quantitative	Malawi
SL1	Arsad et al., 2016	Climate variability and yield risk in South Asia's rice-wheat systems: Emerging evidence from Pakistan	J-P Stochastic Production Function	Quantitative	Pakistan
SD9	Surendran et al., 2015	Modelling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resources management: A case study in Palakkad district of humid tropical Kerala, India	FAO Penman Monteith method, using decision support software – CROPWAT 8.0	Qualitative & Quantitative	India
SD8	Khatri-Chhetri et al., 2017	Farmers prioritization of climate-smart agriculture (CSA) technologies	Participatory approaches & Willingness to pay	Qualitative & Quantitative	India
SD7	Uy et al., 2015	Factors impact on farmers' adaptation to drought in maize production in highland area of central Vietnam	Factor analysis & Multinomial Logit Regression Analysis	Quantitative	Vietnam
SD6	Chipanshi et al., 2015	Evaluation of the Integrated Canadian Crop Yield Forecaster (ICCYF) model for in-season prediction of crop yield across the Canadian agriculture landscape	Integrated Canadian Crop Yield Forecaster	Quantitative	Canada
SD5	Reed et al., 2013	Combining analytical frameworks to assess livelihood vulnerability to climate change and analyse adaptation options	Integrated analytical livelihood framework	Qualitative	-
SD4	Anandhi, 2017	CISTA-A: Conceptual model using indicators selected by systems thinking for adaptation strategies in a changing climate: A case study in agro-ecosystems	System thinking approach& CISTA-A Conceptual model	Qualitative	-
SD3	Sahu & Mishra, 2013	Analysis of perception and adaptability strategies of the farmers to climate change in Odisha, India	Case study approach & Logit regression technique	Qualitative & Quantitative	India
SD2	Toda et al., 2017	A LiDAR-based flood modelling approach for mapping rice cultivation areas in Apalit, Pampanga	LIDAR-based digital elevation model & flood inundation maps	Quantitative	The Philippines
SD14	Ghahramani et	The value of adapting to climate change in Australian	The Agricultural Production Systems	Quantitative	Australia

	al., 2015	wheat farm systems: Farm to cross-regional scale	Simulator - APSIM (version 7.5)		
SD13	Harvey et al., 2017	The use of ecosystem-based adaptation practices by smallholder farmers in Central America	Participatory mapping, descriptive statistics & Principle Component Analysis (PCA)	Quantitative	Central America
SD12	Islam et al., 2016	Structural approaches to modelling the impact of climate change and adaptation technologies on crop yields and food security	A combined structural approach	Quantitative	
SD11	Schut et al., 2015	RAAIS: Rapid Appraisal of Agricultural Innovations Systems (Part I). A diagnostic tool for integrated analysis of complex problems and innovation capacity	Rapid Appraisal of Agricultural Innovation Systems (RAAIS)	Qualitative	Tanzania and Benin
SD10	Andrieu et al., 2017	Prioritizing investments for climate-smart agriculture: Lessons learned from Mali	Climate-Smart Agriculture Prioritization Framework (CSA-PF) & cost-benefit analysis (CBA)	Qualitative & Quantitative	Mali
SD1	Esteve et al., 2015	A hydro-economic model for the assessment of climate change impacts and adaptation in irrigated agriculture	Hydro-economic modeling framework	Quantitative	Spain

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Biochar Effects on Carbon Stocks in the Coffee Agroforestry Systems of the Himalayas

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Abstract

Coffee agroforestry is an emerging agricultural practice in the mid hills of Nepal. Smallholder farmers of low-income strata have progressively adopted coffee as a perennial crop over seasonal crops. A multi-year study was conducted to test effects of locally produced biochar derived from coffee wastes, e.g., pulp and husks, on carbon stocks of: i) coffee trees, and, ii) soil organic carbon (SOC) in selected coffee growing pockets. We conducted on-farm experimental trials in three different physiographical locations of the Nepal mid-hills, namely, Chandanpur (Site I at 1475masl), Panchkhal (Site II at 1075masl), and Talamarang (Site III at 821masl) where smallholders grow coffee together with other cereal crops and vegetables. We applied biochar to the soil at a rate of 5 $Mgha^{-1}$, then, monitored the SOC and biomass growth of the coffee trees in the three treatment plots at sites I, II and III over two years beginning in 2013. The average stocks of aboveground carbon in coffee trees increased from 6.2 ±4.3 $Mgha^{-1}$ to 9.1 ±5.2 $Mgha^{-1}$ over the trial period of two years in biochar treated plots. The same in control plots increased from 5.6 ±2.8 $Mgha^{-1}$ to 6.7 ±4.7 $Mgha^{-1}$. In the biochar plots, the average increments of ABG carbon was 0.73 Mgh^{-1} while in the control it was 0.29 Mgh^{-1}. Analysis of soil organic carbon of the plots indicated overall incremental change in carbon stocks in the coffee farms. During the base year, the average SOC stocks in the top 0-15cm layer of the soil at sites I, II, and III were estimated 74.88 ±15.93; 63.96 ±16.71 and 33.05 ±4.42 $Mgha^{-1}$ respectively. Although both the biochar treated and control plot registered incremental change in SOC stocks, the volumes were remarkably higher in the former than the latter. Compared to the baseline data, the changes in SOC stocks in the three biochar treated plots were 19.8, 49.8 and 45.3 $Mgha^{-1}$, respectively, whereas in the control plots these were 8.3, 29.3 and 11.3 $Mgha^{-1}$, respectively. The higher incremental rates of C-stocks in all the biochar treated plots in comparison to the corresponding control plots of the coffee agroforestry implies that application of biochar can enhance accumulation of carbon in the form of aboveground biomass and soil organic carbon.

Keywords: mountain farmers, coffee waste, biochar, aboveground carbon stocks, soil organic carbon, hill agricultural systems and biochar treated soils

1. Introduction

Globally, agroforests (AFs) contribute significantly to sequester and store carbon (C) in the form of aboveground and belowground biomass and soil organic carbon (Nair, 2011). Agroforestry systems have higher potential to sequester C than pastures or field crops (Kirby and Potvin, 2007). Over 630 million hectares of unproductive croplands and grasslands are available for conversion into agroforestry systems to potentially sequester 1.43 and 2.15 Tg (10^{12}g) of CO_2 annually by 2010 and 2040, respectively (IPCC, 2000). Such a potential indicates an instrumental role that AFs can play to moderate climate change depending on strategies of adaptation e.g. retaining soil nutrients and moisture, and mitigation e.g. enriching soil organic matter or carbon (OM or SOC). Limited studies on the C stock dynamics in various agroforestry systems remain a constraint to harness these potentials (Jose and Bardhan, 2012). It has been reported that the average SOC in South and Southeast Asia is 8.7 kg/m^2 which is considerably lower than the global average of 11.3 kg/m (Dahal et al., 2010).

Coffee agroforestry (CAF), a sub component of agroforestry systems (AFS), is identified as potential source of carbon pooling under land use systems (Noponen et al., 2013). With more than 1000 million (M) ha of CAF area coverage globally, this system is a principal component among the various AFS of (Nair et al., 2009a), therefore, carries an enormous potential for sequestrating C in the forms of aboveground and belowground biomass with expanding trends (Albrecht and Kandji, 2003; Soto-Pinto et al., 2010; Verchot et al., 2007). Studies undertaken by Segura et al., (2006) in Nicaragua and Negesh et al., (2013) in Ethiopia are among few appropriate models available for estimating carbon stocks in CAF system, and, the former is considered more appropriate for the CAF practices in the Himalayas where majority of farms including the experimental plots have adopted coffee Arabica variety.

The middle hills of the Himalaya that passes through Nepal ranges between the altitudes of 800 and 2400m forms a complex mosaic of the rugged terrain, cross-crossed by rivers and valleys, and receive 80% of annual rainfall during monsoon between June to September. During the four months of rainy summer, farmlands, forests and barren lands are covered with rapid growth of vegetation when the annual stock of above-ground biomass (AGB) reaches at its peak before it starts decline in the subsequent months. However, the Mid Hills have been densely settled and intensively cultivated for several centuries by replacing natural forests with arable crops, which means the AGB was greatly reduced, often to <10% of the original (Sharma et al., 2008). Deforestation also depleted the quantity of organic matter in the soils, to about one half of the contents under forest in topsoils and to about two-thirds in subsoils. The loss of forest AGB and litter plus the decline in soil organic matter mean that C storage in the Middle Hills have been greatly reduced (Dahal and Bajracharya, 2011). The decreases in organic matter content and the substitution with nitrogenous fertilisers degrade soil physical fertility, and lead to coarse hard clods, lower soil moisture retention, and poorer workability (Pilbeam et al., 2005). The farmers of the Middle Hills have adapted to these conditions and developed management systems that integrate crops, livestock, forestry, and grassland. They are able to sustain substantial rural populations at subsistence levels on very small farms (Carson, 1992; Tamang, 1991). Common elements in the heterogeneous traditional systems include crop rotation, fallows, grazing of crop residues, zero grazing, irrigation where water is accessible and manageable, and the application of farmyard manure (FYM) (Schreier and Shah, 1999; Suwal et al 1991).

Majority of mountain farmers of Nepal and the Himalayas eke out their livelihoods through subsistence agriculture practices in the non-irrigated uplands locally known as *bari* (Dahal, 2012). Mountain regions have seen production of major cereal crops virtually stagnant for over the past 15-20 years (Kaini et al., 2004), some of the main reasons for the low yield are believed to be the lack of replenishment of SOC together with inadequate and inappropriate use of fertilizers (Bajracharya et al., 2004, Shrestha et al., 1995 and UNEP, 2012). Over half of the 75 districts of Nepal are categorized under the food-insecure region (FAO, 2009), and nearly all of them fall in the hilly or mountain region. This is an irony for the region where majority of population live on agricultural business. As a consequence, farmers tend to look opportunities for transforming their traditional upland crops such as maize, potato and green vegetables with multi-year crop such as coffee and fruits which have high value in the market. In recent decades, sizable smallholders in the hilly terraces of the Himalaya grow coffee as a perennial crop. According to an estimate, about 20,000 families are engaged in the production of coffee in Nepal (Ghimire, 2009), thus, generating more than 7,700 full-time employment equivalent (ITC 2007). In order to reap benefits of high market value of coffee, they have converted their conventional crop growing uplands into coffee agroforests. The change in the hilly landscape is spectacular after perennial coffee bushes have replaced seasonal crops in the range between 800m and 1600m altitudes. Potential coffee production area in Nepal has been estimated to be around 1.9M ha (MoAD, 2014).

The climate and topography of the lower Himalayas, specifically soils, altitude range, and hilly landscape are conducive to coffee farming where vast potential exists for its expansion (Table 1). Despite the growing demand of Nepali coffee in the local and international markets, farmers have found reasons to grow perennial crops such as coffee relative to seasonal crops. The hardship of practicing agriculture manually in hilly terrains, particularly maintaining and replenishing optimum level of manures to the soil, has been a driving factor to farmers to adopt agro-forestry system. Traditionally, Nepali hill farmers practiced subsistence agriculture and relied mostly on farmyard manure (FYM) and some compost to replenish plant nutrients in soils. Although farmers find the FYM and compost beneficial to their lands, rising labor costs and intangible benefits (slow and indirect returns) remain the major constraints for their sustainable uses. In turn, industrial fertilizers are widely applied over the FYM although the latter is still on practice in limited scales (Bajracharya and Sherchan, 2009). With the advent of modern agricultural practices from low intensity (subsistence oriented) to more intensive cropping (commercial), farmers depend more on chemical fertilizers rather than FYM, which they find labor intensive. Nevertheless, a significant number of hill farmers continue to use FYM particularly those who have adopted an improvised practice called ‘sustainable soil management or SSM’ as this helped them make FYM more effective and sustainable (Dahal and Bajracharya, 2012). Marschner (2006) elaborates that plant productivity is directly influenced by nutrient availability, which is a product of nutrient transformations in the soil environment. More recently, agencies working in the field of hill agriculture have introduced biochar as a measure to tackle the issue of productivity and SOC losses (Dahal and Bajracharya, 2013).

Several studies have highlighted efforts of the mountain farmers in maintaining soil quality against degradation of soil fertility, surface erosion, and landslides (Biswokarma *et al.*, 2014, Regmi *et. al*., 2005, Bajracharya and Atreya, 2007, SSMP, 2009, and, Dahal and Bajracharya, 2011). Among other actions, they use farm yard manure (FYM) in *bari* every year that contributes to maintain or enhance soil organic matter, thus, sequestrating carbon in the form of SOC. The FYM is prepared with waste biomass from agriculture fields and forest litter mixed with dung from livestock. These are few of their good practices that they are doing from generations, on which there are limited studies regarding impacts of such practices on soil carbon pool.

Biochar, a pyrolysis product of biomass wastes, is used as organic additive for soil amendment to improve soil health, thereby, increase crop yields and productivity through reduced soil acidity, enhancing water retention, and minimizing the needs of some chemical and fertilizer inputs (Glaser et al 2002; Lehmann and Rondon, 2006). Applications of biochar in agricultural fields have dual impacts- effect on soil quality and plant production (Lehmann, 2007). In addition to its direct contribution of available nutrients to the soil, biochar has a variety of physical and chemical properties that influence soil nutrients transformations (Deluca et al., 2009). This study further indicates that biochar additions to soil have the potential to change the microbial biomass, community composition and activity of soil microbes, all of which can influence nutrient mineralization from decomposing plant residues as well as several specific nutrient transformations. According to Pietikäinen and Fritze, (1993) the porous structure of biochar offers habitat to proliferate soil microbes. Likewise, a study by Major et al., (2010) has discussed positive effects of biochar on plant growth and associated C inputs, and those by DeLuca et al (2006) and Ni et al., (2010) highlighted sorption effects of biochar on microbial signaling compounds or inhibitory plant phenolic compounds as well as its effect on soil physical and chemical properties.

Biochar as a stable substance of soil organic matter (SOM) accounts for its dual roles in carbon stock enhancement in the soil (Anders et al., 2012). First, its particles remain locked in the soil with limited or no decomposition, and second, its catalyzing effect, which accelerates mineral uptake capacity of the plants that contributes to prevent mineral leaching. This study aimed to evaluate biochar effects on C-stocks in coffee agroforestry plantations to give a new dimension of knowledge on biochar. Taking cases of expanding coffee agroforestry practices in the mid-hills of Nepal, this paper analyzes biochar effects on the total carbon stocks of agroforestry systems in the Himalayas.

However, inadequate understanding about the specific mechanisms through which biochar influences soil microbial community properties remains as a bottleneck (Lehmann et al., 2011). Nevertheless, roles of organic inputs including FYM, compost and biochar for soil amendment and maintaining soil health have been widely recognized although precautionary note such as of Mukherjee and Lal, (2014) continue to emerge against exaggeration of about its merits over demerits.

2. Materials and Methods

Research sites: The three experimental sites of this study represent a diverse geo-climatic feature of the Himalayas where mountain or hill farmers of Nepal have a tradition of farming in a distinct manner. On-farm field trials were undertaken between 2013 and 2015 in three locations of Nepal mid hills at altitudes between 821m to 1475m that reflect an agro-ecological diversity of the Himalayas. The trials were conducted in the private farms where the smallholders produce Arabica coffee variety together with other cereal crops and vegetables. The three sites exhibit a diverse characteristic of the middle Himalayas dominated by densely populated river valleys, rivers, hillocks and agriculture based livelihoods along the hilly terrains where contrasting micro-climate variation exists as the altitudes, aspects, and slopes vary. Site I, Chandanpur, is located at 1475m facing south of the Mahabharat range, has terraced field with average slopes of 20 degree and the soil with loam texture. Site II, Panchkhal, lies at 1075m in the central mid hills facing northeast with 25 degrees on average slope, and the soil with silt loam texture. Likewise, Site III, namely, Talamarang, is situated at an altitude of 821m near the bank of the snow-fed Melamchi River from the Himalayas to the northern part of the mid hills. The average slope of the coffee farm is 15 degrees facing to the east with soil texture of sandy silt loam. The different locations of the experimental sites fairly capture diversity of micro-climatic variations as they are apart from each other between 20 to 80km and exhibit contrasting climatic variations although all these sites receive over 80% of annual rainfall volumes during the four months of monsoon (June to September). The coffee growers often rely on a manual of organic coffee producers (MOAD, 2014) developed by supporting agencies including the Department of Agriculture.

Among the coffee growing farmers, a couple of households were selected in each site for the trials based on their willingness to participate voluntarily in biochar making and application on their respective plots. These were farmers who had been growing coffee for 5 years or more, and, willing to participate voluntarily. Accordingly, farmers offered their full cooperation to identify plots, tag sampled trees, and collect soil samples as well as measure biomass from the designated plots. Monitoring an effect of biochar trial in a farmer's field environment of coffee agroforestry was undertaken carefully to ensure that the trial plots get same level of treatments than the rest of the fields. During the trials, the farmers, who own the lands of the experimental plots, continued their regular activities including pruning and removal of diseased trees.

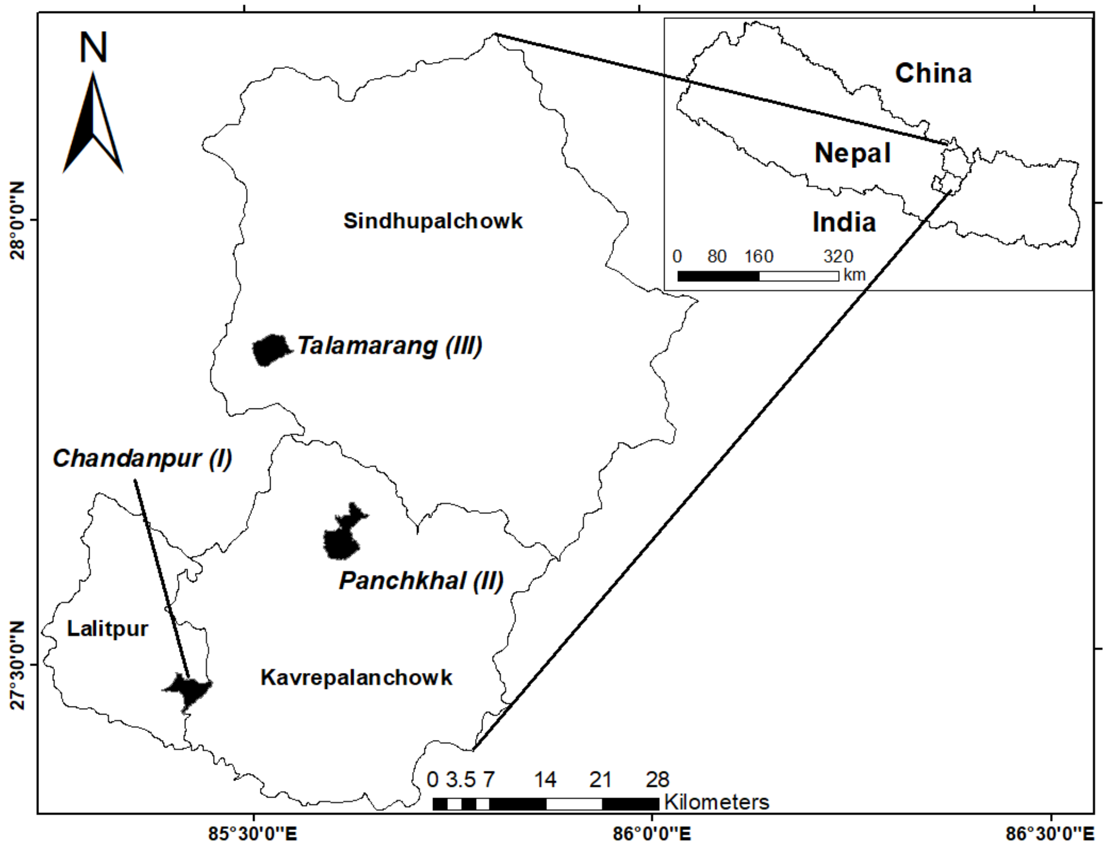

Figure 1. Map showing the locations of the research sites in Nepal

The individual smallholders who switched parts of their traditional maize and millet growing lands to coffee agroforestry are driven by the interest of maximizing benefit over their conventional farming practices. The evolving coffee agroforestry systems in the region are among the least studied in terms of carbon stocking. With three trial plots that represent a diverse climatic context, this study reported the results and analyses of the trials undertaken from farmers' fields.

Table 1. Geographical characteristics of the experimental plots established in each of the three coffee growing belts of Lalitpur, Kavrepalanchok and Sindhupalchok districts of Nepal

Locations of experimental plots	Latitude, Longitude	Elevation / Type*	Size of trial plots	Number of coffee trees per plots	Number of trees per hectare	Current coffee area in the district*	Potential coffee area in the district**	Dominant soil texture	Soil organic matter (SOM)
I. Chandanpur, Lalitpur	27°28'36.16" N, 85°24' 50.02" E	1475m Upland	100 m^2 out of 0.3561 ha planted area	655	1840	90 ha	8548 ha	Silt loam	10%
II. Panchkhal, Kavrepalanchok	27°37'48.08"N, 85°36'21.32"E	1075m Upland	100 m^2 out of 0.4578 ha planted area	960	2097	116 ha	3679 ha	Silt loam	3.5%
III. Talamarang, Sindhupalchok	27°51' 15.90" N, 85°32' 43.15" E	821m Upland	100 m^2 out of 0.2543 ha planted area.	535	2104	95 ha	19427 ha	Sandy loam	3%

*The upland type of land category usually represents a rainfed agricultural land in the hill agricultural system, which is locally known as *bari* in the local term and perceived as a low grade compared to the *khet* due to latter's access to irrigation. ** Source: MOAD, 2014.

Design of experimental plots: Taking account of the local practices of plantation density, which is approximately 4000 trees per hectare, experimental plots was designed of the size covered by 40 coffee trees (100 m^2) in each of the farms in the three locations, namely, Chandanpur, Panchkhal and Talamarang of Nepal (table 1). The sizes of the three farms where the plots established were of 0.2543 ha, 0.3561 ha and 0.4578 ha with number of trees 535, 655 and 960 respectively. All these farms were older than 8 years and, each of the trees were matured enough for annual harvesting of fruits (cherries). Using a stratified random sampling approach, 120 coffee trees were identified and tagged, 40 each from the three sites for monitoring of biomass growth. The farmers were advised to carry on their business as usual way without differentiating their activities including pruning, trimming, harvesting and intercropping of the vegetable crops of their choices in the treatment areas from rest of the farm areas. Accordingly, they followed their usual practices. The height and basal diameter at 15 cm of the tagged 120 coffee trees were measured. Effect of farmers' preferences on height of coffee tree was observable as they carry out cutting and pruning as well as intercropping of seasonal vegetables. The follow up monitoring of the sites was conducted. Of the 120 tagged trees, biochar was applied to the 60 (20 from each of the 3 experimental sites), and rest 60 (20 each from the respective sites) were left with no—biochar treatment for control.

Soil sampling: Soil samples were collected from the experimental plots prior to the treatment with biochar. The samples were taken from top layer soil (0-15cm) with five replications from the three experimental plots. A corer of 100 cm^3 was used for measuring bulk density (Blake and Hargte, 1986). The baseline sampling was followed immediately by applications of biochar as follows: 1) out of the 120 coffee trees (40 each from the three sites), half or 60 of them (20 from each site) were identified as 'biochar treated', and rest 60 as control (as discussed earlier). 2) Applied biochar to the soil of the 60 tagged trees within a radius of 57cm at a rate of 5 ton/ha (5 $Mgha^1$). The samples were tested in the university lab for SOC composition, and, 3. The process of soil sampling and testing was repeated identically after 2 years for a comparison of the results.

Biochar production and application as a soil amendment agent: Biochar was produced using coffee waste materials as a feedstock in a specially designed stove for dual purposes of preparing biochar while cooking animal feed at household levels (Dahal and Bajracharya, 2013). Coffee wastes were considered an appropriate feedstock types as these are the least recycled refuses compared to other locally generated biomass wastes. Wastes generated through processing of coffee beans from pulping centers are abundantly available during harvesting months of December and February. A variety of coffee processing wastes such as pulps, husks, and discarded cherry beans; and those produced from cutting and pruning of coffee trees are mixed up together to prepare the feedstock as these are not preferred for feeding cattle or composting (Dahal et al, 2013). Low temperatures 350 and 550 degrees Celsius was maintained in order to prevent burning the pyrolysed feedstock into ashes. For the purpose of testing biochar effects on the coffee plants, 500 grams of mixed biochar was applied to each of the 60 coffee trees (50% of those selected for trial, leaving the rest 50% as control) in the three sites. The biochar input area was within the radius of 57cm (1m^2 area) of each tree, which is equivalent to 5 $Mgha^1$. The soils and bichar were tested prior to the application of biochar. Basic properties of baseline samples of soil and biochar are presented in the table 2.

Table 2. General properties of soils at pre-treatment stage and sample of applied biochar

Parameters	Chandanpur	Panchkhal	Talamarang	Sample of applied biochar
pH	6.026	5.8	5.23	8.54
Soil Organic Matter (SOM)%	10.37	6.564	5.758	19.47
Bulk Density (gm/cm3)	0.83	2.012	1.956	-
Total Nitrogen (ppm)	1388.8	3281.6	2396.8	14840
Available Phosphorus (ppm)	137.6	520.04	323.36	5273
Available Potassium (ppm)	267.96	244.78	202.84	1386
CEC (m. e./100gm)	59.44	49.64	39.36	90

Estimation of coffee tree biomass: In each of the three trial sites, 20 coffee trees were identified and applied biochar while another set of 20 coffee trees were tagged as control for the purpose of biomass monitoring based on tree height and stem diameter at 15cm above the ground (d_{15}) to estimate biomass stock of each tree. In the absence of specific biomass equation for the coffee plant grown in Nepal, the best fitted model developed by Segura et al (2006) was applied, which was derived based on the extensive field trials from 37 coffee farms in Nicaragua; and, is expressed as:

$$\text{Log}_{10}\ (B_T) = a + b * \text{Log}_{10}\ (d_{15}) + c*\text{Log}_{10}\ (h) \tag{1}$$

Where B_T is total aboveground biomass of an individual coffee tree in kilogram; a, b and c are the model's fitted parameters with values 1.113, 1.578 and 0.581, respectively; d_{15} is stem diameter at 15cm height (cm), and plant height (h) in m. According to this model, the total above ground biomass of each coffee plant ranged from 0.005 to 2.8 kg. Carbon values were derived from biomass values using a conversion factor "carbon fraction" (CF) of 0.47 (Adale, et al., 2006). Based on monitoring of d_{15} and h, the aboveground biomass of the tagged plants was measured two times; first between April to June at the time when biochar was applied, and, second in the same months after two years.

Estimation of SOC stocks: The soil organic carbon (SOC) in the top soil layer (0-15cm) was estimated using Pearson et al., (2007) approach, and, expressed as: SOC ($Mgha^{-1}$) = SC/1000* BD*SD*10000 Mg ha^{-1} ; where SOC is total soil carbon pool in Mg ha^{-1}, SC is concentration of soil C in gkg^{-1} soil, BD is bulk density in gcm^{-3}, and SD is soil depth in m. We compared the changes in SOC stocks between the treatment and control plots separately in each of the three locations, namely, Chandanpur, Panchkhal and Talamarang (table 1).

Statistical Analysis: To illustrate specific treatment effects, an ANOVA test was carried out on changes in AGB carbon and SOC stocks among the plots at the three sites using minitab 17 version. Similar analyses were conducted on changes in SOC stocks. The results are presented graphically as SOC stocks in $Mgha^{-1}$ for carbon accounting, and for assessing the net impact of treatments on ecosystem carbon storage and, thus, their potential for climate change mitigation.

3. Results

Aboveground Carbon Stock: Comparative results of pre-treatment (base year) stage with those of post-treatment stage are presented in the table 3 for both biochar treated and control plots. Results of two years of monitoring of aboveground biomass at the three sites generally indicated incremental stocks of carbon. Of the two plots, with and without biochar amendment, growth rates were higher in the former, implying the positive effect of biochar on the coffee plants. Both the biochar applied and non-biochar plots showed modest increments.

The average stocks of aboveground carbon in coffee trees increased from 6.2±4.3 $Mgha^{-1}$ to 9.1±5.2 $Mgha^{-1}$ over the trial period of two years in biochar treated plots. The same in control plots increased from 5.6±2.8 $Mgha^{-1}$ to 6.7±4.7 $Mgha^{-1}$. Specific to experimental plots, the stocks in site I increased by 4.65 $Mgha^{-1}$ followed by 3.04 $Mgha^{-1}$, and 1.02 $Mgha^{-1}$ in sites III and II respectively. Farmers' maintenance of plant height of coffee tree is common. In site I and III, coffee growers maintained relatively taller size as they perceive better harvest in taller trees compare to shorter one. The farmers at site II, however, maintained relatively shorter heights for the ease of harvesting coffee cherries, which is reflected in the carbon volumes as well as Site II recorded lower amounts compared to the rest two sites. In the biochar plots, the average increments of ABG carbon was 0.73 Mgh^{-1} while in the control it was 0.29 Mgh^{-1}. These different rates of change may be explained as a biochar effect on biomass growth. We didn't account the fruits as this involved a tedious task of maintaining tree specific records of intermittent harvest over a period of several weeks or a month.

Table 3. Results of above-ground carbon stocks of coffee agroforestry systems over two years after application of locally produced biochar at the rate of 5 $Mgha^{-1}$

Experimental Sites	**Treatments**	**Number of Samples (n)**	**Base Year (Mean ± Standard deviation in Mgha^{-1})**	**Number of samples (n)**	**Post treatment stage (after two years) (Mean ± Standard deviation in Mgha^{-1})**
I. Chandanpur	Control	20	6.95±5.12	16*	10.19±7.92
	Biochar applied	20	7.57±3.01	20	12.22±5.18
II. Panchkhal	Control	20	3.27±1.48	20	3.50±1.12
	Biochar applied	20	3.56±2.8	20	4.58±2.76
III. Talamarang	Control	20	6.58±4.23	20	6.59±5.07
	Biochar applied	20	7.43±6.99	19*	10.47±7.83
Average	Control		5.6±2.8		6.7±4.7
	Biochar		6.2±4.3		9.1±5.2

*The number indicates that farmers removed the diseased coffee trees, which occurred on those in two control plots but no such issues occurred in the plots treated with biochar.

The incremental growth of C-stocks in the biochar applied plots was higher than those for the non-biochar plots in all the three sites. Analysis of variance (ANOVA) suggests that the incremental rates of the aboveground carbon stocks are statistically significant, both by location and by treatment (table 4).

Table 4. ANOVA test result using Minitab version 17 indicates significant effects of treatment and location on the aboveground carbon stocks of coffee trees in biochar treated plots

Source	DF	Adj SS	Adj MS	F-Value	p-Value
Location	2	50.60	25.300	12.61	0.000**
Treatment	1	16.76	16.761	8.35	0.005**
Replication	19	32.92	1.733	0.86	0.627
Error	97	194.62	2.006		
Total	119	294.90			

The C-tocks in the initial stage (pre-treatment) and final stage (post treatment at the end of year 2) are presented in a simple graph with trend lines (figure 2). Crossing of the two trendlines each other may be interpreted as an effect of biochar treatment on the C-stocks build up in the trees.

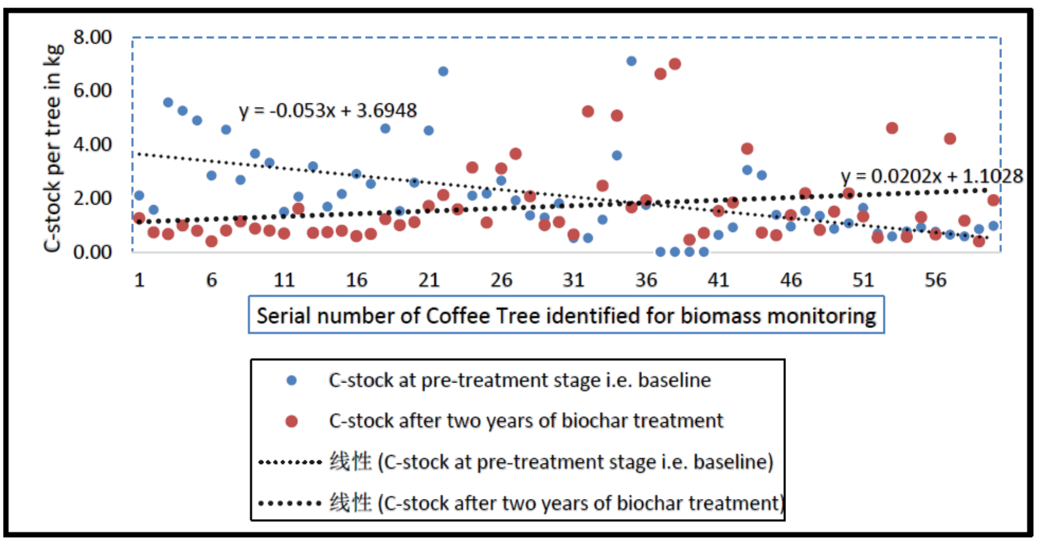

Figure 2. Changes in C-stocks in coffee trees at pre-treatment and post-treatment stages. Crossing of the trendlines between the pre and post treatment stages over the two years after biochar application indicate an effect of biochar

Changes in stocks of soil organic carbon (SOC): In the base year, 2013, the average stock in the three sites: I, II, and III, was 74.88 ± 15.93; 63.96 ±16.71 and 33.05 ±4.42 $Mgha^{-1}$, respectively. The disparity in SOC stocks of coffee farms among the three locations as indicated by figure 2 reflects the diverse characteristics of soils as well as farming practices including inputs provided in the forms of compost and FYM over a decade or more as determinant factors (Biswokarma et al, 2014). Incremental changes in SOC stocks were observed in all the biochar treatment plots (Figure 3) compared to baseline estimates. The changes in SOC stocks in the three biochar treated plots of Chandanpur, Panchkhal and Talamarang were higher with 19.8, 49.8 and 45.3 $Mgha^{-1}$, respectively, compared to 8.3, 29.3 and 11.3 $Mgha^{-1}$ in the corresponding control plots. A wide range of incremental changes of SOC in biochar treated plots and control during the study period evidently offers a positive indication for interpretation regarding a cause-effect relation between biochar and SOC.

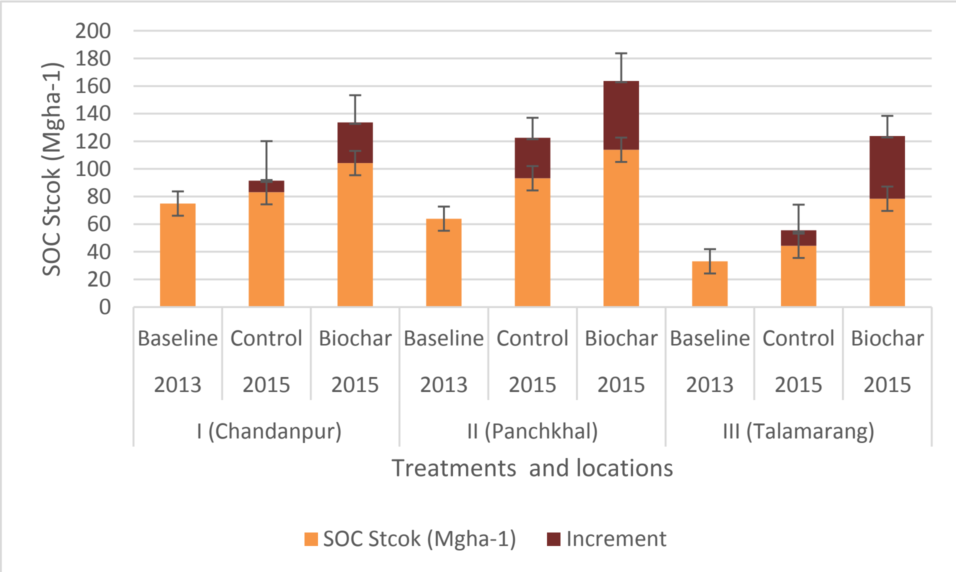

Figure 3. Changes in SOC stocks ($Mgha^{-1}$) with biochar treatment in the top soil layer

In spite of different level of baseline SOC stocks in the three experimental sites, which is as expected due to decades of agricultural practices and natural composition of soils, the higher rates of incremental changes of SOC in all the biochar treated plots compared to the control plots is evident. This implies a positive indication of biochar effects on SOC stocks although the results are subject to validity with larger scale trials.

4. Discussion

Among the plots, higher amount of stocks were recorded in those where pruning is less frequent, and, taller size of trees were maintained (for example in Talamarang) than those where pruning/trimming was practiced regularly (for example in Panchkhal). These findings may serve as a reference for incentivizing the agroforestry farmers with carbon co-benefits in the future. Major aspects of findings of this study are discussed in the subsequent sections below.

Carbon stock in coffee agroforestry: We estimated the aboveground biomass carbon of the coffee plants applying Segura et al., (2006) model, which was derived from Nicaraguan coffee agroforestry context. Basal diameter (d_{15}) and tree height are the key parameters of this model. The results are comparable to the findings of similar studies in Guatemala by Schmitt-Harsh et al (2012) who recorded above-ground C-stocks of 12.9 $Mgha^{-1}$ on an average. The figure is in close agreement to our estimates of Site I (12.22 $Mgha^{-1}$) and Site III (10.47 $Mgha^{-1}$) but higher than those of Site II (4.58 $Mgha^{-1}$). According to Nair et al., (2009b) SOC stocks are higher in agroforestry system compared with treeless seasonal crop systems. As our study did not include carbon stored in shade trees and understory vegetable crops, these results are not comparable with the total carbon stocks of agroforestry systems including shade trees. Two of the three farms under this study have no shade trees (sites I and III), hence, may be categorized as 'sun coffee' and the remaining farm (Panchkhal, the site II) can be categorized under limited shade trees. In order to enhance applicability of the model to estimate aboveground carbon stocks of coffee trees in the Himalayan context, further field trials are imperative for three reasons. First, the results can be analyzed against two baselines- changes in carbon stocks along a timeline and, - in situ change the emerging practices of coffee agroforestry; second, it is not clear whether the model has taken the fruits into account or not, and third, some of the coffee trees were diseased and removed from plots during the follow up monitoring leading to lower estimation.

Biochar effects on growth of coffee plant: The incremental effects of the aboveground carbon stocks of coffee trees in the two of the three plots of this study may be attributed to biochar action together with some minerals and micronutrients available in it to stimulate the tree growth. The results also indicate higher rates of incremental change in biochar treated plots compared to the control or no-biochar plots although not all the increments were statistically significant. These findings corroborate with the results of a long term research by Noponen et al., (2013) in the coffee agroforestry of Nicaragua and Costa Rica where inputs of organic mineral are credited for the increased stocks of carbon on the top soils. A recent study by Gautam et al., (2017) about an effect of biochar on crop systems in the hilly agricultural systems of the Himalaya demonstrated that effectiveness of biochar was even higher on SOC increment when applied together with FYM with a result of 2% increase with biochar alone and 6% increase with biochar plus FYM.

Effectiveness of biochar on soil SOM: The average rates of increase of SOC in biochar applied plots in comparison of control indicate an effect of biochar treatments at various levels. The incremental carbon stocks are remarkably higher in soil than those of trees. In the farmer's field, the growth of carbon stocks, however, may not be attributed to biochar only but other factors including biomass inputs in the form of organic compost and farm yard manure as well. The overall results suggest that biochar effectively plays a stimulating role to improve the organic matter status where it is deficient. It leads to reduce susceptibility of soil erosion, thus, lower retention of fertilizers and less production of crops and further depletion of SOM in the hilly region. Likewise, Dahal and Bajracharya, (2012) reported the SOC level in parts of mid hills Nepal, namely, Baglung, Dhading, Kavre and Okhaldhunga, within the range of 23 to 47 $Mgha^{-1}$ in the top layer (0-15cm), which were remarkably higher than this study. The difference could be the result of differences in the nature of agricultural practices where sustainable soil management practices were introduced. Reports of incremental change in SOC stocks after changes in agricultural management is based on extrapolation from rates of C-sequestration by growing plants using weak evidence about the processes by which this might influence the C-stocks, which can be positive or negative (Sanderman and Jeffrey, 2010). Pointing to the vicious cycle of SOC depletion, Lal, (2009) depicted two major causes. The first is the long-term use of extractive farming practices and, the second is the conversion of natural ecosystems such as forest and grass lands, into croplands where SOC stocks suffer losses due to a number of factors like low biomass input, tillage practices, crop harvesting, excessive inputs of chemical fertilizers, and soil erosion. This is important because protection of surface soils in the hilly agricultural landscape remains a critical challenge particularly when intense rainstorms are common during the pre-monsoon and monsoon months (March to September). High degree of erosivity and erodibility of the hilly slopes make the top soils and nutrients with organic matter vulnerable to erosion losses.

Benefits of biochar to the local coffee growers: Smallholders coffee growers who actively cooperated in this study were particularly interested in three benefits of biochar effects; first, the quantity and quality of fruits (volume and size of cherries), second, the soil properties (acidity, compactness, moisture retention), and, third, carbon sequestration benefits. This study reports the positive effects of biochar for enhancing carbon sequestration, which is on the interest of the local farmers as they may fetch incentive for a contribution to reduce emission. CAF systems as a potential source of above- and below-ground C-sequestration may offer dual opportunities of climate adaptive and economic benefits.

5. Conclusions

The practice of conversion of conventional upland agricultural lands of the Himalaya into various types of agroforests including coffee is gaining popularity in recent years. This makes the mid-hills coffee agroforestry a new source of carbon stock in the agricultural fields. Effects of biochar on carbon stocks of coffee agroforests were studied at on-farm sites of three location of Nepal mid hills with an intent to understand carbon dynamics in the aboveground biomass and top soils in the Himalayan context. A remarkable finding of this study is the increase in carbon stocks of 3 agroforestry farms in 3 districts of eastern Nepal after application of biochar at a nominal rate of 5 tons per hectare. Specifically, the growth coffee trees leading to higher biomass carbon, and SOC were noted to be higher in biochar applied plots compared to non-applied plots, although not all the changes were statistically significant. The study also indicated that biochar can be more effective to enhance carbon stocks in soils than those of tree biomass. As the study was undertaken in a limited environment of coffee agroforests with no cover of shade trees and farmers' field, a longer term and comprehensive study covering both in a controlled environment and sizable number of on-farm sites is a prerequisite for a conclusive finding.

It was noted that a major challenge in estimating carbon stock accurately in on-farm agroforestry systems is due to the heterogeneous interventions such as understory or intercropping practices and fertilizers. Such interventions were not monitored closely and may have affected the results. Anthropogenic factors that affect biomass stock of a coffee tree exist due to the preferential management practices of cutting and pruning of the coffee trees usually in the period from 1 to 3 years.

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Risk and Economic Analysis of Greenhouse Cucumber and Tomato Cropping Systems in Oman

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Abstract

The agriculture investment decision affected by risk of capital and operation cost, yield and sale price of planted crops. This study examined risk of investment in green-house cucumber and tomato production and optimum mix of crop pattern at Al Batinah, Al Sharqiya Regions of Oman. The net present value with Monte Carlo simulation models are used to test risk efficiency and project viability. The result indicated that investment in two green-houses and growing one tomato crop and two cucumber crops (Tom1Cuc2) per year is more profitable and risk aversion. Stochastic Efficiency with Respect to a Function (SERF) performed and confirmed that (Tom1Cuc2) is the most risk efficient cropping system and got a positive NPV with 62% probability followed by growing tomato crop in two seasons with a positive NPV with probability of 58%. The study concluded tomato and cucumber producers are faced with different production and financial situations and their risk preferences play an important role in determining their production decisions. Risk premium analysis shows that greenhouse tomato growers need to be paid up to RO 2 847 to keep growing tomato instead of (Tom1Cuc2) cropping system. Greenhouse cucumber growers can sacrifices of RO 5 373 to justify not to switch from planting cucumber to grow (Tom1Cuc2) cropping system. Government subsidy should be given to farmers to construct new greenhouses to maximize their resource use efficiency, benefit from extended cropping season, protect their crops from adverse environmental conditions and increase food security.

Keywords: stochastic efficiency with respect to a function, risk simulation model, green-house cropping systems, risk aversion

1. Introduction

The vegetable crops cultivation area in Oman in 2017 recorded 52.9 thousand (acres) with a total vegetables production of 815 thousand tons. The vegetable cultivated area increased by 28% in 2017 compared to 2016 and total production is increased by 85% on the same period. The gap between demand and supply is still high and recorded 32% during summer season, (Ishag, 2017). The introduction of new technologies and green-houses will improve vegetable production growth and reduce import during summer season.

Green-house tomato production consist about 2%-5% of total Oman tomato production whereas green-house cucumber production cover about 61%-73% of total Oman cucumber production. Tomato is planted two to three times a year in green-houses and it benefits from a large harvesting period. Green-house cucumber is planted three to four times during the year and it takes short time for fruit maturity and harvesting. Although green-house technology offer fresh cucumber and tomato off-season and contributes in food security, risk of yields and price variability and profit sustainability need to be tested and investigated.

The agricultural activities development and excessive use of land and water at coastal areas in Al Batinah, Al Sharqiya and Al Dhahira Regions' caused water table dropped to a low level, and water salinity of the wells had increased and reduced water quality. That was mainly due to excessive underground water depletion and over pumping by new turbine power full water pumps introduced recently in Oman. The sea water intrusion Oman costal area is mixed with fresh underground water. The continuous irrigation with brackish water increased soil and water salinity and affected crop yields and cropping systems.

The Government authority recently announced that the underground water reserve and ground water recharge is 1295 millions m ^{3} per year, which is less than water consumption of about (25%). This unbalance underground water reserve is one of the most challenges factor facing agriculture sector development in the country.

As a result, cucumber producers and open field vegetable grower are searching for alternative to overcome water shortage and salinity problems and mitigate risk of yield and price variation loss.

1.1 Literature Review

The green house farming technology use is increasing in Oman and around the world due to continues resources and environmental pressure such as land, water and disease on open filed farming. A vertical farming gives a good environmental solution to areas interested to be self-sustainable, (Kumar et.al 2018). Eihab et.al (2017), used minimization of total absolute deviations (MOTAD) approach to investigate risk of water and environmental constrain on green house crop mix and crop risk efficiency.

Green house cropping system viability and sustainability refer to system ability to generate profit in spite of major constrains and disturbance. The system resilience and ability to continue in the future in term of financial viability and natural resources degradation can be taken as a tool to choice between alternative greenhouse cropping systems, Lien G. et.al (2007). Stochastic and dynamic nature of the cropping systems can be model to estimate positive return for each alternative green house cropping system.

Monte Carlo Simulation Dynamic Model can be used for project viability and was addressed by Savvakis C. Savvides in (1994). He argued that this integrated analysis provided a range of outcomes that can reduce the risk of uncertainty inputs parameters and generate reliable results for decision makers and investor. Additional information related to simulation dynamic model and policies analysis can be found in Blumenfeld et al. (2009); Carpenter, Brock and Hanson (1999); Chen et al. (2009); Folkes et al (2002), MA (2005); Sanders and Lewis (2003).

Monte Carlo Simulation models were used in this study to quantify risk and uncertainty associated with green house cucumber and tomato cropping system. The quantitative risk analysis of optimum crop mix will provide decision makers cropping system viability and probability by estimating NPVs for each model. The model will also help in improving green-house management and help policy makers to form accurate policy and maintain national food security and preserving the environment. S. Quiroga (2010) used Monte Carlo simulations to estimate crop yield risk to water variability.

The stochastic efficiency of alternative green-house cropping system can rank risky alternative over a range of risk aversion. This technique developed by Hardaker et al. (2004) and called stochastic efficiency with respect to a function (SERF). SERF is based on the notion that ranking risky alternatives in terms of utility is the same as ranking alternatives with certainty equivalents (CE). CE is defined as a granted return the farmers except with the same utility as the expected utility of the risky prospect (Hardaker et al., 2004). (Lien et al., 2006) used Stochastic Efficiency with Respect to a Function (SERF) to supplement sustainability criterion. In this study, the (SERF) technique is applied to assess a set of alternative risky crop optimum mix and cropping systems. The SERF method ranks alternative risky green-house cropping systems in terms of the CE of cropping system return over a range of risk aversion levels. SERF can compare any level of decision makers‟ preferences including risk-averse, risk neutral and risk loving. The green house cucumber and tomato data collected from excremental data from Plant Production Research Center at Director General of Agriculture and Livestock Research. The stochastic simulation models were employed to examine NPV distribution for four cropping system alternatives. The main objective of this paper is to investigate optimum crop mix, sustainability and risk efficiency over a range of risk aversion level.

2. Materials and Methods

The study evaluated the investment in green-house to grow cucumber and tomato crops through estimating and calculating future costs and revenues of the project. The net present values (NPV) of cash flows are calculated by multiplying the predicted net cash flows by a discounted rate of 10%, which is similar to commercial Bank interest rate. The inputs data, yield and price were collected from Agriculture Research Station experimental date and farmers' survey.

The study used dynamic simulation model to evaluate investment in two green houses and calculate Net Present Value (NPV) of four cropping systems to evaluate risk and economics sustainability. The stochastic budgeting data of green-house cucumber and tomato cropping systems were used to consider risk and uncertainty of yield and price for each green-house cropping system. The study used (@Risk 7.5) program to account for the stochastic nature of key cropping system variables in the Monte Carlo simulation model. Parameters of input distribution were used in the model and cash flow for each cropping system estimated for 10 years and presented in Table 1. A range of NPVs were obtained by using stochastic inputs variables in below formula.

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n}$$

Where,

Cn = the net cash flow in year n (n = 0, 1, 2, …. n), represented by farm income in this study.

n = the planning period which equals ten years in the current analysis.

r = the discount rate.

2.1 Net Present Value and Simulation Models

The study first identified the main key inputs variables and yield to estimate the best fit of variable probability distribution function which describes the range of the uncertainty around the expected variables. A historical data from Agriculture Research Station experimental data were used in the model to generate value for each greenhouse cropping systems. Monte Carlo Simulation analysis were used to incorporate stochastic variables main inputs cost, crop yield and price in the model. The probability distributions of each risky input variable i.e. (triangle – normal - binomials) were used to estimate Cumulative Distribution Function (CDF) of the model output (NPV) for each cropping system.

To investigate green-house cropping system risk efficiency and sustainability, the study performed Stochastic Efficiency with Respect to a Function (SERF) Analysis for different cropping system. The data were collected and calculated to generate Certainty Equivalent (CEs) and rank green house cropping system alternatives according to their risk efficiency and economic sustainability. The data for each green house cropping system model in this study is grouped to two categories (Table 1):

Table 1. Input used seasonally and capital fixed materials used in the models

Inputs used seasonally	Capital fixed materials replaced each 5 years
– Seeds	– Fans
– Fertilizers and Insecticides	– Cooling pads
– Plastic sheets	– Polyethylene sheets
– Hanging ropes	– Irrigation system
– Pruning scissors	– Tractors
– Insect yellow traps	– Car (Van)
– Packing boxes	– Planting trays
– Planting soil	

2.2 Stochastic Efficiency with Respect to a Function (SERF)

Simulation model is used to investigate risk management tool that can be used to improve sustainability of green house cropping systems and obtain the best sustainable cropping system. The model is run for (10,000) times for 10 years in the future to estimate Cumulative Distribution Function (CDF) of the model output (NPV) for each cropping system and assess the economic sustainability of different alternatives. The model failure measured in financial terms of getting a lowest or negative NPV, Hansen and Jones, (1996).

Stochastic efficiency with respect to a function (SERF) is used to rank the risky cropping systems alternatives simultaneously for decision makers with different risk aversion preferences. Risk Premium is also calculated by subtracting CE Certainty equivalent for less preferred alternative from dominant alternative. The certainty equivalent equation used in the study is presented below and include a utility function u (·), a random wealth variable X, and an initial level of wealth w0, the certainty equivalent is :

$$CE = u{-}1\{E[u(X + w0)]\} - w0,$$

The risk premium measure the minimum amount that would have to be paid to a farmers and decision maker to justify a switch from alternative present green house cropping system to other less risky cropping system. An analysis of four greenhouses cropping systems was conducted using a ten years experimental data and simulation model. Each green house cropping system is represented by two green house and yield, price, investment and operation cost data are collected from experiments data. Four models simulated the costs and returns of the four cropping systems to obtain the NPV probability distributions generated by the simulation model and used to rank the best alternative green house cropping system across a full range of Risk Aversion Coefficients -RACs.

2.3 Model Structure

The modeling structure represents Al Batinah and Al Sharqiya Regions with hot temperature and high humidity, began by defining inputs and parameters effecting crop cultivation income and return. The purpose of the study is to provide a high level of understanding of risks of growing green house cucumber and tomato in Oman. The main risk and uncertainty variables identified in the models were :

- Variable cost increase and it is effect on NPV.
- Cucumber and tomato selling price volatility and their effect on NPV.
- Cost of production per ton for each cropping system and it is effects on NPV.
- Annual increase in sales price and unit cost.
- Total sale volume for each cropping system.
- Probability of competitor entry to the market from year one.
- Cucumber and tomato yield variation at four cropping systems.

The quantitative risk analysis is performed after selecting key parameters and estimated inputs probability distribution for four green house cropping systems grown in two green houses as follows :

- One tomato crop and two cucumber crops per year in two greenhouses (Tom1Cuc2).
- Three cucumber crops in one greenhouse and mixed crops in second greenhouses (Cuc&Mix).
- Two tomato crops per year in two greenhouses (Tomato).
- Three cucumber crops per year in two greenhouses (Cucumber).

The model estimate individuals risk parameters affecting the combination of greenhouse cropping system in term of financial performance and cash flows. The probability distributions of the parameters are incorporated in to Monte Carlo Simulation Model which allows evaluation and quantified risks range of each parameters.

Four models were formed to represent four greenhouse cropping systems. Investment capital cost, crop yield, total sale volume, sale price and per unit cost of production for each cropping system is estimated. The estimation of each input variable and probability distribution at each cropping systems identified and incorporated in the analysis and shown by below Table (2).

Table 2. Input parameters distribution range used in greenhouse MCS for Tomato Models

Risk	Affects	Distribution	Absolut/ percentage	Impacts		
				Min	Most likely	Max
1st year tomato yield2 houses	Revenue	Normal	Absolut	15		16
Increase in yield ton	Revenue	Triangular	Percentage	1%	2%	3%
Sale Price/ton	Revenue	Triangular	Absolut	300	333	450
1st year unit cost/ton	Cost	Triangular	Percentage	35%	37%	45%
Increase in sales price	Revenue	Triangular	Percentage	0.5%	1%	1.5%
Increase in cost	Cost	Triangular	Percentage	0.5%	1%	1.5%

The study runs four greenhouse cucumber and tomato models tests and scenarios. The Stochastic Monte Carlo Simulation Models and Stochastic Efficiency with Respect to a Function (SERF) were used to evaluate and compare greenhouse cucumber traditional popular model (Basic Model) with other three cropping system models. The Stochastic Efficiency with Respect to a Function (SERF) performed to select the risk-efficient greenhouse cucumber and tomato cropping system in Oman.

A Latin hypercube sampling procedure with @Risk software from Palisade Corporation (7.5.0 Version) was used to calculate NPVs and statistic results with 10,000 number of iterations. In the simulation, values of parameters entering into the model were chosen from their respective probability distributions by Latin hypercube sampling technics and were combined according to functional relationships in the model to determine cropping system outcome and return i.e. NPV. The process was repeated a large number of times to give estimates of the output distributions of the performance measure which was expressed as cumulative distribution functions (CDFs) and Probability Density function PDF. The StopLight function analysis is also performed to develop probability of positive NPV and ranking graphs.

3. Results and Discussion

3.1 Monte Carlo Simulation Models Run Results

The study investigated the green house cropping system economic performance and sustainability and calculates NPV by using experimental data. Model (1) cropping system which grows tomato for one season and cucumber for two times (Tom1Cuc2) achieved the highest NPV i.e. RO 7 106 followed by (Tomato) model with RO 4 258 NPV, and (Cucu&Mix) model with RO 3 792. The net present value figure indicates and measures investment viability and economic performance of the cropping systems. The Stander Deviation SD for Model (1) is highest i.e. 24 348 and for Model (4) is lowest i.e. 17 754 and indicates low variation of cucumber outputs cropping system.

The Coefficient on of Variation of the probability distribution of NPVs was low for Model (1) and (3) and record 3.43% and 5.07% respectively and indicates that growing one tomato crop and two cucumber crops is most sustainable cropping systems with a risk efficient Net Present Value. The result also shows that Model (1) will get a positive NPV with 62% probability and Model (4) will get positive NPV with 58% probability. Table 3 below summarized the statistical results of four green-house cropping systems models.

Table 3. Green house cucumber and tomato cropping system statistics for NPVs for each model

Models	Model (1)	Model (2)	Model (3)	Model (4)
Cropping system	Tom1Cucu2	Cucu&Mix	Tomato	Cucumber
Mean RO	7 106	3 792	4 258	1 732
SD	24 348	20 737	21 599	17 754
CV	3.43%	5.47%	5.07%	10.25%
Skewness	-0.077	0.247	-0.027	-0.035
Kurtosis	-0.201	0.614	0.099	0.272
Min	(63 203)	(58 191)	(61 919)	(63 929)
Max	90 140	79 277	80 328	58 442
Range	153 343	137 468	142 247	122 371

The probability density function analysis for four cropping systems was estimated to consider a full range of possible outputs of cropping systems NPVs. It gives all possible outputs result and cover a range of (ARAC) level and shows Cucumber is most preferred model at upper risk aversion coefficient (URAC).

3.2 Cumulative Distribution Function

The Cumulative Distribution Function (CDF) chart for four green-house cucumber and tomato cropping systems is drown by using Simetar Program and displayed below in Figure 1. The CDF graph shows that the (Tom1Cuc2) cropping system lies more to the right than the other three alternatives cropping systems. This result suggests that growing one tomato rotation in August and two cucumbers rotation scenario (Tom1Cuc2) is preferred and risk aversion over the others scenarios because at each probability level of this scenario is associated with higher NPV. The cultivation and growing of three cucumber rotations (Cucumber) Scenarios lies further to the left than the others and it is the least preferred cropping system for the same reason. Although the CDF Graph procedure is superior to the other ranking methods it does not always result in an unambiguous ranking of the cropping system strategies.

When the CDF lines cross each other's there will be no clear ranking and the cropping systems need to be ranked based on expected utility principles such as stochastic dominance i.e. first and second degree stochastic dominance, certainty equivalents, stochastic efficiency with respect to a function (SERF), and risk premiums analysis.

3.3 Stochastic Dominance with Respect to a Function (SDRF)

The Stochastic Dominance with Respect to a Function (SDRF) analysis and certainty equivalent is performed under alternative utility for each cropping system and is used to rank greenhouses cropping systems scenarios. The preferred risky alternative is also calculated for the lower risk aversion coefficient (LRAC) and upper risk aversion coefficient (URAC) level. Table number 4 and 5 below shows and rank the risky alternative according to certain equivalent figures (CE) and shows model (Tom1Cuc2) cropping system is preferred for lower RACs level and considered to be the risk efficient cropping system followed by (Tomato) model. (Cucumber) model is preferred for upper RAC level as its price is more stable than tomato crop. Eihab F. et.al (2017), found that risk is reduced as greenhouse cucumber production increases due to the high level of tomato price volatility as the alternative to cucumber. The Stochastic Dominance with Respect to Function (SDRF) criteria is useful for ranking risky alternatives cropping system which CDFs are crossed.

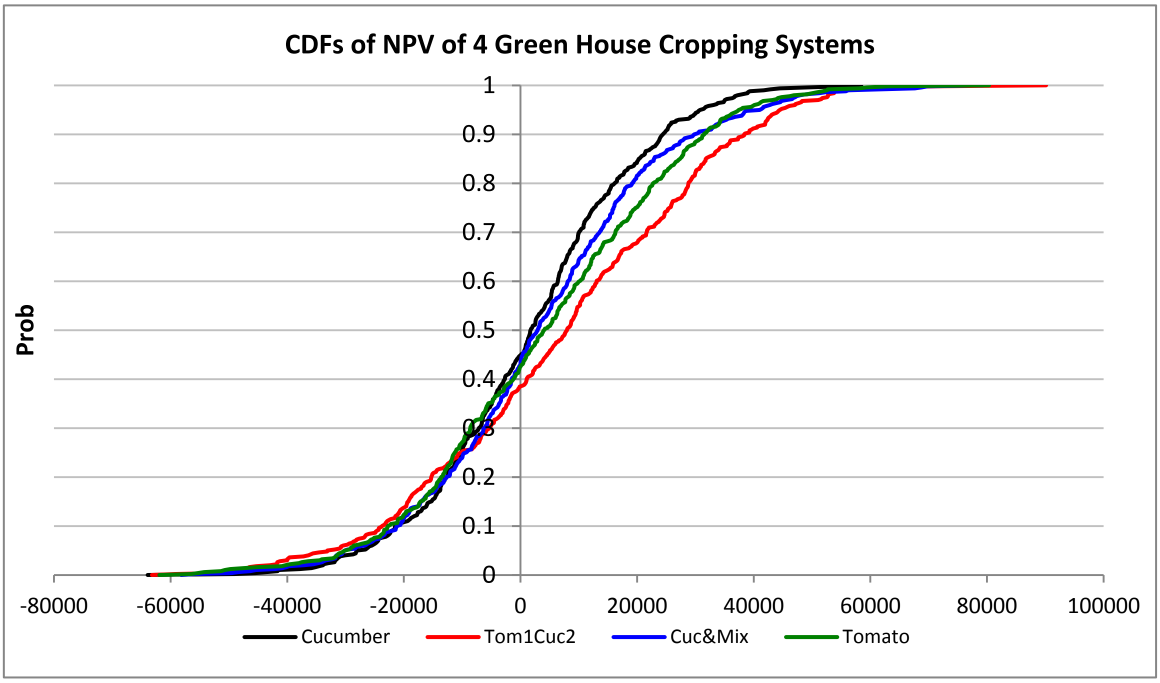

Figure 1. Cumulative Distribution Function of four green-house cucumber and tomato cropping systems

Table 4. Stochastic Dominance with Respect to a Function (SDRF) Analysis :

	Efficient Set Based on SDRF at			Efficient Set Based on SDRF at	
	Lower RAC	0.000		Upper RAC	0.0001
	Model	Level of Preference		Name	Level of Preference
1	Tom1Cuc2	Most Preferred	1	Cucumber	Most Preferred
2	Tomato	2nd Most Preferred	2	Cuc&Mix	2nd Most Preferred
3	Cuc&Mix	3rd Most Preferred	3	Tomato	3rd Most Preferred
4	Cucumber	Least Preferred	4	Tom1Cuc2	Least Preferred

The main limitation of Stochastic Dominance with Respect to a Function (SDRF) is that this technique it is a pairwise ranking of risky alternatives and not a simultaneous ranking of all alternatives. Another limitation is that if the LRAC and URAC are set to far apart the procedure will not result in a consistent ranking at both RACs level and only one alternative in the efficient set. However, the incentive in setting RACs for SDRF is to set them as far apart as possible to include a larger class of decision makers.

Table 5. Certainty Equivalents Under Alternative Utility Functions

	Model	CE Under Exponential Utility		CE Under Power Utility	
		Lower	Upper	Lower	Upper
1	Cucumber	1,731.67	-15,692.63	1,731.67	2,136.83
2	Tom1Cuc2	7,105.53	-20,194.13	7,105.53	25,315.57
3	Cuc&Mix	3,792.39	-16,502.69	3,792.39	3,645.92
4	Tomato	4,258.16	-19,270.94	4,258.16	22,501.94

3.4 The StopLight Function Analysis

The StopLight function analysis is performed by using Simetar program to develop probability ranking graphs. The StopLight graph summarizes the probabilities of NPV for each cropping system scenarios with lower and higher decision maker target. The study identified the NPV of less than zero NPVs which showed in red color. The graph also shows the probabilities that the risky alternatives exceed a maximum target of NPV of RO 15,000 and shows in green color. The probability of each scenario falling between the two targets is reported in the graph in a yellow color. StopLight analysis performed in this study and shows that green house cropping system (Tom1Cuc2) model got a positive NPV with a probability of 62% and (Tomato) model got a positive NPV with a probability of 58%. Figure (2) below displayed the probabilities of a risky alternative exceeding an upper target of RO 15,000 and falling below a lower target of (zero) NPV. This analysis is a powerful tool and help farmers and decision makers to rank risky alternatives and cropping systems according to their NPV profitability.

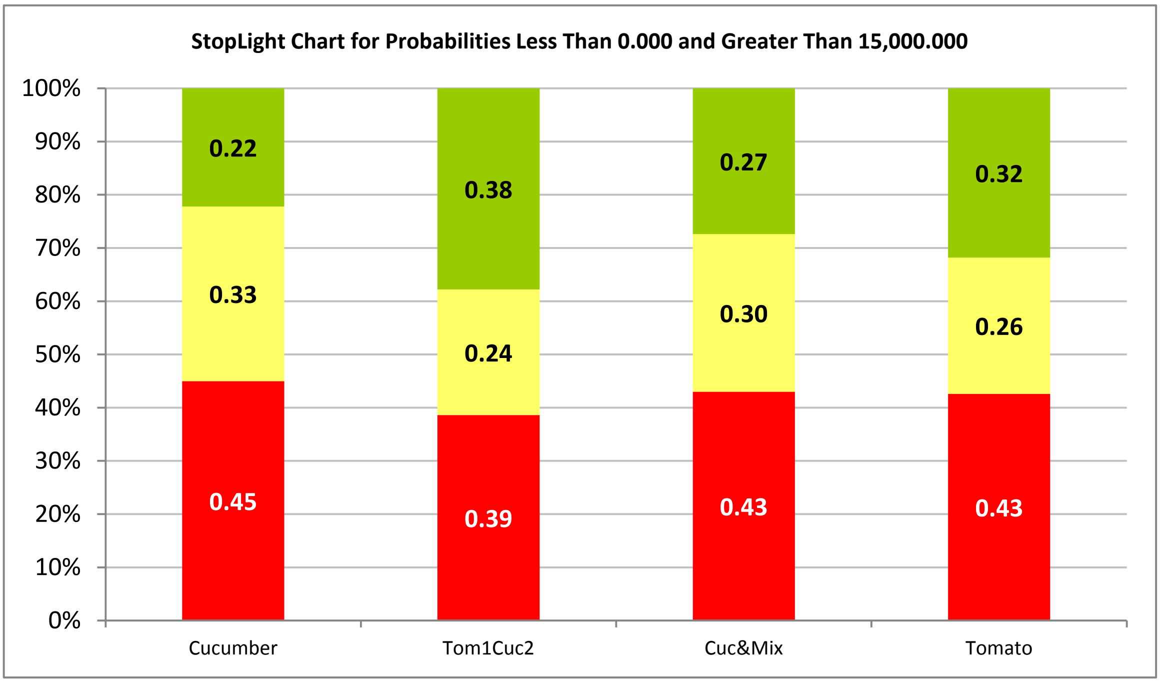

Figure 2. Cumulative Distribution Function of four green-house cucumber and tomato cropping systems

3.5 Stochastic Efficiency Respect to a Function (SERF)

The Stochastic Efficiency with Respect to a Function (SERF) analysis used a utility function with a range of risk aversion instead of evaluating CEs at the two extreme absolute risk aversion coefficients ARACs levels. The (SERF) analysis evaluates CEs for a range of ARACs and between the lower risk aversion coefficient (LRAC) and the upper risk aversion coefficient (URAC). The ARAC represents a decision maker's degree of risk aversion. The stochastic efficiency with respect to a function (SERF) ranking analysis is performed in this study to test green-house cropping systems risky efficient alternatives simultaneously.

The study performed Stochastic Efficiency with Respect to a Function (SERF) analysis between (0.000) ARAC which represent risk neutral decision makers and (0.0001) ARAC which represent extremely risk averse decision makers. The analysis ranked model (Tom1Cuc2) as the first and model (Tomato) as the second cropping system alternatives at risk neutral ARAC. Farmers at extremely risk averse ARAC degree, ranked model (Cucumber) as the first choice and model (Cuc&Mix) as the second cropping system alternative followed by model (Tomato) as shown in Figure (3) below.

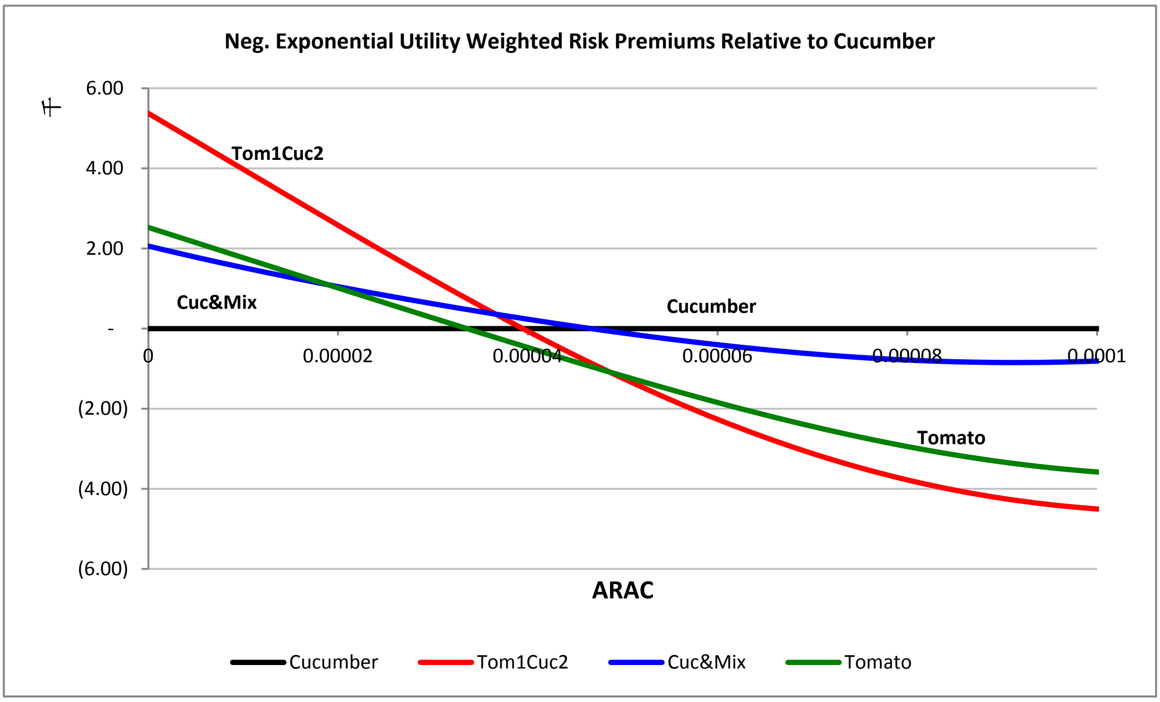

Figure 3. Cumulative Distribution Function of four green-house cucumber and tomato cropping systems

3.6 Probability Density Function (PDF) and Price Volatility Analysis

The historical data analysis of cucumber and tomato market prices showed a large price variation during the year due to crop cultivation seasonality. The gap between local tomato supply and demand increased during the summer and recover through imports from Jordan and other Gulf Cooperation Council Countries. While Jordan open field tomato grower and tomato import agency try to keep tomato at high prices, local greenhouse tomato grower try to benefit from October and November tomato high market price as shown in Figure 4 below. The investment in greenhouse technology will increase yield and reduce risk and offer tomato in lower compatible price. The investment in new greenhouse technology needs an appropriate cropping systems practices and mitigate price risk competition between local greenhouse tomato producer and tomato import agency during summer season.

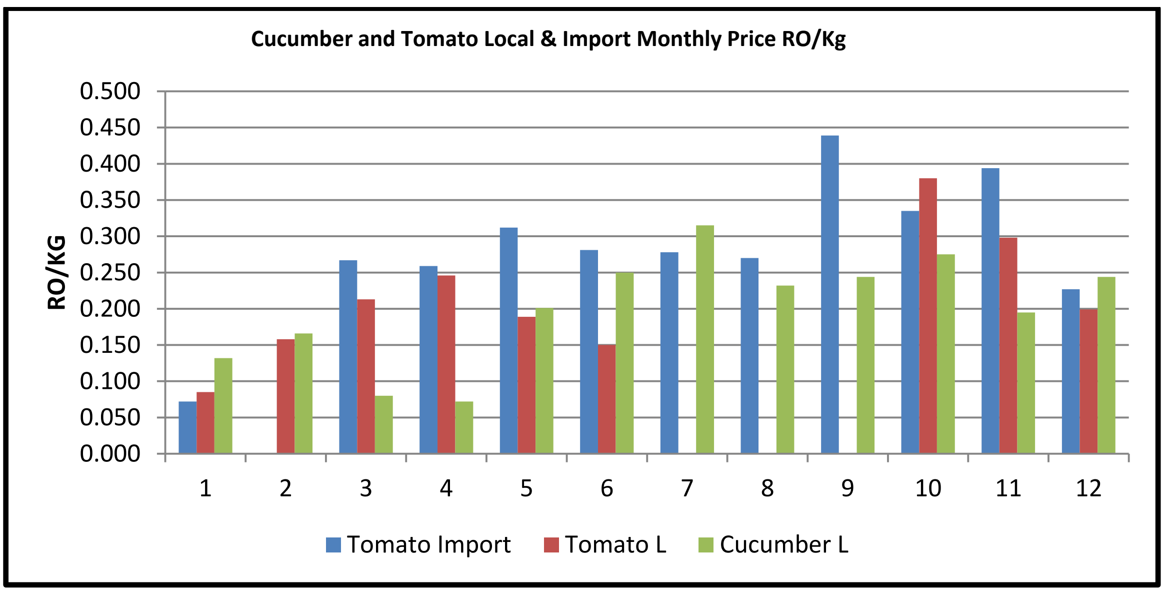

Figure 4. Cucumber and Tomato local and import monthly price RO/Kg

The NPV Probability Distribution Function analysis is performed and shows model (Tom1Cuc2) and model (Tomato) as negatively skewed distribution and have a great potential of downside risk management cropping system alternatives. The analysis shows that model (Cucumber) NPV Probability Distribution Function have a lower upside potential and downside risk and more appropriate and attractive to risk aversion decision makers as per Figure (5). The risk premium of this cropping systems scenario is high and account for R.O. 5 373 to justify not to switch from planting cucumber to grow more risky cropping system such as (Tom1Cuc2). Green-house cucumber growers are not willing to trade less profit model (Cucumber) with additional risky model (Tom1Cuc2).

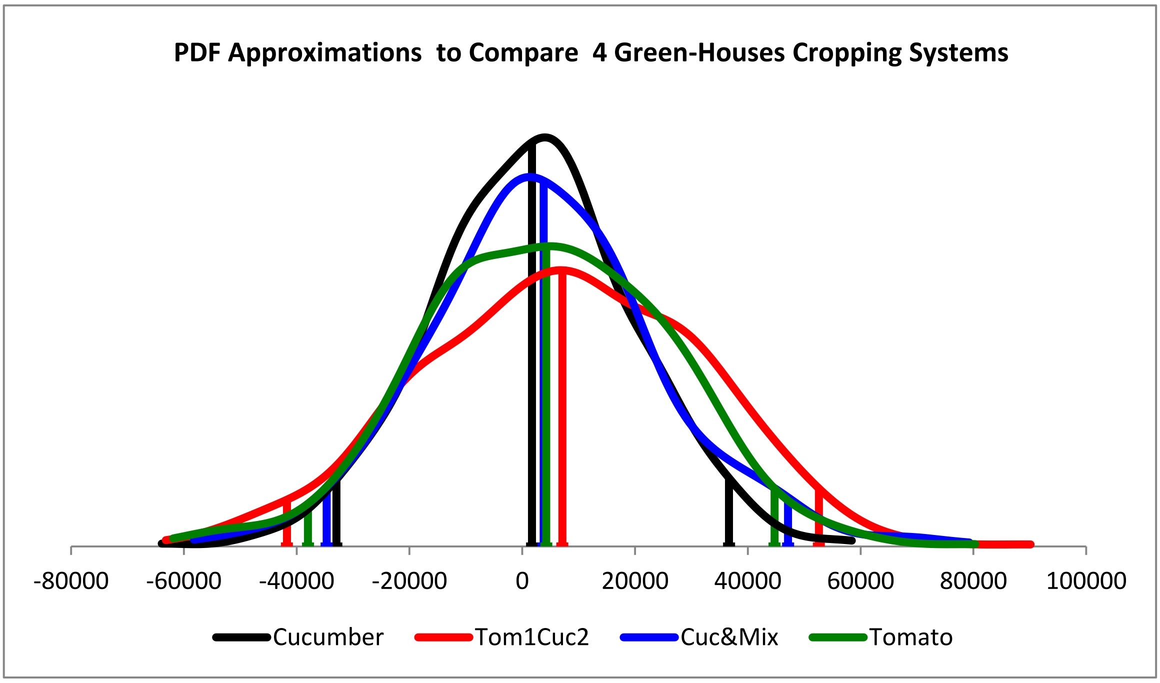

Figure 5. NPV Probability Density Function of four green-house cucumber and tomato cropping systems

4. Conclusion

The main task of this paper is to investigate green house cucumber and tomato cropping system sustainability and ranked them over the range of risk aversion levels. The study also evaluated the economic sustainability and optimum mix of cucumber and tomato crop growing in two green houses. Four stochastic simulation models were identified by using excremental and historical data from Plant Production Research Center at Director General of Agriculture and Livestock Research. The net present value of each greenhouse cucumber and tomato combination models are estimated and calculated. The risk of yield and price seasonal volatility for each cropping system incorporated in the models by identifying probability distribution for each uncertain variable.

The Stochastic Dominance with Respect to a Function (SDRF) analysis and certainty equivalent (CE) is performed under alternative utility function and deferent level of (ARAC). Model (Tom1Cuc2) cropping system is most preferred for lower RACs level and considered to be the risk efficient cropping system followed by (Tomato) model and (Cuc&Mix) model. (Cucumber) model is most preferred for upper RAC level due to yields and price stability compared to tomato crop.

Stochastic efficiency with respect to a function (SERF) and risk premiums analysis is performed for risk neutral decision makers and extremely risk aversion decision makers. Model (Tom1Cuc2) identified as the most risk efficient cropping system and got a positive NPV with 62% probability followed by tomato model cropping system with a positive NPV with probability of 58% for risk neutral farmers. Farmers at extremely risk averse ARAC degree, ranked model (Cucumber) as the first choice and model (Cuc&Mix) as the second cropping system alternative followed by model (Tomato) and model (Tom1Cuc2).

The study indicates tomato and cucumber producers are faced with different production and financial situations. Their risk preferences play an important role in determining their production decisions and Government supporting policy are required. The risk premium (RP) analysis shows that greenhouse tomato growers need to be paid up to RO 2 847 to keep growing tomato model instead of (Tom1Cuc2) cropping system and cucumber growers can sacrifices of RO 5 373 to justify not to switch from cucumber model to (Tom1Cuc2) cropping system model. The Government authority should subsidized farmers to construct additional new greenhouse to grow (Tom1Cuc2) cropping system and maximize their resource use efficiency, benefit from extended cropping season, protect their crops from adverse environmental conditions and increase food security.

Competing interests

The authors declares that he has no competing interest and declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Synthesis of Environmental Research Knowledge: The Case of Paraguayan Pantanal Tropical Wetlands

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Abstract

The Paraguayan Pantanal offers a valuable case of research regarding natural resource management in tropical wetlands. It is one of the world´s largest wetland of globally important ecological and cultural value that is threatened from environmental exploitations. Paradoxically, this area is rarely scientifically investigated. Therefore, in this paper, this case was chosen to identify literature indirectly related to the area and to highlight the dominant research trends and corresponding gaps. This research was conducted to cluster the available science-based research of Pantanal´s tropical wetlands in order to advocate for more environmental governance focus. Concepts used in the scientific literature of the Paraguayan Pantanal were extrapolated and summarized in category system. A cluster framework of 12 variables of community-based natural resource management (CBNRM) was classified into three main search-categories: community engagement and participatory approach (CEPA), natural resources management (NRM) and framework developed (FD). The frequency of different categories demonstrates the natural science´s perspectives dominate over human sciences and humanities. Most of the Paraguayan Pantanal has been studied with regard to its ecological, biological and physical properties. The development of research interest over time and the primary focus on ecological baseline conditions are related to its designation as a Ramsar Site, an UNESCO tentative World Heritage Site and the orientation of national policies towards either environmental protection or regional economic development. A substantial research gap was identified in the FD as studies tended to link their findings to human activities but disregarded the connection between governance variables, natural resource and environmental developments. It is suggested to expand the natural science´s perspective on Paraguay´s wetlands to account for economic, social and political aspects in order to develop a holistic and environmentally sustainable production of science in and about the area.

Keywords: community-based natural resource management, community-governance, literature analysis, Pantanal, Paraguay

1. Introduction

Science based-researches on environmental sustainability have generated numerous theories and principles about the use and management of natural resources worldwide. In the context of South American tropical wetlands, a literature analysis of the Paraguayan Pantanal was chosen because of its global relevance as Wetlands of International Importance (known also as Ramsar Site) and a potential candidate within UNESCO World Heritage List Nominations (WWF, 2016a, 2016b). With a surface area of over 230.000 square kilometres the Pantanal is the world´s largest freshwater wetland system (Swarts, 2000; WWF, 2016). This ecoregion is considered one of the most biodiverse places in the world and includes countries of Brazil, Bolivia and Paraguay. The Paraguayan Pantanal is 5 to 10% of the area and includes a great variety of flora and fauna. There are 650 different birds, 240 fish species, 60 species of amphibians and 100 reptiles, at least 120 mammal species and 1,700 plant species (Horton, 2010; WWF, 2016). Besides, ethnographic, cultural and historical principles and values are core factors of the richness of the Pantanal.

The expansion of agroindustry, extensive overgrazing, distribution and insecurity of land tenure, cattle ranching, unsustainable infrastructure development, weak enforcement of laws, as well as the lack of awareness of civil society are the main threats to biodiversity conservation and local communities (WWF, 2016). Yet most science-based literature disregards such topics, limiting the scenario for inclusive and comprehensive strategies for environmentally sustainable development. Governance studies are needed in the region, not only to complement existing research strands but also to create a science network and a platform for expert exchange. Because of the key role of community-based governance models to generate, describe and investigate frameworks for environmental sustainability, the political ecological approach is focused on the theory of community-based natural resource management (CBNRM). Despite the importance of concepts that describe key factors for using and managing natural resources (Ostrom, 1990; Sarker & Itoh, 2001; Quinn et al., 2007; Sattler et al., 2016), CBNRM theory contains characteristics that constitute a distinctive way of using and managing natural resources. In the last two decades, these characteristics have been the subject of a robust set of literature and have contributed to frameworks for sustainable development (Agrawal & Gibson, 1999; Armitage, 2005; Bradshaw, 2003; Leach, Mearns, & Scoones, 1999; Olsson, Folke, & Berkes, 2004).

Table 1 displays a concise matrix of 12 CBNRM organisational characteristics or variables developed and applied by Gruber that are used here as a set of essential and resumed variables in order to develop this study (Gruber 2010, 2018 n.d.). These 12 principles guided the study and support the legitimacy of the findings. Besides, what functions as the overall hypothesis is the basic assumption that local communities are considered the best resource managers for their closeness, greater knowledge and dependency of natural resources (Agrawal & Gibson, 1999). For this reason, CBNRM is crucial for science works of environmental sustainability. Hitherto, there is no available science-based literature on CBNRM in the study-area. Therefore, in order to fill this gap, literature was clustered from correlated research areas. These included natural sciences (both life and physical sciences), human sciences and humanities. By digging into selected literature searches to find the existence, role or prevalence of the 12 CBNRM variables, the objective was twofold: (a) to investigate the dominant research trends and (b) to identify the research gaps.

Table 1. The Organisational Principles of CBNRM

1.	Public Participation and Mobilisation
2.	Social Capital and Collaborative Partnerships
3.	Resources and Equity
4.	Communication and Information Dissemination
5.	Research and Information Development
6.	Devolution and Empowerment including Establishing Rules and Procedures
7.	Public Trust and Legitimacy
8.	Monitoring, Feedback, and Accountability
9.	Adaptive Leadership and Co-Management
10.	Participatory Decision-Making
11.	Enabling Environment: Optimal Pre or Early Conditions
12.	Conflict Resolution and Cooperation

Source: Gruber 2010

2. Methodology

A comparative analysis of applied concepts used in prior science-based literature of the Paraguayan Pantanal was applied. The first screening of science-based literature was done from the 1970s until early 2018. Eleven studies between 1995 and 2010 were identified as most significant for their focus on the area, the scientific relevance and the availability. These are listed in Annex 1. They were collected via online database, such as google scholars and science direct, as well as via national literature archives in both English and Spanish. A key words search included terms like: *Pantanal, Wetland conservation, Community-based governance, natural resource governance*. A cluster framework to classify the 12 CBNRM variables into three categories was designed based on concentration of key governance concepts. This is shown in Table 2. The search-categories are also shown in Figure 1.

First, a search into the literature on community engagement and participatory approach (CEPA) was carried out in order to learn about the impact of natural resource ́s degradation and exploitation on local communities. The scenario analysis depicted multidisciplinary case studies as well as the integration of stakeholder views and values. This requisite often leads to the development of integrated knowledge for alternative development models or policy-recommendations. The second category searched was on natural resource management (NRM), both renewable and non-renewable, of the Paraguayan Pantanal with regard to its ecosystem services it provides and its ecological, biological and physical properties. From this, the intrinsic link to the intensiveness of the exploitation of Pantanal ́s natural resources, was deduced. The human impact over the Pantanal was a key element of this search, as well as the related health of the resources found in the area. Thirdly, the expected outcomes of the analysed literature searches were to be the frameworks developed (FD), if any. Systems of legal, economic, policy, social, and environmental frameworks could help scaling up proactive solutions for CBNRM models. In the context of governance, it was hypothesized that literature searches would show the way to maintain and sustainably manage both landscapes and livelihoods of local communities.

Table 2. Search-categories: Gruber ́s 12 principles of CBNRM

		Categories
1.	Public Participation and Mobilization	CEPA
2.	Social Capital and Collaborative Partnerships	CEPA
3.	Resources and Equity	NRM
4.	Communication and Information Dissemination	FD
5.	Research and Information Development	FD
6.	Devolution and Empowerment including Establishing Rules and Procedures	CEPA
7.	Public Trust and Legitimacy	CEPA
8.	Monitoring, Feedback, and Accountability	FD
9.	Adaptive Leadership and Co-Management	NRM
10.	Participatory Decision-Making	CEPA
11.	Enabling Environment: Optimal Pre or Early Conditions	CEPA
12.	Conflict Resolution and Cooperation	NRM

Source: Author ́s own elaboration

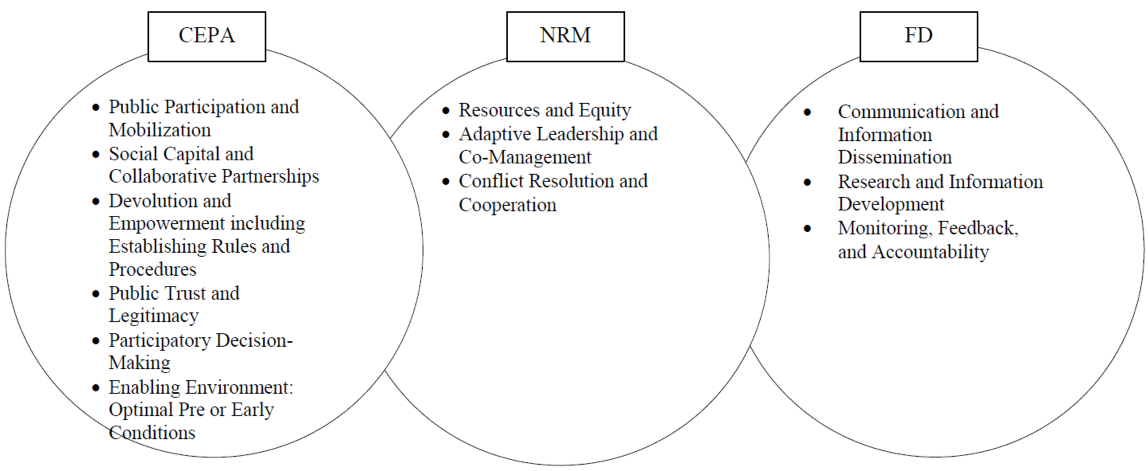

Figure 1. Concentration of key governance concepts

Source: Author ́s own elaboration

3. Results and Discussion

The results offer the list of issues of analysis, the research trends and the frame of the three categories applied in this study: CEPA, NRM and FD, as shown in Table 3. Five out of the eleven researches prioritized on natural sciences (both life and physical sciences), that resulted to be the major research trend. The main gaps were found in the production of frameworks (FD). The following discussion is divided in three main blocks according to the category distribution applied in this study: CEPA, NRM and FD.

Table 3. Category distribution results

Authors	Year	Issue of analysis	Research Trend	CEPA	NRM	FD
Blaser, M.	2009	Community-Indigenous	Human Sciences Humanities	√	√	-
Blaser, M.	2010	Community-Indigenous	Human Sciences Humanities	√	-	√
Danilo A. et al.	2004	Biodiversity-Environment	Natural Sciences	-	√	√
DGEEC	2004	Community-Indigenous	Humanities	-	√	√
IDEA	2002	Economy-Environment	Natural Sciences	√	√	-
Hetherington, K.	2009	Economy-Environment	Humanities	-	√	-
Horton Emily Y.	2010	Environment	Natural Sciences Human Sciences	-	√	-
Susnik, B.	1995	Community-Indigenous	Human Sciences	√	-	-
Swarts Frederick A. *Selected Discourses*	2000	Economy-Environment	Natural Sciences	√	√	-
Swarts Frederick A.	2000	Economy-Environment	Natural Sciences	-	√	-
Zanardini, J., Biedermann, W.	2001	Community-Indigenous	Human Sciences Humanities	-	-	√

Source: Author ́s own elaboration

Table 4 lists researches and studies where relevant contribution to CEPA was found. It was observed that recurrent and common elements of the studies included the role of public participation and mobilization. The four selected studies described and included multi-stakeholder approaches, as well as community and identity patterns found in the Pantanal. These form key aspects of effective local and inclusive participation, which can empower community-members, raise knowledge levels and build or increase public trust, confidence and legitimization (Gruber, 2010). Hints of social capital and collaborative partnerships were found in the literature-description of networks. Examples of community-relationships can be depicted in the study and description of the Yshiro (Chamacoco) indigenous community living in study-area. Their practices and visions of life and the world (called the *yrmo*) are connected to the Yshiro myth-history. For them, as stated by Blaser (2010, 33) “the backbone of reality is constituted by relations in a permanent state of flux”. From this, additional hypothesis and suggestions for further researches might emerge. For instance, “how to include indigenous Cosmo-visions into projects of environmental sustainability?” or “what formal and informal social norms exist to increase relationships and networking in the area of study?” Stakeholders’ mutual understanding and agreements at multi-level scales are presented in the CEPA literature as an important contribution to long-term sustainable development strategies.

In addition, two out of four studies also described and analysed the role of multilevel governance and cross-scale coordination for NRM. Alongside the focus of rural and indigenous communities, these science-based works promoted public and community initiatives, such as the creation of side-projects on sustainable production and marketing of honey and craft products, among others (IDEA, 2002). In the socio-institutional context of the Paraguayan Pantanal, these researches offer notions of authority devolution and empowerment as they claim for decentralization of power and decision making. Multiple layers of governments and initiatives related to the role of decision making, monitoring, conflict resolution and governance are often mentioned to advocate for the creation of clear rules that can help empowering local communities. Cases of stakeholders ́sharing power and responsibilities are presented as forms of devolution of authority and responsibility. In the construction on sustainable development, the inclusion and representation of all groups (including the most marginalised) is very important in order to create or modify formal and informal rules and norms (Gruber, 2010). The socio-economic approach of the selected CEPA literature presents a first analysis of the situation and the subsequent development of solutions designed by multi-stakeholder initiatives (Swarts, 2000; IDEA, 2002). Likewise, social and community-based strategies are grounded in the identification of leaders, fostering the formation of groups capable of representing the community and supporting its transformation within formal institutions (e.g. municipalities) and informal ones (e.g. neighbour committees) (IDEA, 2002).

Community leadership, especially among indigenous communities, is observed as a key factor to stronger implement authority devolution and decentralization. Likewise, the integration of ideas and projects can strengthen community relations at all levels. This approach generates inclusiveness and it can be used to problem solving and decision making as it increases public trust and legitimacy (Suskin, 1995; Swarts, 2000; IDEA, 2002). The CEPA literature also stresses the need to establish frameworks for participatory decision-making that includes the holistic vision to anticipating environmental, economic and social outcomes of socio-economic and ecological challenges (Suskin, 1995; Swarts, 2000; IDEA, 2002; Blaser, 2010). Based on this participatory decision-making framework, community-identities and a shared sense of belonging build the foundation to enabling environment for sustainable development strategies and actions, as well as people ́s involvement (Blaser, 2009, 2010).

Table 4. CEPA

Authors	Year	Issue of analysis	Research Trend	CEPA	NRM	FD
Blaser, M.	2009	Community-Indigenous	Human Sciences Humanities	√	√	-
Blaser, M.	2010	Community-Indigenous	Human Sciences Humanities	√	-	√
IDEA	2002	Economy-Environment	Natural Sciences	√	√	-
Susnik, B.	1995	Community-Indigenous	Human Sciences	√	-	-
Swarts Frederick A. *Selected Discourses*	2000	Economy-Environment	Natural Sciences	√	√	-

Source: Author ́s own elaboration

Table 5 displays the corresponding texts of interest on NRM. A primary focus of this literature regards social welfare of local communities as it is frequently connected to the role of community values and beliefs (Swarts, 2000; IDEA, 2002; Danilo et al., 2004; Blaser, 2009). In the context of conservation, the initiatives of local community that are compared reflect the importance of multiculturalism in relation to natural resources and the environment. According to Blaser (2009, 15), "having a variety of tools (i.e. different cultures) with which conservation can be realized, whether one uses one or another, is indistinct as long as the environment is affected in the same way". As a result, the take from environmental sustainability is reflected in the inclusion of local knowledge into public and private initiatives. Resources and equity are taken into account in order to describe past and present connections between local economies and conservation (Danilo et al., 2004; Blaser, 2009). Basic needs and fair distribution of local benefits (i.e. compensation for protecting natural resources or regulations on payments for environmental services) are presented as recommendations for the implementation of regulations and sanctions that help the equity of use and management of natural resources (IDEA, 2002; Horton, 2010).

To this regard, what is often considered a central issue is the impact of historical land distribution in the area. For instance, over the past 20 years the role of foreign speculation and dominant economic-political class over land use and distribution in the Pantanal has led to low international prices and unfavourable purchasing conditions (Guereña & Rojas, 2016). Furthermore, agrarian reforms implemented between 1954 and 2003 shaped the land propriety rights in Paraguay. The effects on the Pantanal resulted in hundreds of land concessions, comprising a total area of 4 million ha part of which were confiscated from local and indigenous ancestral territories. Paraguay's indigenous populations and other impoverished minorities are still harbouring the fear of continuation of the land reform as they work out a legal rights-based mechanism that might replace it (Hetherington, 2009, 236). Hence, linkages between territorialism, identities and the past and present system of land use rights define an important research narrative of NRM. The role of multi-stakeholder inclusion and engagement (i.e. capacity building on conservation strategies, trainings and better management systems) is partly addressed in the creation and implementation of projects for environmental sustainability. This approach is taken to be the NRM element of adaptive leadership and co-management because of the importance given to social-ecological organisations, both local and international, to design programs on adaptive capacity (Gruber, 2010). From this perspective, the resilience of Pantanal ́s biological diversity has been studied in parallel to the evolution and development of cultural diversities and identities (Swarts, 2000; Blaser, 2009; Horton, 2010).

On a similar note, conflict resolution and cooperation are two connected and recurrent elements of the NRM literature. Although the broad understanding of these two concepts remains merely conceptual and no clear examples can be found, data on community-behaviour can possibly serve as the basis for further development in this regard. For instance, socioeconomic, ethnographic and demographic characteristics of rural and indigenous communities of the Pantanal exist and are widely available (DGEEC, 2002). In addition, NRM strategies should include the analysis of accountability of public and private entities. It is widely agreed that the recognition of the central role of institutions outside rural and indigenous communities is a key learning notion of conflict management strategies (Gruber, 2010). However, as for the case described in the Paraguayan Pantanal, the lack of effective and multi-stakeholder inclusive decision making processes tends to prevent the promotion of dialogue and increases factionalism (Hetherington, 2009; Blaser, 2009).

Table 5. NRM

Authors	Year	Issue of analysis	Research Trend	CEPA	NRM	FD
Blaser, M.	2009	Community-Indigenous	Human Sciences Humanities	√	√	-
Danilo A. et al.	2004	Biodiversity-Environment	Natural Sciences	-	√	√
DGEEC	2004	Community-Indigenous	Humanities	-	√	√
IDEA	2002	Economy-Environment	Natural Sciences	√	√	-
Hetherington, K.	2009	Economy-Environment	Humanities	-	√	-
Horton Emily Y.	2010	Environment	Natural Sciences Human Sciences	-	√	-
Swarts Frederick A.	2000	Economy-Environment	Natural Sciences	√	√	-

Source: Author ́s own elaboration

Table 6 presents the set of literature searches that, in different ways and forms, were able to produce frameworks developed (FD) from science-based methods. The development of systems of policy, social, and environmental schemes were found to be an important contribution to the analysis of the Paraguayan Pantanal, scaling up proactive solutions for CBNRM. The elaboration of atlas, maps, data systematization and statistical methods represent the kind of FD found in the literature. More specifically, we found valuable information about indigenous communities living in the study area. There are ten linguistic trunks, each of them divided in the corresponding forty ethnic groups and exact location within departments and districts of Argentina, Bolivia, Brazil and Paraguay (Zanardini & Biedermann, 2001; DGEEC, 2004). Annex 2 shows the different linguistic families and how they are related to their own corresponding ethnic groups and the location according to the country. This systematization, which prioritizes the ethnic criterion over the geographical one, takes into consideration the way of traditional land use and management of indigenous peoples. Hence, it has a statistical scope rather than a legal one and it intends to provide basic information about each of the indigenous settlements that exist in the country.

As the initial research approach, the role of such systems could strengthen the communication and information dissemination of present and future strategies for environmental sustainability. The role played by transparency and openness of information encourages dialogue between experts and non-experts in multiple approaches and forms (i.e. workshops, fundraising opportunities, seminars, training and capacity building etc.). This ultimately helps supporting decision making, learning and change (Gruber, 2010). In parallel with the basics of transparency and openness, the ones on research and information development were described in the FD literature. For instance, the diversification of information topics only regarded discourses of anthropological, ethnographic and biophysical relevance (Zanardini & Biedermann, 2001; DGEEC, 2004; Danilo et al., 2004; Blaser, 2010). Nonetheless, this is considered as a valid starting point for the production of accessible scientific researches that can influence formal and informal norms to be based upon systematic body of information (Gruber, 2010).

The key element of FD that wasn ́t found in the literature analysis is one on monitoring, feedback and accountability of science-based and environmental projects. This possibly may be due to the existing low level of openness, transparency, monitoring, mutual accountability, collaboration, and power sharing between stakeholders and partners in the area. Therefore, this factor isn ́t performed in the selected literature, representing a research gap. To fill this gap, it is recommended that systems of reviewing the performance (i.e. monitoring and evaluation methods) should be promoted to those who make the decision and describe them (Gruber, 2010). Systematic processes of collecting, analysing and using information are useful in tracking the progress of programs (i.e. on environmental sustainability) and science-based researches.

Table 6. FD

Authors	Year	Issue of analysis	Research Trend	CEPA	NRM	FD
Blaser, M.	2010	Community-Indigenous	Human Sciences Humanities	√	-	√
Danilo A. et al.	2004	Biodiversity-Environment	Natural Sciences	-	√	√
DGEEC	2004	Community-Indigenous	Humanities	-	√	√
Zanardini, J., Biedermann, W.	2001	Community-Indigenous	Human Sciences Humanities	-	-	√

Source: Author ́s own elaboration

4. Conclusion

The conclusion of this synthesis of environmental research knowledge of the Paraguayan Pantanal tropical wetlands lists the dominant research trends and corresponding gaps:

- The branch of natural sciences (both life and physical sciences) was revealed as the main science-based research trend.
- The main gaps were found in the production of frameworks (FD).

Both findings stress the importance to increase and diversify, from both a qualitative and a quantitative perspective, science-based research in the study-area. The reason for it lies beyond the biological and cultural diversity and importance of the site. It has the significance to create, develop, improve and re-shape projects and programs on governance and sustainable development. In this paper, by developing and applying a cluster framework about the concentration of key governance concepts we tried to promote and suggest the inclusion of Gruber ́s 12 principles for effective and successful CBNRM. In the study of environmental governance, we believe this tool and method can be transferred to other contexts where field-science is scarce. The importance of diversifying science-based researches offers a more holistic perspective where communities are included (CEPA), the use and management of natural resources is more effective (NRM) and a stronger legacy for future studies and interventions is developed (FD).

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Annex

ANNEX 1. Compared literature

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Source: Author´s own elaboration

ANNEX 2. Linguistic families

Abipón, Argentina, historic group
Angaite (Angate), northwestern Paraguay
Ayoreo (Morotoco, Moro, Zamuco), Bolivia and Paraguay
Chamacoco (Zamuko), Paraguay
Chané, Argentina and Bolivia
Chiquitano (Chiquito, Tarapecosi), eastern Bolivia
Chorote (Choroti), Iyojwa'ja Chorote, Manjuy), Argentina, Bolivia, and Paraguay
Guana (Kaskihá), Paraguay

Guaraní, Argentina, Bolivia, Brazil, and Paraguay
Bolivian Guarani
Chiriguano, Bolivia
Guarayo (East Bolivian Guarani)
Chiripá (Tsiripá, Ava), Bolivia
Pai Tavytera (Pai, Montese, Ava), Bolivia
Tapieté (Guaraní Ñandéva, Yanaigua),eastern Bolivia
Yuqui (Bia), Bolivia
Guaycuru peoples, Argentina, Bolivia, Brazil, and Paraguay
Mbayá (Caduveo), historic
Kadiweu, Brazil
Mocoví (Mocobí), Argentina
Pilagá (Pilage Toba)
Toba (Qom, Frentones), Argentina, Bolivia, and Paraguay
Kaiwá, Argentina and Brazil
Lengua people (Enxet), Paraguay
North Lengua (Eenthlit, Enlhet, Maskoy), Paraguay
South Lengua, Paraguay
Lulé (Pelé, Tonocoté), Argentina
Maká (Towolhi), Paraguay
Nivaclé (Ashlushlay, Chulupí, Chulupe, Guentusé), Argentina and Paraguay
Sanapaná (Quiativis), Paraguay
Vilela, Argentina
Wichí (Mataco), Argentina and Bolivia

Source: Zanardini and Biedermann 2001

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