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# SUSTAINABLE AGRICULTURE RESEARCH

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# Effect of Different Mulching Materials on the Growth and Yield of Green Bean (*Phaseolus vulgaris* L.) in Nfonta the Western Highlands of Cameroon

Chi Christopher Tamu[1], Tatah Eugene Lendzemo[2] & Ferdinard Vugheh[2]

[1] Department of Agricultural Engineering, College of Technology, The University Of Bamenda, P.O.Box 39, Bamenda NWR, Cameroon

[2] Department of Crop Production Technology, College of Technology, The University of Bamenda, P.O.Box 39, Bamenda NWR, Cameroon

Correspondence: Tatah Eugene Lendzemo, Department of Crop Production Technology, College of Technology, The University of Bamenda, P.O.Box 39, Bamenda NWR, Cameroon.

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**Abstract**

Mulching is a common technique used across the world by farmers to especially conserve soil moisture in vegetable production but farmers in Nfonta and the entire western highlands of Cameroon have not practiced the uses of mulching. In this experiment, a randomized complete block designe with 5 treatments and 3 replications was set up to study the effect of elephant grass, saw dust and white plastic as mulching materials on the growth and yield of green bean (*Phaseolusvulgaris* L.) in Nfonta. Data was collected on plant height; number of leaves per plants, leaf area index and yield of mature pods per plant. Data was analyzed using one way ANOVA from stat graphics centurion xv and means were separation using the Fischer least significant difference (LSD) test at 95% confidence interval. Results showed white plastic, and elephant grass mulches to have significantly ($P<0.05$) affected the growth and yield of green bean. White plastic mulched plants exhibited the highest growth parameters and subsequently produced the highest yield of 12.00 mature pods per plant with average pod length of 11.97cm and average mature pod weight of 4.22g compared to the other mulch treatments. There were no significant ($P>0.05$) differences in yield of green bean grown with no mulch (control), saw dust mulch and corn stalk mulch. Corn stalk mulched bean plants produced the lowest yield of 7.83 mature pods per plant with average pod length of 9.17cm and an average mature pod weight of 2.83 which was not much different from that produced by the control. These results call for more investigations to the potentials of white plastic as best mulch material for achieving optimum green beans yield in Nfonta and the entire western highlands of Cameroon.

**Keywords:** mulch, green beans, white plastic, saw dust, corn stalk, elephant grass

## 1. Introduction

Green bean (Phaseolus *vulgaris* L.) plant also known as Snap beans, bush beans or string beans is an annual legume grown for its tender green pods. Due to their richness in protein, low caloric, no fat, zero sodium and low cholesterol contents, they count among important vegetable crops in the world (FAO, 2020; Freytag and Debouck, 2002; Porch et al., 2013) including Cameroon. Based on FAOSTAT, Cameroon green beans production has increased steadily from the year 2000 through to the year 2019. The increase has been observed in total area harvested as well as in the per hectare yield. The statistics shows that Cameroon produced about 3.6 tons of green bean per hectare and this experienced a steady increase throughout to 2019 with about 6.3tons per hectare. The average productivity calculated over the 20years (2000 - 2019) is about 5tons per hectare. This is very low as compared to the world average production of 13.2 t $ha^{-1}$ as reported by FAO, 2012.

Their nutritional value is further enhanced by their richness in beta-carotene, fiber, potassium, calcium, and phosphorus. In the Grass fields of Cameroon Snap bean is commonly mixed with minced meat, carrots, bell pepper and white rice to make a popular dish called gelof rice which is highly cherish in many ceremonial events. Besides food security, research has shown that adoption of green beans as an alternative crop can boost the family income of poor smallholder farmers compared to other conventional vegetables (Beshir, 2015, CIAT, 2006; Food and Agriculture Organization, 2011, Ramirez et al., 2011, Kalima, 2013).

The shallow rooting depth of bean plants poses problems of especially post emergence cultivation for weed management (Widuri et al., 2017).Since one of the benefits of mulching is weed suppression, mulching green beans can help reduce labour requirement on weed management as well as avoid problems of damaging the shallow roots especially during the first weeding. Green beans use about the same amount of water on a weekly basis as other vegetables, but their relatively shallow rooting depth coupled with short growing period expose them high to risk of yield loss if dry spells occur as is the case during the dry season in Nfonta and the entire western highlands of Cameroon.

Climatically snap beans are warm season crops and hence very sensitive to frost. Having optimum temperature for plant growth set at $29^0$C, temperature above $32^0$C is devastating to yield as this cause blossoms to drop and ovules to abort while surviving pods become fibrous as well malformed. The dry season do not pose a problem of temperature in Nfonta and the entire western highlands of Cameroon, but the dry harmattan winds and high solar radiation increases the evapotranspiration across farms in the whole region. This increases soil water loses such that the farmer's main problem is how to conserve soil moisture.

Although green beans can perform well in many kinds of soils, best yields are obtained in well-drained, clay loam soil, rich in organic matter and with pH ranging from5.5 to 7.5.Snap beans require a constant supply of moisture during the growing season and water deficiency or stress, especially during the blossom to pod set period, has been demonstrated to cause blossoms and pods drop, resulting in a poor-quality crop and reduced yields. Also, excess water at any time during growth has been shown to increase the plant's susceptibility to root rot infection, which also can reduce yields. Soil water management is therefore very critical to achieving commercially acceptable high yields in green beans cultivation. This goes hand in hand with managing soil fertility, pest pressure and the quality of seeds as well as adaptability of variety used.

Cameroons western highlands are a tropical highland with two distinct dry and rainy seasons (Molua and Lambi, 2007) which makes it vulnerable to water deficit especially in the dry season when green vegetables becomes a rarity. Farmers resort to diverse methods to satisfy the green vegetable demands of the population. Common methods used by farmers here include the use of manual watering cans, fallowing and the lawless but dangerous exploitation of the few vital wetlandswhich has intensified recently due to demographic pressure and the increasing demand for year round market gardening (Nyambod, 2010; Tita et al., 2011). Mulching is apparently a highly neglected method among farmers in Nfontadespite abundance availability of natural grasses like elephant grass, Thatch grass etcthat could serve as cheap organic mulch materials. This may be as a result of lack of knowledge by farmers or lack of explicit government policies that promote soil and water management as an agricultural adaptation practice (Unique-Kulima/GIZ, 2020).The objective of this study was to select a cheap but effective mulching material among elephant grass, saw dust, white plastic and corn stalk which are very readily available in Nfonta and the entire western highlands of Cameroon.

## 2. Material and Methods

### *2.1 Description of Research Site*

This research was carried out at Nfonta seed multiplication and experimentation farm of the Cameroon government Institute of Agriculture for development known by its French acronym as IRAD. It is located in the Western Highlands Agro- ecological Zone covering the North West and West Administrative regions of Cameroon. Nfonta is a generally level location at latitude $6^o$ north of the Equator and about 1250m above sea level and with clay loam soil which favours the cultivation of crops such as maize, legumes, vegetables and Irish potatoes.

Nfonta is characterized mainly by two seasons, the rainy and dry season in which the raining season begins in mid-march and ends in mid-November while the dry season covers the rest of the year. The temperatures are usually slightly cold with an average minimum and maximum of 18 and $28^o$C respectively. It has an average humidity of 75% which drops to 52% in the rainy and dry season. It has an annual rainfall of 2230mm/annum uniformly distributed from mid-march to mid-November with the highest peak of 380mm occurring in the month of July and August.

### *2.2 Experimental Materials and Experimental Design*

Quality green beans seeds and experimental plot were obtained from the station manager. The variety used was a dwarf variety called Cora and imported from a French Company called Technisem. The plot was cleared using a manual machete and hoed and ridged using a hand hoe commonly used by local farmers. Appropriate fine Seed beds were prepared using a manual farm rake. The entire prepared land was divided into three blocks with each block measuring 7x3m and a 1m distance between blocks. This gave a total experimental area of $117m^2$. Each block was further divided into five plots with one treatment per plot. Each plot measures 3x1m and a 0.5m distance between plots. The final experimental design was a randomized complete block design (RCBD) with five treatments and three replications giving a total of 15 plots in the experimental area. A border line of 1m was allowed all-round the experimental site and planted with maize.

### *2.3 Acquisition, Preparation and Application of Treatments (Mulches)*

#### 2.3.1 Acquisition, Preparation and Application of Elephant Grass Mulch

Elephant grass was harvested from IRAD's experimental farm at Nfonta using a machete. During harvesting, only the leaves were selected for use. The grass was then chopped into small sizes to ensure uniform application. It was then spread over the necessary plot making sure that it was at least 1cm thick.

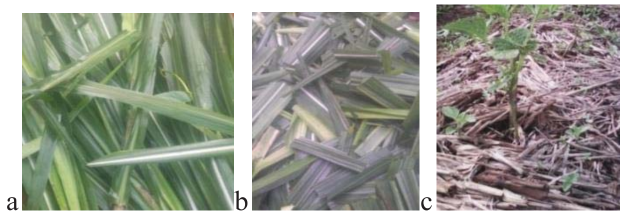


Figure 1. Elephant grass mulch; a) harvested mulch, b) prepared mulch ready for application and c) mulch on ridges with crop

#### 2.3.2 Acquisition, Preparation and Application of Saw Dust Mulch

Saw dust was obtained from local carpenters at Nfonta and an application of 2kg/m$^2$was done. This gave a total of 6kg of saw dust per plot. Before applying the saw dust, the plot was pecked and saw dust was not applied to the spots where the seeds were to be planted.

Figure 2. Right saw dust before application; left saw dust Mulched with growing green beans crop

#### 2.3.3 Acquisition, Preparation and Application of White Plastic Mulch

White plastic films measuring 1x0.5m were bought from Nfonta farmers market and washed with sterile solution. A razor blade was used to open holes on the plastic in the spots where seeds were planted. This was done in order to prevent the plastic from impeding the shooting of the seeds once they germinated.

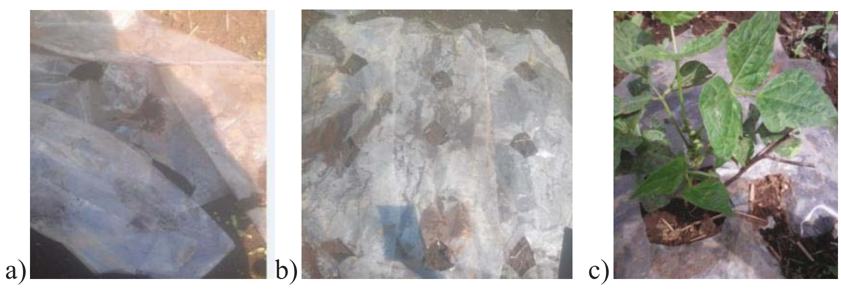


Figure 3. White plastic mulch a) before application b) applied on the ridges and c) with crop growing

2.3.4 Acquisition, Preparation and Application of Corn Stalks

Corn stalks were harvested from IRAD's experimental farm in Nfonta from maize plants that were grown in the previous season. The corn stalks were chopped into smaller sizes using a machete. Chopped corn stalks were put inside a bag and 18kg were weighed out using a scale balance. Six (6) kg was applied to each plot. The chopped corn stalks were then uniformly arranged on the surface of the various plots.

a b

Figure 4. Prepared corn stalk mulch on ridges and b mulch with crop

The resulting experimental treatments were as follows;

- Treatment 1 ($T_1$)= Elephant grass at a thickness of 1m on each plot gotten from IRAD Farm
- Treatment 2 ($T_2$)= saw dust at 2kg per $m^2$ gotten from local carpenters
- Treatment 3 ($T_3$)= white plastic measuring 1x0.5m per plot/ gotten from Nfonta farmers market
- Treatment 4 ($T_4$)= corn stalks at 6kg/plot gotten from IRAD farm
- Treatment 5 ($T_5$)= no mulch(control)

They were all applied on the same day as the seeds were planted. The application of saw dust, corn stalk and elephant grass mulches were done at the stations recommended rate of 9050-13,450kg per hectare. After applying the mulches on the various plots, the seeds were planted at the stations recommended planting distance of 30x25cm.

2.3.5 Miscellaneous Management Activities

Weed Pest and disease control were planned for all plots to ensure constancy of site factors. Only treatment 5(control) had a significant amount of weeds worthy of controlling. Stem and root soft rot, aphids, and leafhoppers were observed in all treatments and controlled using a fungi champ and broad spectrum insecticide called PYRIGA 480EC respectively.

**3. Data Collection and Analysis**

In a bit to evaluate the effects of mulching material on the growth and yield of green beans, bean plants were cultivated using five different mulch materials- elephant grass, corn stalks, saw dust and white plastic mulch as treatments. A control with no mulch was also used. Data on Plant height; number of leaves per plants, leaf area index and yield of mature pods per plant were collected from the second week starting after planting (2WAP) and continued at two weeks interval. The last was during the eight weeks after planting (8WAP). All the measurements for these parameters were taken from five plants selected randomly from the middle of each plot from each treatment. The value of each parameter per treatment was calculated by using the average from the five randomly selected plants.

*3.1 Data Collection on Plant Height*

Plant height which was considered as the distance from base of the stem to the tip of the plant was measured using a 30cm ruler.

*3.2 Data Collection on Number of Leaves per Plant*

Numbers of leaves per plant were taken at 50% flowering by counting all the healthy leaves from the base to the tip of five randomly selected bean plants from each plot and treatment.

*3.3 Data Collection on Leaf Area and Leaf Area Index*

A Healthy leaf was selected from each of the five bean plant and the length and width were measured using a 30cm ruler. The measurements were used to calculate the leaf area (LA) according to Edje and Ossom, 2009in as follows:

Leaf area = leaf length x width of terminal leaflet x 2.88(correction factor)

Using the LA results, the leaf area Indices (LAI) were calculated and expressed in Centimeter squares (cm2) using the following formula

Leaf area index (LAI) = [Leaf area ($m^2$)/Ground cover (m2)]

*3.4 Data Collection on Yield of Mature Pods per Plant*

Yield and length of mature pods per plant were obtained from harvesting at 8WAP and 10WAP. From each harvest five most succulent pods from each treatment were counted out and weighed using an electronic scale balance. Lengths of the same five pods were taken using a 30cm ruler. The average of the values gave the weight and length of the pods from each treatment.


Figure 5. Selected and weighed succulent pods samples

*3.5 Data Analyses*

Data obtained on various growth and yield parameters was analyzed using one way ANOVA from stat graphics centurion xv and means were separation using the Fischer least significant difference (LSD) test at 95% confidence interval. Results obtained and their discussions are presented as follows:

**4. Results and Discussions**

*4.1 Effect of Different Mulching Materials on Plant Height*

Table 1 below present the statistical results obtained for effects on beans height when elephant grass, saw dust, white plastic and corn stalk were used separately as mulching material.

Table 1. Effect of different mulching materials on plant height

| **treatments** | **Weeks after planting (WAP)** | | | |
|---|---|---|---|---|
| | **2** | **4** | **6** | **8** |
| Elephant grass | $7.57\pm0.503^{a}$ | $8.57\pm0.764^{b}$ | $9.20\pm1.212^{cd}$ | $9.30\pm1.212^{b}$ |
| Saw dust | $6.33\pm0.289^{b}$ | $7.00\pm0.6^{d}$ | $8.27\pm1.401^{b}$ | $8.77\pm1.704^{a}$ |
| White plastic | $7.30\pm0.265^{bc}$ | $9.63\pm0.851^{ab}$ | $11.27\pm1.106^{b}$ | $12.67\pm0.802^{a}$ |
| Corn stalk | $6.70\pm0.265^{cd}$ | $6.87\pm0.379^{c}$ | $7.67\pm0.513^{b}$ | $8.10\pm0.361^{b}$ |
| control | $7.40\pm0.656^{cd}$ | $10.00\pm0.2^{c}$ | $10.67\pm0.351^{ab}$ | $11.17\pm0.208^{a}$ |

The letters of Alphabets are used to denote significant differences between the means. Means with the same alphabet letters are not significantly different at P>0.05 while Means with different letters are significantly different at P<0.05 according to fishers LSD test. Value ± denote standard error

According to table 1, at 2WAP, plant height increased across the treatments at all the growth stages no significant difference (P>0.05 were observed between plants on saw dust ($T_2$) and white plastic ($T_3$) mulched and between plants with white plastic ($T_3$), corn stalk ($T_4$) and control ($T_5$). Elephant grass mulched plants ($T_1$) differed significantly (P<0.05) from the other treatments during this same 2WAP. Results from the 4WAP, showed no significant differences (P<0.05) in plant height between plants grown with elephant grass ($T_1$) mulched and those grown with white plastic ($T_3$) mulch. Plant height under control ($T_5$) differed significant from those under elephant grass, saw dust and white plastic mulches but no significant difference was observed between plants grown with corn stalk mulch ($T_4$).

During the 6WAP period, plant heights grown with elephant grass mulch (T1) differed significantly from those of plants grown on the rest of the treatments.

At 8WAP, while no significant differences were observed between plant heights under control ($T_5$) and those under white plastic ($T_3$) and saw dust ($T_2$) mulches, significant differences were recorded between plants heights under elephant grass mulch and corn stalk mulch. The lowest plant height of 8.10 cm was recorded by plants under corn stalk mulch during the 8WAP while the highest plant height of 12.67cm was recorded by plants under white plastic mulch during the 8WAP. Fig 6 below show variation in plant height recorded with the diverse mulches and the four growth stages.

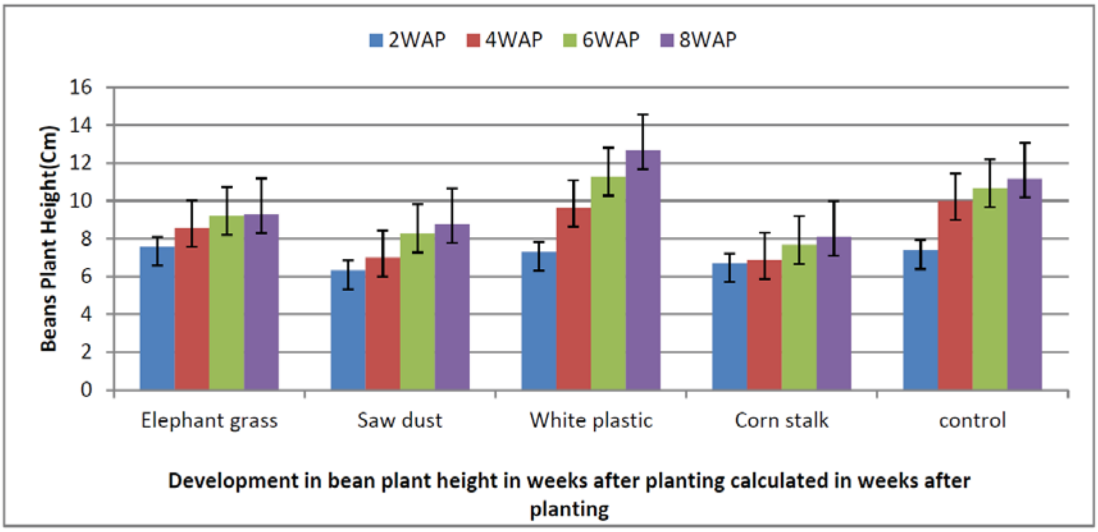


Figure 6. Variation in plant height in the various treatments

The observed lack of any significant difference in height between the corn stalk mulched plants and control plot during the 2WAP can be attributed to the poor decay speed of corn which as a result could not add nutrients to the soil to boost significant plant growth. Poorly decayed corn stalk tends to absorbed soil water thereby depriving plant root zone of ample available water. This may the reason why plant height was lowest (8.10cm) when grown with corn stalk mulch. The reason why plants grown with White plastic mulch produced the tallest plant was attributed to the common knowledge that white plastics mulching not only conserve moisture better but also increased soil temperature which gave plants the most favorable condition as reported by Safiullah et al., 1996.

### *4.2 Effect of Different Mulching Materials on Number of Leaves per Plant*

Statistical results obtained for effects on number of leaves produced by green bean plants when elephant grass, saw dust, white plastic and corn stalk were used separately as mulching material. In a column, means with the same letters are not significantly different (FMRT 5%)

Table 2. Effect of different mulching materials on the number of leaves

| **Treatment** | **Weeks after planting** | | | |
|---|---|---|---|---|
| | **2** | **4** | **6** | **8** |
| Elephant grass | $7.33 \pm 0.643^{cd}$ | $9.60 \pm 3.026^{cd}$ | $12.13 \pm 3.900^{ab}$ | $11.87 \pm 3.828^{a}$ |
| Saw dust | $6.33 \pm 0.115^{d}$ | $9.53 \pm 1.616^{ab}$ | $12.07 \pm 1.701^{ab}$ | $11.87 \pm 1.102^{a}$ |
| White plastic | $10.33 \pm 2.212^{b}$ | $13.47 \pm 2.082^{b}$ | $16.40 \pm 3.219^{ab}$ | $15.13 \pm 3.062^{a}$ |
| Corn stalk | $6.20 \pm 0.871^{c}$ | $8.60 \pm 0.917^{d}$ | $10.40 \pm 0.8^{d}$ | $10.40 \pm 1.249^{b}$ |
| control | $8.93 \pm 1.331^{ab}$ | $12.33 \pm 0.577^{ab}$ | $13.73 \pm 2.540^{ab}$ | $15.67 \pm 4.119^{a}$ |

The letters of Alphabets are used to denote significant differences between the means. Means with the same alphabet letters are not significantly different at $P>0.05$ while Means with different letters are significantly different at $P<0.05$ according to fishers LSD test. Value ± denote standard error

From table 2, it can be inferred that while the number of leaves per plants grown with corn stalk mulch ($T_4$) did not change, the number of leaves per plant increased from 2WAP to 6WAP for all treatments but dropped at 8WAP for plants grown with elephant grass (T1) and saw dust ($T_2$) mulches. At 2WAP, no significant differences (P>0.05) were recorded in the number of leaves per plant between plants under control ($T_5$) and those grown with white plastic ($T_3$) mulch. At 4WAP, the number of leaves per plant in the control plot did not differ significantly (P>0.05) from that grown with white plastic ($T_3$) and saw dust ($T_2$) mulches. During the 6WAP period, no significant differences were observed in number of leaves per plant between plants grown under control (T5) and those grown with saw dust (T2) and elephant grass (T1) mulches. Results from the 8WAP showed significant differences (P<0.05) in number of leaves per plant between plants grown with corn stalk(T4) mulch and the rest of the treatments as well as between green bean plants mulched with White plastic and the rest of the treatments. The lowest numbers of leaves per plant were recorded by plants grown with corn stalk ($T_4$) mulch and the largest numbers of leaves per plant were recorded by plants grown with the white plastic (T3) mulch. This again may have been because of poor decomposition of corn stalk which prevented the addition of extra available nutrients that subsequently retarded plant growth and the positive water retention of nutrients (due to reduced volatization), moisture and warmth by plastic which provided the root zone with favorable conditions for growth. Tarara, 2009 and Kwambe et al. 2015 both reported that warm roots grew faster and resulted in accelerated plant growth.

*4.3 Effect of Different Mulching Materials on Leaf Area Index*

Presented in table 3 are results of effects of the five mulch treatments on the leaf area indices of green beans plants. In a column, means with the same letters are not significantly different (FMRT 5%).

Table 3. Effect of different mulching materials on the leaf area index

| **Treatment** | **Weeks after planting** | | | |
|---|---|---|---|---|
| | **2** | **4** | **6** | **8** |
| Elephant grass | $0.20{\pm}0.007^{ab}$ | $0.25{\pm}0.030^{b}$ | $0.26{\pm}0.054^{b}$ | $0.28{\pm}0.101^{ab}$ |
| Saw dust | $0.18{\pm}0.052^{c}$ | $0.26{\pm}0.037^{c}$ | $0.27{\pm}0.065^{c}$ | $0.29{\pm}0.070^{ab}$ |
| White plastic | $0.24{\pm}0.034^{b}$ | $0.34{\pm}0.015^{a}$ | $0.36{\pm}0.023^{b}$ | $0.43{\pm}0.007^{a}$ |
| Corn stalk | $0.15{\pm}0.006^{a}$ | $0.21{\pm}0.019^{b}$ | $0.22{\pm}0.019^{b}$ | $0.19{\pm}0.008^{d}$ |
| control | $0.25{\pm}0.018^{a}$ | $0.35{\pm}0.049^{c}$ | $0.35{\pm}0.011^{a}$ | $0.39{\pm}0.072^{cd}$ |

The letters of Alphabets are used to denote significant differences between the means. Means with the same alphabet letters are not significantly different at P>0.05 while Means with different letters are significantly different at P<0.05 according to fishers LSD test. Value ± denote standard error

Table 3 shows that with the exception of plants grown with corn stalk (T4) mulch in which the the leaf area index dropped from the 6WAP to the 8WAP, the leaf area index increased across the growth stages for the rest of the treatments. During the 2WAP and 6WAPperiods, Leaf area indices of plants grown with saw dust (T2) mulch were significantly different (P<0.05) from those of plants grown with the rest of the treatments. During the 8WAP period, no significant difference (P>0.05) in the leaf area indices was recorded between plants grown with corn stalk (T4) mulch and those under control (T5). During the 4WAP, 6WAP and 8WAP, the leaf area index of plants grown with saw dust and under control were significantly different (P<0.05) from those of the other treatments. The lowest leaf area index (0.19) was recorded with plants grown with corn stalk (T4) mulch treatment while the highest (0.43) was recorded by plants grown with the white plastic (T3) mulch treatment. Carmichael *et al*. (2012.) reported statistically correlation between leaf number and leaf area index. Results of leaf number above were found to be lowest with plants grown with corn stalk mulch and highest with plants under white plastic (T3) mulch.

*4.4 Effect of Different Mulching Materials on the Yield of Green Beans*

Results of effect on yield of green bean plants captured as number of pods, pod length in centimeters and pod weights in grams when grown with elephant grass saw dust, white plastic and corn stalk as mulching materials are presented on table 4 below. In a column, means with the same letters are not significantly different (FMRT 5%)

Table 4. Effect of different mulching materials on the yield of green beans

| **Treatment** | **Number of pods** | **Pod length (cm)** | **Pod weight (g)** |
|---|---|---|---|
| Elephant grass | $7.67 \pm 0.877^{a}$ | $10.07 \pm 0.569^{ab}$ | $3.65 \pm 1.755^{ab}$ |
| Saw dust | $8.00 \pm 0.166^{d}$ | $9.19 \pm 0.551^{c}$ | $2.83 \pm 1^{c}$ |
| White plastic | $12.00 \pm 0.165^{c}$ | $11.97 \pm 4.147^{a}$ | $4.22 \pm 1.323^{bc}$ |
| Corn stalk | $7.83 \pm 0.220^{a}$ | $9.23 \pm 0.585^{bc}$ | $3.16 \pm 1.041^{bc}$ |
| Control | $9.50 \pm 0.171^{cd}$ | $10.40 \pm 0.264^{d}$ | $3.76 \pm 1.732^{b}$ |

The letters of Alphabets are used to denote significant differences between the means. Means with the same alphabet letters are not significantly different at P>0.05 while Means with different letters are significantly different at P<0.05 according to fishers LSD test. Value ± denote standard error

From this table, the number of pods per plants under control ($T_5$) was not significantly different (P>0.05) from those grown with the white plastic ($T_3$) and saw dust ($T_2$) mulch. The smallest number of pods was obtained from plants grown with elephant grass (T1) mulch while the highest were obtained from the plants grown with white plastic ($T_3$) mulch.

The pod length from the control ($T_5$) plot significantly differed from the rest of the other treatments. Plants grown with saw dust ($T_2$) mulch produced the shortest pods (9.17cm) while the longest pod (11.97cm) were produced by plants grown with white plastic ($T_3$) mulch.

No significant differences (P>0.05) were found between the pod weight of plants from control ($T_5$) and those from corn stalk ($T_4$), white plastic ($T_3$), and the elephant grass ($T_1$) mulches. The lightest pods (2.83g) were obtained from plants grown with saw dust ($T_2$) and the heaviest (4.22g) came from plants grown with white plastic ($T_3$) mulch.

Pod yield (fresh mass) between plants harvested from white plastic, elephant grass and corn stalk mulches significant differed (P<0.05) from those obtained from saw dust mulch and control. The highest pod yieldswere obtained from plants grown with elephant grass mulches and the lowest from Saw dust mulch. Based on the fact that only elephant grass leaves were used, one will relate the positive performance of green beans grown with elephant grass as mulch to the easy decay of the leaves which must have added extra available nutrient to the soil. This observation was also made by Anon., 2008.The relatively low pod yields obtained from Saw dust mulch could be related to potential allelopathy effects especially if the saw dust was from Eucalyptus or from pine woods notwithstanding the possibilities that like corn stalks, saw dust could equally soak soil water depriving plants from available water for yield production.

## 5. Conclusions and Recommendations

Mulching was found to boost green beans yield in Nfonta in the western highlands of Cameroon. The difference in effects from using Organic and inorganic was very clear as plastic (inorganic) mulch outperformed all the organic mulches(saw dust, corn stalk, elephant grass) in all the cases considered. White plastic produced the best results in terms of both growth and yield, followed by elephant grass mulch. .These findings are in unison with Quamruzzaman et al, 2021 who reported plastic mulch to have boosted the yields of both fruit and vegetables in an experiment.

- Based on the results of this research, one is tempted to recommend plastic mulch as the solution to combating soil moisture shortages by farmers in Nfonta. Despite the positive outcome, farmers will need to be educated on the adverse effects of plastics as well as be educated about biodegradable plastics which unfortunately are not available, accessible or affordable in Cameroon for now. It is also recommended that producers use the locally available mulching materials. There is hence a need for further research and a sound government policy as to the use of plastics on farms in Cameroon.
- From the study of effects of the four different mulching materials on the yield of green beans in table 4 above , Elephant grass mulch and saw dust despite both being organic were observed produced significantly different number of pods, pod length and pod weights used to measure final bean yield. Similar findings were also made by Jodaugiene et al. 2018 who attributed the differences to the presence of Allelopathic chemicals in saw dust as compared to elephant grass. Saw dust is a highly available and affordable mulching material in the grass field and farmers will easily go for them. Hence a research evaluating the allelochemicals in diverse woods used by local carpenters is highly recommended if farmers in Nfonta are to be encouraged to use saw dust as a cheaply available mulching material.

- Ajibola et al, 2014 and Teame et al; 2017 both reported improved crop yield in plots mulched with elephant grass which agrees with the findings in this research as can be inferred in fig 4.
- Elephant grass is a common weed along road sides and farms in Cameroon. Recommending this as mulch material for farmers is sustainable as it is cheaply available and accessible and can be managed by ratooning. It will even go far into solving problems such as highway visibility and avoid common accidents associated with too much elephant grass along Cameroon motorways. In recommending elephant grass as mulch material it will be necessary to study its allelochemical potentials as well as manure quality.
- Since different growth stages produced different results with the different mulches, further research should to investigate the growth stage and the appropriate mulch to use for best results may not be a wrong recommendation.
- One and if not major use of Mulches in agriculture is to conserve soil moisture especially in rainfed areas like Nfonta. This research like others have shown tIt is recommended that this research be repeated and include the effects of the four mulches on shat mulching is a a way to boost crop yield. This research should be repeated with main objective to study the effects of the four Mulches on soil properties especially those affecting moisture.

**References**

Ajibola, A., Modupeola, T., & Adenuga, A. (2014). Effect of different weed control practices on growth and yield of sesame in south-west Nigeria. *Journal of Biological and Chemical Research, 31*(2), 1093-1100.

Anonymous. (2008). Harmonization of wastelands/degraded lands datasets of India.*Published by National Rainfed Area Authority* (NRAA). *Ministry of Agriculture, Government of India, 5*, 66-67.

Beebe, S. E., Rao, I. M., Mukankusi, C., & Buruchara, R. A. (2012). Improving resource use efficiency and reducing risk of common bean production in Africa, Latin America, and the Caribbean. In C. H. Hershey (Ed.), *Eco-Efficiency: From vision to reality* (p. 18). Centro Internacional de Agricultura Tropical (CIAT), Cali, CO. Retrieved from https://hdl.handle.net/10568/55608

Beshir, M. H. (2015). *Improving Snap Bean (Phaseolus vulgaris L.) Production under Reduced Input Systems.* A PhD Thesis submitted to University of Saskatchewan, Canada. pp. 24-72.

Carmichael, P. C., Shongwe, V. D., Masarirambi, M. T., & Manyatsi, A. M. (2012). Effect of mulch and irrigation on growth, yield and quality of radish (Raphanus sativus L.) in a semi-arid sub-tropical environment. *Asian Journal of Agricultural Sciences, 4*(3), 183-187.

Edje, O. T., & Ossom, E. M. (2009). *Crop Science Handbook*. Crop Production Department, Faculty of Agriculture. University of Swaziland.

FAO. (2012). *FAOSTAT statistical database*. Food and Agriculture Organization of the United Nations, Rome, Italy. Retrieved from https://www.fao.org

FAO. (2020). *Fruit and vegetables - your dietary essentials*. The International Year of Fruits and Vegetables, 2021, background paper, Rome. https://doi.org/10.4060/cb2395en

Freytag, G. F., & Debouck, D. G. (2002). *Taxonomy, distribution, and ecology of the genus phaseolus (Leguminosae-papilionoideae) in North America, Mexico and Central Americ*a. Botanical Research Institute of Texas (BRIT), Forth Worth, TX, USA. pp. 298. Retrieved from https://hdl.handle.net/10568/54291

Jodaugiene, D., Sinkeviciene, A., Pupaliene, R., Ninkovic, V., & Kriauciuniene, Z. (2018). Allelopathic effect of organic mulches on vegetable germination and early development. *Acta Sci. Pol. Hortorum Cultus, 17*(3), 73-82. https://doi.org/10.24326/asphc.2018.3.7

Kaiser, C., & Ernst, M. (2017). *Snap Beans*. CCD-CP-118. Lexington, KY: Center for Crop Diversification, University of Kentucky College of Agriculture, Food and Environment. Retrieved from http://www.uky.edu/ccd/sites/www.uky.edu.ccd/files/snapbeans.pdf

Kalima, S. P. (2013). *Physiological responses of common bean (Phaseolus vulgaris L.) genotypes to water stress* (MSc Thesis). University of Zambia, Lusaka. pp. 91.

Kimani, P. M. (2006). *Snap beans for income generation by small farmers in east Africa* [on line]. Centro Internacional de Agricultura Tropical (CIAT), Kampala, UG. pp. 2. Retrieved from https://hdl.handle.net/10568/70449

Kwambe, X. M., Masarirambi, M. T., Wahome, P. K., & Oseni, T. O. (2015). *The effects of organic and inorganic mulches on growth and yield of green bean (Phaseolus vulgaris L.) in a semi-arid environment*.

Manzini, S., SafiuIlah, M., Ahmed, S. U., & Rahman, M. H. (1996). Effect of mulching on the growth and yield of Cabbage. *Progressive Agriculture, 7*(1), 15-19.

Molua, E. L., & Lambi, C. M. (2007). *The Economic Impact of Climate Change on Agriculture in Cameroon*. Policy Research Working Paper No. 4364. World Bank, Washington, DC. Retrieved from https://openknowledge.worldbank.org/handle/10986/7362

Negash, A., Tulu, S., & Getachew, E. (2018). Yield and Yield Components of Snap Bean (Phaseolus vulgaris L.) as affected by N and P Fertilizer Rates at Jimma, Southwestern Ethiopia. *Adv Crop Sci Tech, 6*(3), 369. https://doi.org/10.4172/2329-8863.1000369

Nyambod, E. M. (2010). Environmental consequences of rapid urbanisation: Bamenda city, Cameroon. *Journal of Environmental Protection, 1*(1), 15-23. https://doi.org/10.4236/jep.2010.11003

Porch, T. G., Beaver, S. J., Debouck, G. D., Jackson, A. S., Kelly, D. J., & Dempewolf, H. (2013). Use of wild relatives and closely related species to adapt common bean to climate change. *Agronomy, 3*(2), 433-461. https://doi.org/10.3390/agronomy3020433

Quamruzzaman, A. K. M., Islam, F., & Mallick, S. R. (2021). Mulch Effect on Growth and Yield of Vine Vegetables. *European Journal of Agriculture and Food Sciences, 3*(1), 143-147. https://doi.org/10.24018/ejfood.2021.3.1.244

Tamfuh, A. P., Tsozué, D., Tita, M. A., Boukong, A., Tchinda, N. R., Ntangmo, T. H., & Mvondo, Z. A. D. (2017). Effect of Topographic Position and Seasons on the Micronutrient Levels in Soils and Grown Huckleberry (*Solanum scabrum)* in Bafut (North-West Cameroon). *World Journal of Agricultural Research, 5*(2), 73-87. https://doi.org/10.12691/wjar-5-2-3

Tarara, J. M. (2009). Book Review: Plant Growth and Climate Change. *Hort Science, 43*(23), 23-99.

Teame, G., Tsegay, A., & Abrha, B. (2017). Effect of Organic Mulching on Soil Moisture, Yield, and Yield Contributing Components of Sesame (*Sesamum indicum L.). International Journal of Agronomy, 2017*. https://doi.org/10.1155/2017/4767509

Unique-Kulima Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ GmbH). (2017). *Agricultural adaptation: Six categories of good practices and technologies in Africa - Project Report.* Retrieved from http://www.nepad.org/system/files/Implementation%20Strategy%20Report%20English

Widuri, I. L., Lakitan, B., Sodikin, E., Hasmeda, M., Meihana, M., Kartika, K., & Siaga, E. (2018). Shoot and Root Growth in Common Bean (Phaseolus vulgaris L.) Exposed to Gradual Drought Stress. *Journal of Agricultural Science, 40*(3), 442-452. https://doi.org/10.17503/agrivita.v40i0.1716

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# An Overview of Land Degradation and Sustainable Land Management in the Near East and North Africa

F. M. Ziadat[1], P. Zdruli[2], S. Christiansen[3], L. Caon[1], M. Abdel Monem[4] & T. Fetsi[1]

[1] Food and Agriculture Organization (FAO) of the United Nations, Land and Water Division, Viale delle Terme di Caracalla, 00153 Rome, Italy

[2] International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM) - Mediterranean Agronomic Institute of Bari, Land and Water Resources Management Department, Via Ceglie 9, 70010 Valenzano (BA), Italy.

[3] Independent Consultant, 61526 West Ridge Ave, Bend, OR 97702, USA

[4] FAO Regional Office for Near East and North Africa, 11 Al-Eslah Al-Zerai Street, Dokki, Cairo, Egypt

Correspondence: F. M. Ziadat, Food and Agriculture Organization (FAO) of the United Nations, Land and Water Division, Viale delle Terme di Caracalla, 00153 Rome, Italy. E-mail: feras.ziadat@fao.org

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**Abstract**

Land degradation and desertification (LDD) and climate change are having increased effects in the Near East and North Africa (NENA) impacting the livelihoods of about 410 million people. Agriculture is a vital sector, contributing on average 14% to the Gross Domestic Product (GDP) (excluding oil producing countries) and providing jobs and incomes for 38% of the region's economically active population. Nevertheless, most NENA countries import at least 50% of the calories they consume. Furthermore, it is estimated that the total area that is desertified or is vulnerable to desertification cover 9.84 million $km^2$ or about 86.7% of the total NENA region. Soil erosion by water, wind, and sand and dust storms (SDS) cause losses of about USD 13 billion of GDP each year. To confront these hardships, the region must endorse proper land use planning, prioritization of target areas for restoration and adoption of sustainable land and water management (SLWM) to reverse the situation. This paper analyses the inter-linkages between LDD, resource base management and food security under different scenarios and offers mitigation and remediation options. These include knowledge management and sharing; establishment of a regional platform to facilitate dialogue; public and private investment opportunities; provision of tools to scale-out sustainable land and water management options; and creation of a conducive enabling environment supported by policies and strategies. The paper provides policy and decision-makers with priority actions and options to enhance productivity, and combat land degradation to improve food security in the region.

**Keywords:** land use, food security, climate change, desertification, land restoration

## I. Introduction

Impacts of land degradation and desertification (LDD) on livelihoods, environment, economic growth and migration are becoming more apparent throughout the Near East and North Africa region (NENA), a densely populated region with limited land and water resources for food production (Zdruli, 2014). NENA is home to about 410 million people, or 10% of the world's population (Croitoru and Sarraf, 2010) and despite arable land covers only 4.6% of the total land area (FAOSTAT, 2018), or about 0.142 ha/per person (FAOSTAT, 2018), agriculture remains a vital socio-economic sector, contributing on average 14% to the Gross Domestic Product (GDP) (excluding oil producing countries) as well as generating jobs and incomes for 38% of the region's economically active population (FAO, 2017c).

Land degradation is also a natural and human-induced process that negatively affects the land's natural functions related to water, energy, nutrient storage, and recycling, leading to a decline in land productivity. The United Nations (UNEP, 1992) define desertification as "land degradation in arid, semi-arid and dry sub-humid regions resulting from various factors, including climatic variations and human activities". LDD affects in different ways about 86% of NENA's total area of 14.1 million $km^2$ (Abahussain *et al.*, 2002; FAO and ITPS, 2015). Growing populations and increased demand for agricultural products pose a tremendous pressure on soil and water resources and may trigger even more future reliance on imports in a region where many countries import even more than 50% of the consumed calories, exposing them to food insecurity and social unrest (Zdruli, 2014). Despite the importance of maintaining or increasing agricultural productivity, inappropriate policies and practices such as the conversion of fertile agricultural lands into other uses (including urbanization), mismanagement of government subsidies, land fragmentation, overgrazing, deforestation, and inappropriate irrigation and cultivation methods are some of the factors that contribute to the degradation of agricultural land and reduce its productivity over time. Furthermore, problems of wind and water erosion, sand and dust storms, nutrient depletion, salinization and sodification are increasingly affecting the productive capacity of the NENA soils (FAO and ITPS, 2015; FAO, 2019c). Climate change, socio-economic changes and conflicts further exacerbate these challenges (FAO, 2016b). The interaction between LDD, climate change, water scarcity and food security and how these affect migrations in NENA are important dimensions yet to be explored in detail.

NENA's regional cost of environmental degradation in 2010 ranged from 2.1 to 7.4% of the GDP for different countries (Croitoru and Sarraf, 2010) which is much higher when compared to 0.9% of the average global environmental degradation in terms of GDP in 2008 (Hussein, 2008). Moreover, the cost of land degradation alone affects 1.62% of the NENA's GDP (Nkonya, *et al*., 2016).

A worldwide synthesis of meta-analyses suggests that a global median loss of 0.3% of annual crop yield occurs because of soil erosion, and warned that a total reduction of 10% loss could be projected for 2050 globally (FAO, 2019a). This yield loss due to continued soil erosion could be equivalent to the removal from crop production of 4.5 M ha $yr^{-1}$ of agricultural soils (FAO and ITPS, 2015; FAO, 2019a). Comparing these data with the estimated soil erosion rates in NENA that are on average 1-2 orders of magnitude greater than rates of soil formation (Montgomery, 2007; Stockman *et al*., 2014), implies that the depletion of soil as a non-renewable resource could become extremely critical for the region (FAO and ITPS, 2015).

Nonetheless, there are also many opportunities to reorient these trends toward sustainability and resilience. Globally, it is estimated that over two billion hectares of land could be subject to restoration and rehabilitation through the application of sustainable land and water management (SLWM) techniques (World Resources Institute, 2014). SLM is defined as "*the use of land resources, including soils, water, animals and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions*" (United Nations, 1992).

Throughout NENA there are roughly 3.5 million $km^2$ of land potentially suitable for introducing SLWM practices in irrigated, rainfed and rangeland agroecosystems (Ziadat *et al*., 2014). Data from other regions such as South-East Asia, based on an assessment of the Economics of Land Degradation (ELD) (ELD, 2018) indicate that the benefits due to SLWM practices are worth about USD 3.01 billion, while acting against soil erosion in Africa could generate benefits of about USD 2.48 trillion (ELD and UNEP, 2018).

Nevertheless, proceeding with land restoration and reclamation requires the identification of areas suitable for introducing specific SLWM options, and creating an enabling environment to support farmers and land users in adopting these options. Furthermore, it is important to invest in capacity building, education, and awareness to establish and/or strengthen extension services, both public and private, and to create a political and economic environment that enables land users to implement SLWM. Experience has shown that it is only when local land users are put at the center of the land management and restoration interventions that success is achieved (Liniger and Chritchley, 2007, Ziadat *et al*., 2015). Based on these experiences, this paper provides examples of efforts and success stories from various countries in the NENA region. Moreover, these examples are needed to identify cost-effective solutions to support governmental legislation, policies, funding, and actions to curtail the costs of degradation, improve environmental conditions and the livelihoods of local people.

## 2. Climate Change, Sustainable Development Goals (SDG) and Land Degradation Neutrality in NENA

Human-induced land and soil degradation have affected the region for millennia (Zdruli *et al.,* 2010; Zdruli, 2014), but recently they are gaining even more international attention. Soil is central for realizing 8 of the 17 SDGs, and the most important effect is on the large number of small-holder farmers in the poorest countries (Hou, 2020; Hou, *et al*., 2020). At the UN Framework Convention on Climate Change (UNFCCC, 2017) COP23, the role of soil and water management in combating climate change was acknowledged and included as a significant element in the Decision 4/CP.23 known as the Koronivia Joint Work on Agriculture.

Furthermore, the IPCC indicated that climate change exacerbates the rate and magnitude of several on-going land degradation processes and introduces new degradation patterns also emphasizing that both land degradation and climate change, individually and in combination, have profound implications for natural resource-based livelihood systems and societal groups (IPCC, 2019). At the same time land degradation is a driver of climate change through emission of greenhouse gases and reduced rates of carbon uptake. NENA is particularly sensitive to climate change and the North Africa and Middle East region in particular will become hotter and drier (Tuel and Eltahir, 2020).

Efforts are under way also in the context of the Nationally Determined Contributions (NDC) to climate change mitigation and adaptation as emphasized also by the COP26 of UNFCCC held in Glasgow in 2021. A global analysis indicates that the agriculture sectors (crops, livestock, forestry, fisheries, and aquaculture) are featured prominently in the NDCs and are among the foremost priorities in countries' mitigation contributions and adaptation objectives (FAO, 2017b). Eighty-nine percent of all countries and 86% of all developing countries refer to agriculture (crops and livestock) and/or land use, land-use change and forestry when outlining their mitigation contributions. Furthermore, 67% of all countries reveal climate-related hazards including extreme events, long-term impacts, and variability of climate phenomena as the most pressing issues when dealing with climate change. SLWM and land use planning remain the key tools identified by many countries to achieve climate change targets through the NDC process (FAO, 2018a). SLWM and its contribution to global environmental benefits in terms of climate and biodiversity are also well recognized and supported by several international agreements (GEF, 2018).

Countries of the NENA region expressed their commitments and actions to face the climate change challenges in the submitted NDC reports. Seventy five percent of the countries reported agriculture in their NDCs, while 56 and 44% included forestry and fisheries accordingly. Furthermore, 69% mention mitigation targets and/or actions, while 25% emphasize cropland management as a priority area for action and another 13% mention grazing land management as a priority (FAO, 2016b). The preparation of the new reporting on the NDCs for the countries of the region offers a good opportunity to emphasize the challenges of climate change on land resources and the measures needed for adaptation.

The SDG process, including its targets and indicators, is the strategic framework of the 2030 Agenda for Sustainable Development. There are several SDGs directly or indirectly linked to food security, natural resources management and planning. They relate to ending hunger and achieving sustainable agriculture (SDG 2) (Lipper *et al*., 2020); protecting and restoring water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes (SDG 6); protecting and restoring terrestrial ecosystems and promoting sustainable use of land (SDG 15), and combating climate change and its impacts (SDG 13). In the context of SDG 15 (Life on Land), and particularly target 15.3 "*Protect and restore terrestrial ecosystems and promote sustainable use*", the focus is on deploying tools and strengthening countries' capacities in regular data collection and analysis through appropriate methodologies and databases (Liniger *et al*., 2018).

The technical principles recommended by the Voluntary Guidelines for Sustainable Soil Management (VGSSM) are a good instrument to be implemented in NENA to enhance soil health and sustained food production. These include the following: (1) minimize soil erosion; (2) enhance soil organic matter content; (3) foster soil nutrient balance and cycles; (4) prevent, minimize and mitigate soil salinization and alkalinization; (5) prevent and minimize soil contamination; (6) prevent and minimize soil acidification; (7) preserve and enhance soil biodiversity; (8) minimize soil sealing; (9) prevent and mitigate soil compaction; and (10) improve soil water management (FAO and ITPS, 2017).

At the Rio+20 Summit, the world's leaders committed to achieve a land degradation neutral world in the context of sustainable development. Land Degradation Neutrality (LDN) is defined as "*a state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specific temporal and spatial scales and ecosystems*". The goal of LDN is to maintain or enhance the land resource base - the stocks of natural capital associated with land resources and the ecosystem services that flow from them (UNCCD-GM, 2016; Akhtar-Schuster *et al.,* 2017; Orr *et al.,* 2017; Liniger *et al.,* 2018). UNCCD-GM (2016), within its LDN Target Setting Program, developed a technical guide on how to define national baselines, identify voluntary targets and associated measures to achieve LDN by 2030 and monitor progress towards LDN targets.

The situation across NENA in terms of LDN reporting vary from country to country, with some like Morocco, Egypt, and Tunisia in an advanced stage, while others like Syria and Libya far behind due to their difficult political situations. Efforts are under way by the League of Arab States and the Council of the Arab Ministers of Environment (CAMERE) and the Arab Organization for Agricultural Development to enhance the LDN process throughout the region. The High-level Political Forum (HLPF) of the United Nations, as a central platform for follow-up and review of the 2030 Agenda for Sustainable Development and the Sustainable Development Goals, has set forward a well-defined and clear outline to meet the SDGs. This includes SDG 1 (no poverty), 2 (zero hunger), 3 (good health and well-being), 8 (decent work and economic growth), 10 (reduced inequalities), 12 (responsible consumption and production), 13 (climate action), 16 (peace, justice, and strong institutions), and 17 (partnerships). This operational framework is also very relevant for NENA.

## 3. Land Resources, Sustainable Agriculture and Food Security in NENA

Globally, one-third of the land used for agriculture is moderately to highly degraded (FAO and ITPS, 2015) but the population in dryland areas is most vulnerable to resource base degradation. Furthermore, it is estimated that food production will need to increase from the current 8.4 billion tons to almost 13.5 billion tons a year to feed a population projected to reach 9.3 billion in 2050 (FAO, 2017e). While the prevalence of malnourishment in NENA has remained stable over the past decade, the region suffers from higher average rates of undernourishment than any other global region aside from Sub-Saharan Africa. Even in stable NENA countries, malnutrition generally ranges between 5-10% of the population (FAO, 2017b). LDD and unstable political situations in several countries impedes the overall strategic objective of achieving food security and reducing hunger. In addition, desertification is nowhere more serious than in the NENA region. Under these circumstances, opportunities for horizontal agricultural expansion are either diminishing or does not exist in many countries, leaving few options available for most of them: i) using the remaining arable lands sustainably and/or ii) rehabilitating and bringing back degraded lands into the production system. Nonetheless, reducing food waste, mostly due to post-harvest losses and improving green and blue water management could be viable options as well.

Unsustainable land use patterns are among the most important drivers of LDD. Using the land without properly considering the limitations and potentials of resources (soil, water, landscape, vegetation, climate, livestock, forest resources and human activities) enhances its vulnerability and risk for degradation (FAO, 2017b). Unfavourable climatic conditions (imposed also by climate change/variability) coupled with mismanagement of resources leads to degradation and vulnerability, while favorable human activities, such as selecting proper land use types and implementing SLWM practices will enhance sustainability and resilience. However, the actual extent of LDD in NENA needs to be more accurately estimated to support realistic and responsive land use planning. Fana *et al*. (2021) stated various options to cope with farmers' vulnerability: improve rural infrastructure and facilities, devising an effective and responsive institutional setup for enhancing the capacities of smallholder farmers in the short-run and minimizing the likelihood of exposure and sensitivity in the long-run.

## 4. Drivers and Processes of Land Degradation and Desertification

The relationships between different direct and indirect drivers of LDD and the impacts from and on climate change, food security and migration are complex in the NENA region. As shown in Figure 1, factors related to natural processes and socio-economic conditions are causing accelerated soil degradation, which together with degradation and scarcity of other natural resources lead to accelerated LDD. LDD is additionally driven by climate change and conflicts and exacerbated by migration and food insecurity. Most of the processes and their dynamics represented as arrows, are reversible. Therefore, combating LDD is possible by tackling the drivers, through implementing proper SLWM practices, which will also reverse the adverse patterns in natural resource depletion, livelihoods, resilience, food security, and migration.

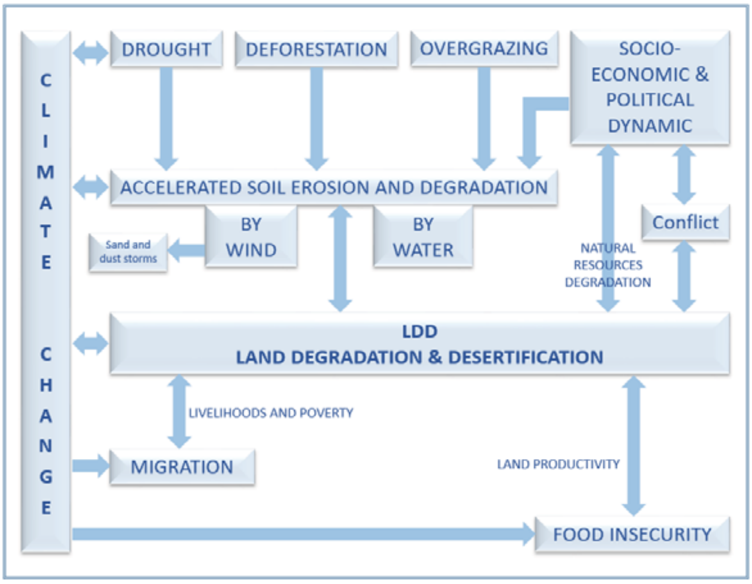


Figure 1. Land degradation, climate change, food security and migration nexus in the NENA region

NENA is affected by different land use practices and land related processes that accelerate land degradation. Soil erosion by water and wind including sand and dust storms (SDS), drought, overgrazing, deforestation merged with socio-economic and political dynamics, including urbanization, are amongst the burning issues in the region and are briefly presented below.

*Soil erosion by water* is caused by improper land use and management, especially in hilly areas and sloping agricultural lands. Continuous cultivation of arable lands, exploitative tillage practices (up and down the slope), absence of intercropping and crop rotations and destruction of vegetation cover contribute to soil erosion (Also, the soil physical properties are an important aspect to consider). Consequently, soil nutrient losses and organic carbon followed by decline in crop productivity and diminished ecosystem services are some of the consequences of erosion. Since 2002, Abahussain *et al.,* (2002) identified the following countries as the most affected by water erosion in NENA, arranged in order of surface area affected: Iran, Sudan, Yemen, Algeria, Tunisia, Morocco, Oman, Libya, Syria and Iraq (FAO and ITPS, 2015). To reverse the situation, there is an urgent need to move from assessments to collective actions and solutions in consensus with all stakeholders across the region.

*Soil erosion by wind* is another severe process since more than half of the NENA region receives on average an annual rainfall of less than 150 mm, vegetation growth is limited, and soil organic matter is very low. Therefore, approximately 60% (or 135 million ha) of soil is eroded by wind (FAO and ITPS, 2015) and this results in dust storms under certain conditions. The following countries are the most affected by wind erosion, arranged in order of surface area affected: Sudan, Saudi Arabia, Libya, Iran, Algeria, Yemen, Tunisia, Syria, Iraq, Jordan, and Egypt. It should be noted that NENA is among the most affected regions from SDS; as the region loses about USD 13 billion in GDP every year due to dust storms (FAO, 2018b). There has been a significant increase in the frequency, intensity, scale and geographical coverage of SDS in the past 15 years. The increased frequency and intensity of SDS in the region, if not counteracted, may jeopardize livelihood systems in affected areas, leading to escalated movement of rural people from their home areas (FAO, 2018b). To respond to current and future threats of SDS, monitoring dust emissions, and further research is critical to ensure informed decision-making both in the short and long-term. There is a need to build national capacity in SDS preparedness and emergency response across sectors. Prevention and mitigation measures on the local level that promote sustainable land and water management are also essential to mitigate the negative effects of SDS. The cyclic nature of the process and the transboundary geographic complexity call for urgent collective and regionally-based actions. Furthermore, both wind and water erosion rates are dependent on the weather. Therefore, linkages between land degradation and climate change are particularly important in NENA.

*Drought:* Severe droughts are becoming more frequent especially in Iraq, Jordan, Morocco, and Syria. For instance, the severe drought of the period 1998-2001 was the worst in the last 30 years (FAO, 2018c). This caused the reduction of cereal production in Syria and Jordan by 40% and loss of animal production by 35%.

Because of the drought, Morocco and Tunisia were forced to import large amounts of cereals to meet the food demands of the population, and Mauritania faced significant increases in food and feed commodity prices (FAO, 2018a).

The LDD process is cyclic and interlinked. For instance, a major problem facing Morocco is the impact of climate change and the increased prevalence of drought. With most farmland located in areas that receive less than 400 mm of rainfall each year, this has serious implications. These prolonged droughts are increasing soil degradation, with desertification threatening 80% of land, and soil erosion affecting nearly half of it (Sustainable Food Trust, 2015).

*Overgrazing* is another important driver of land degradation in the NENA region as it reduces land productivity, accelerates water and wind erosion causing the loss of vegetation cover and soil organic carbon. The process is accentuated by the unregulated movement of herds and uncontrolled grazing often across the political borders of neighboring countries. The growing population and the increasing demand for red meat has led to significant increases in the numbers of livestock. This has led in turn to rapid degradation of rangelands in most NENA countries. It is estimated that average vegetation cover as a percentage of land area in the region decreased from 3.7% in 1990 to 2.8% in 2013, while livestock numbers increased in the same period by 25% (FAO, 2016b). The provision of subsidies to farmers and herders has unintentionally encouraged larger herds than the land can support.

*Deforestation* rates in NENA are high in comparison with the region's limited forest cover (41 531 220 hectares). During the period 1990-2020 NENA experienced a net loss of forest cover of 6 percent and other wooded lands recorded a 15% decline during the same period (FAO, 2021). Information about extent, severity and impact of deforestation, overgrazing and rangeland conditions remains largely unknown and further research is needed, especially at landscape/local level.

*Urbanization.* The most fertile land especially in Egypt is under continuous loss by urbanization with severe destruction of the country's limited agricultural land. Over the last three decades, significant losses in agricultural land were observed together with a remarkable growth in the urban area. It is estimated that agricultural land has decreased by 11.03% in some areas east of the Nile Delta (El-Kawy *et al.,* 2010).

*Socio-economic and political dynamics* are strictly related to land degradation rates. Conflict has become a dominant feature of the NENA region, with continued outbreaks of violence occurring in several countries (FAO, 2017c). The region had over 14 million internally displaced persons in 2017 in addition to 6.7 million refugees fleeing NENA countries in 2016 (FAO, 2017c). Countries such as Jordan and Lebanon that host about 46% of all refugees in the region bear substantial pressure on their natural resources, including land and water. Countries under conflicts also suffer from land abandonment. In addition to being one of the main causes of migration (FAO, 2017c), land degradation contributes to worsening hunger, food insecurity and malnutrition in the region, especially due to the ongoing conflicts and crises in Yemen, Iraq, Syria, Sudan, and Libya.

*Migration:* Land degradation and climate change interact with other processes in ways that undermine the sustainability of household livelihoods and increases the likelihood of migration (IPBES, 2018). Examples show a complex picture when land degradation has caused migration, and on the other hand, where migration has caused or exacerbated land degradation (Mcleman, 2017). Migration rates from 12 out of 20 NENA countries have increased significantly since 2010. Additional research has shown that in Morocco, Tunisia, Lebanon, Syria and Palestine, migrants represent over 10% of the total population (Fargues, 2017).

Conflict in the region is an important cause of migration. However, migration is also triggered by limitations of land and water resources, reduction in land productivity and climate change (rainfall and temperature). High migration rates from non-conflict zone countries have been influenced by environmental resource depletion or degradation. Water scarcity is expected to impact 80-100 million people in the region by 2025, while LDD significantly accelerates migration. Unless concerted regional collaboration for tackling the drivers of LDD are taken, it will result in a worsening situation.

Other migration push factors such as weak *social protection programs* in NENA may aggravate land abandonment, thus degradation. It is known that social protection can influence rural migration patterns in several ways, as it addresses the multidimensional nature of poverty, one of the main drivers of migration. Social protection programs are important in addressing poverty and food insecurity. Only 16% of the poorest of the region's population receives any form of social protection. In addition, the political economy of social protection often influences its delicate framework: as revenues come from national governments, hence, the creation or even expansion of social protection depends on government willingness.

Emerging technologies such as social media, smart phones, services, and apps might offer opportunities to counter land degradation and enhance sustainability. Participatory monitoring of resources through communication and feedback to extension and advisory personnel are becoming increasingly easier. These could be used in conjunction with available databases on best practices to inform the decision-makers and the public about viable options for specific conditions through an informal or private advisory system.

## 5. Opportunities

Due to the urgency and relevancy to reverse LDD, options are available to avoid further degradation and to support the restoration of already degraded lands in several NENA countries. A very efficient method is *land use planning*, a key tool to support decision-makers at various levels and guide the allocation of land resources to optimum uses. But the role of land use planning is not fully exploited due to various factors, such as the lack of data/information to support decision-making, availability of user-friendly tools for planning, absence of political will, lack of readily available approaches to integrate and harmonize biophysical and socio-economic decision-support systems, and information needed for effective planning, management and policy-making. Countries are being supported by various UN agencies and International Development Agencies to tackle these challenges with specialized tools and methods developed for spatial and non-spatial information collection, analyses, and mapping land management and degradation at multiple scales (Ziadat *et al*., 2021; FAO Land Resources Planning Toolbox, 2019b).

Integrated landscape management and land resource planning approaches are key tools implemented for promoting SLWM. The following are some examples that have been implemented in Morocco, Palestinian Authority, Sudan, Tunisia and in the mountainous areas of Oman and Yemen and include: integrated watershed management; community territorial development; forest landscape restoration; sustainable land management; (agro) ecosystem approach; land evaluation and land use planning (Ziadat *et al*., 2021). The United Nations General Assembly declared 2021 – 2030 the UN Decade on Ecosystem Restoration that offers unique opportunity for restoring degraded land and halting desertification, contributing positively to food security in the region.

## 6. Immediate Actions to Promote SLWM in NENA

Immediate actions to promote interventions and provide an enabling environment to enhance SLWM and restoration activities include the following: control overgrazing, keep soil salinity under control, combat sand and dust storms, enhance drought preparedness and adaptation, control erosion and promote climate smart agriculture, and regenerative agriculture, even in countries where these types of agriculture are almost unknown.

Promising SLWM options are available to reverse land degradation such as the one implemented in the Kagera Basin in Africa (FAO, 2017d). A guiding flexible approach is proposed to reverse land degradation by identifying target areas where adaptable SLM options have high potential of success. This is possible when coupled with an implementation and scaling out approach supported by proper policies and financial mechanisms. However, to reach success it requires continuous monitoring and evaluation to assess the impact and guide fine-tuning based on future fluctuations to be able to adjust the decision-making process (FAO, 2017c).

In that context several methods and approaches could be mentioned. An example is the Great Green Wall of Africa (Figure 2) that provides an example of land restoration needs and opportunities with the aim of catalysing action to increase the resilience of people and landscapes to climate change.

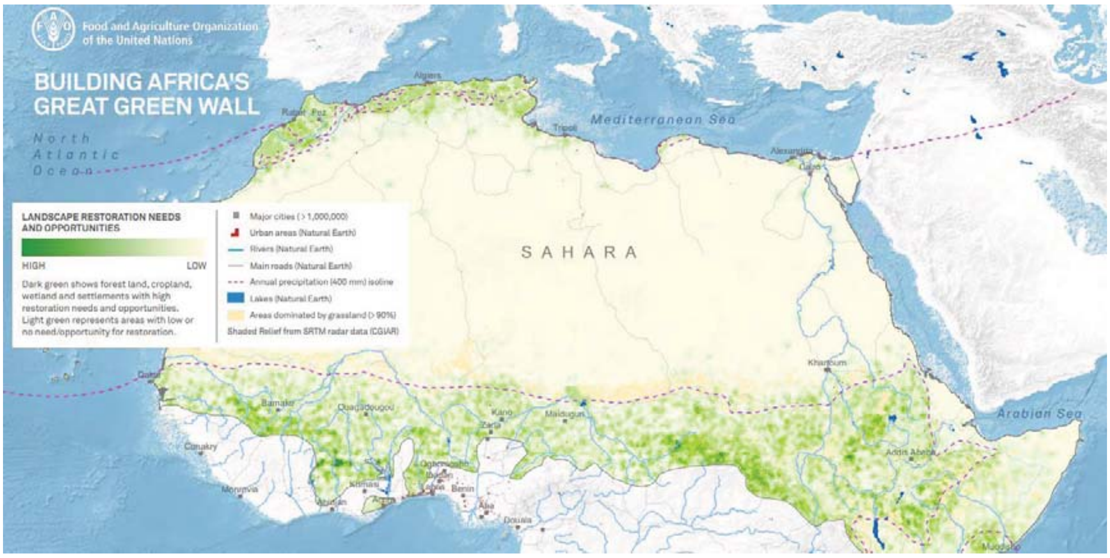


Figure 2. Mapping of restoration needs and opportunities in Africa

Source: Berrahmouni et al., 2016

http://www.greengrowthknowledge.org/sites/default/files/downloads/resource/FAO_Great_Green_Wall.pdf

Another complementary analysis is provided by the similarity assessment (Figure 3) to identify potential areas for scaling out SLWM options (Ziadat *et al*., 2015). Identifying land restoration potential, similarity and suitability analyses should support the decision-making process to identify and prioritize areas for immediate actions at regional, national, and local levels. New cost-effective and time efficient methods for land suitability assessment should be used to enhance the widespread use of land suitability in land use planning (Mahmoodi-Eshkaftaki, *et al*., 2020). Finally, the selection of proper technologies and practices should be guided by local, national, and regional experience and global SLWM knowledge platforms (Liniger and Critchley, 2007; Schwilch *et al.,* 2011; Harari *et al.,* 2017). In order to support countries in assessing the sustainability of the management practices, the FAO Global Soil Partnership released a protocol for the assessment of sustainable soil management (FAO and ITPS, 2020).

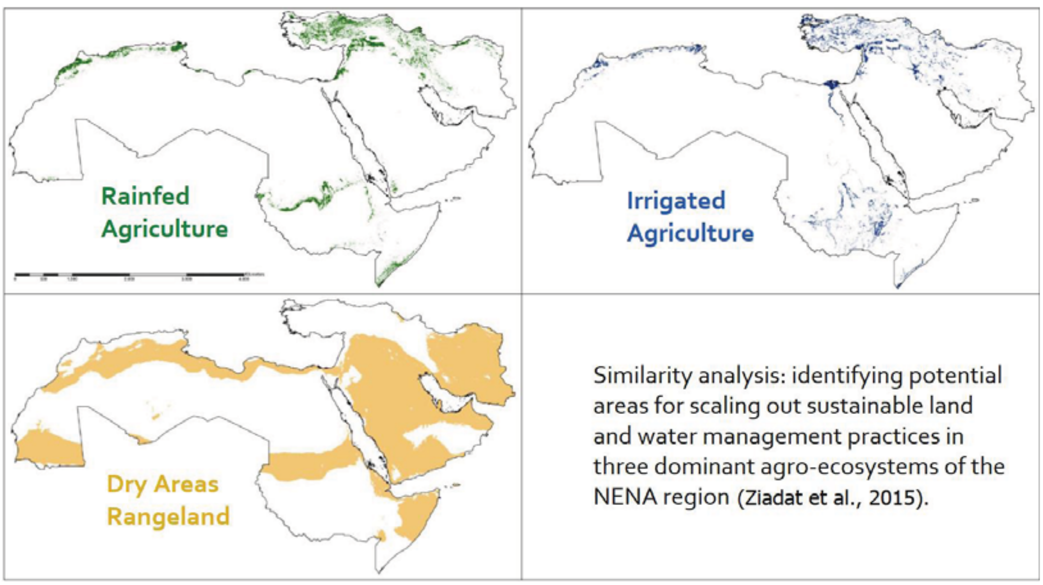


Figure 3. Similarity assessment to identify potential areas for scaling out sustainable land and water options

Source: https://repo.mel.cgiar.org/handle/20.500.11766/8856

## 7. Investment Opportunities for SLWM in NENA

The Economics of Land Degradation Initiative (ELD, 2018) offers a global platform that helps to create the economic evaluation of SLWM. This is supported by research, capacity development and knowledge exchange to ensure that these economics are comprehensively mediated and appropriately implemented to highlight the value of land and its terrestrial ecosystems and services provided to society.

The key challenge is to define at which stage to intervene and what level of finance to invest. It is essential to distinguish between different degrees of LDD and the resulting cost of intervention at each stage. Prevention of LDD is the first stage, before degradation occurs, whereas reduction is the second stage where degradation is on-going. Restoration is the third stage where land has already been degraded (Figure 4). Intervening sooner allows prevention or reduction to be carried out with lower cost and better results. Waiting for land to become severely degraded, allows only the option of restoration, often at very high cost.

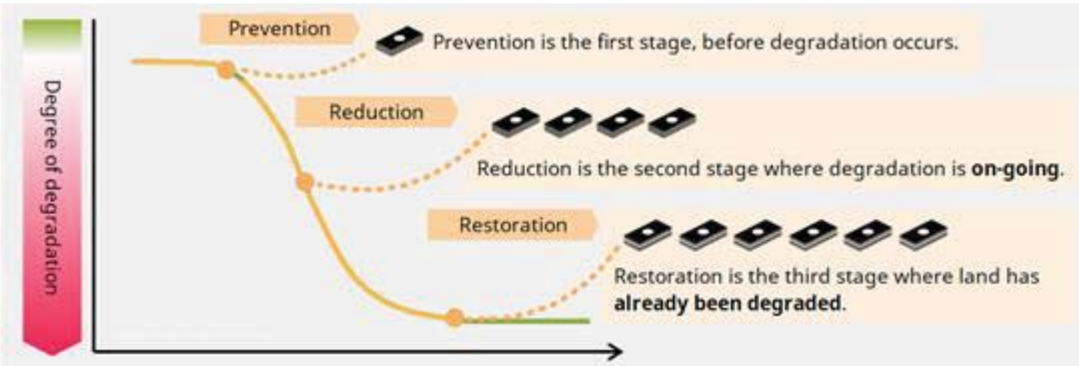


Figure 4. Costs of land degradation and remediation actions

Source: Sustainable Land Management and Restoration, (modified from ELD, 2018).

The cost-benefit analysis compares the costs of adopting a SLWM practice against the benefits derived from it, in order to determine its net economic benefit. Conducting this analysis with different scenarios can help determine which is optimal. The economics of land degradation assessment for Asia (ELD and UNEP, 2018) concluded that benefits through SLWM investments are worth about USD 3,01 billion, equal to USD 6,182 per ha with a benefit cost ratio of about 3.5. To use a NENA region example, in Jordan it is estimated that if the “Hema” traditional practice of managing common land is adopted within the Zarqa River Basin, it could deliver USD 203-408 million of net-benefits through carbon sequestration, increased water infiltration and reduced sediments.

## 8. Planning, Monitoring and Knowledge Sharing

Focusing on the scaling-out of SLWM practices is indispensable to generate tangible positive impacts on the environment, food security and livelihoods. A comprehensive view is needed to consider the barriers that hinder adoption and scaling out of SLWM and to enhance an overall enabling environment that support this process. In particular, the “human” dimension and participatory land use planning approaches (as compared to the bio-physical assessments) needs to be further considered and elaborated. It is very crucial to share knowledge with small-holders and users in these areas to help them to adopt sustainable soil use and management practices (Hou, 2020).

Land use planning is part of the integrated land resources management continuum that starts with assessments of the land resource base followed by identification of needs and challenges, and finally by the selection and implementation of the best SLWM practices. This procedure is described by Figure 5, designed to inform decision-makers and stakeholders on the actions to be taken (Ziadat et. al., 2021). The guiding principles of land use planning places people at the centre of the process that also includes governance, enabling policies and institutions needed to implement sustainable land use planning. These actions are currently implemented or in the process of being implemented in many NENA countries (Zdruli, 2014).

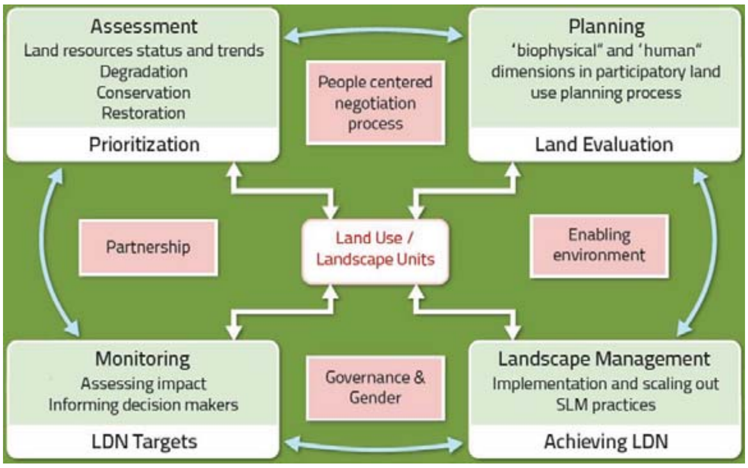


Figure 5. Four inter-related steps in the integrated land resources management continuum

The implementation process includes the development of standardized indicators and tools for assessing and monitoring the status of LDD and then collating this information to generate standard tools and approaches. The aim is to support the sustainable management of land resources through assessment, planning and implementation and to align these with the LDN and with NDC processes (FAO, 2018a) to support countries in achieving and reporting LDN and climate action targets (Figure 6).

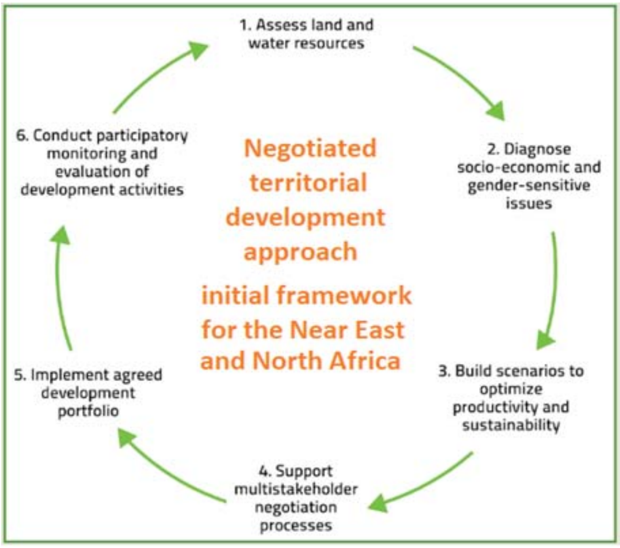


Figure 6. Negotiated territorial development approach – an initial framework for the NENA (FAO, 2016a)

### 9. Conclusions

Due to its large extent, great diversity of natural, socio-economic and political conditions, the NENA region is very complex. The bottom-up approach that puts people at the centre of ecosystems and proposes the development and implementation of good SLWM options is essential to achieve sustainable management of land and water resources and achieving LDN targets in particular and SDGs in general.

The most important conclusions and recommendations of this paper are tailored to provide a comprehensive package that could support sustainable management of precious and scarce land and water resources under harsh environmental and socio-economic conditions in NENA. These include:

- Analysis of the "land degradation – climate change – water scarcity – food security – migration" nexus to tackle the challenges and find sustainable options at different scales is needed to enhance sustainable use and management of limited land and soil resources of NENA.
- Promote the scaling-out of sustainable management options supported by appropriate and site-specific tailor-made policies to be able to enhance productivity and livelihoods.
- Investing in "land", accompanied with a need to provide knowledge on the costs and benefits of SLWM and to encourage investments by the private and public sectors.
- Enhance the governance of land and water resources and support sustainable management, access and tenure.
- Support transformations from degradation and vulnerability to sustainability and resilience. Tools and approaches should be promoted to assess, plan, manage, and monitor natural resources and to inform the decision-making process through a knowledge management and sharing platform.

Finally, enhancing land and water productivity and sustainability, combating land degradation, and coping with water scarcity are crucial for achieving food security, sustainable agriculture, and the SDGs. Options to enhance sustainable land and water management provide promising solutions. However, participatory planning across sectors and landscapes to identify potential solutions, coupled with proper enabling environment and support from policies, governance, and financial/investment mechanisms, are needed in order to enhance food production and sustainability of limited resources.

**Statement**

The views expressed in this publication are those of the author(s) and do not necessarily reflect the views or policies of the Food and Agriculture Organization of the United Nations.

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**References**

Abahussain, A. A., Abdu, A. Sh., Al-Zubari, W. K., El-Deen, N. A., & Abdul Raheem, M. (2002). Desertification in the Arab region: analysis of current status and trends. *J. Arid Environ., 51*, 521-545. https://doi.org/10.1006/jare.2002.0975

Akhtar-Schuster, M., Stringer, L. C., Erlewein, A., Metternicht, G., Minelli, S., Safriel, U., & Sommer, S. (2017). Unpacking the concept of land degradation neutrality and addressing its operation through the Rio Conventions, *Journal of Environmental Management, 195*, 4-15. https://doi.org/10.1016/j.jenvman.2016.09.044

Berrahmouni, N., Laestadius, L., Martucci, A., Mollicone, D., Patriarca, C., & Sacande, M. (2016). *Building Africa's Great Green Wall. Restoring degraded drylands for stronger and more resilient communities.* Food and Agriculture Organization of the United Nations.

Croitoru, L., & Sarraf, M. (2010). Measuring the Cost of Environmental Degradation. In L. Croitoru & M. Sarraf (Eds.), *The cost of environmental degradation: case studies from the Middle East and North Africa*. The World Bank, Washington DC. https://doi.org/10.1596/978-0-8213-8318-6

El-Kawy, O. R. A., Ismail, H. A., Rod, J. K., & Suliman, A. S. (2010). A developed GIS-based land evaluation model for agricultural land suitability assessments in arid and semi arid regions. *Research Journal of Agriculture and Biological Sciences, 6*(5), 589-599.

ELD. (2018). *Economics of Land Degradation Initiative. The Economics of Land Degradation Initiative.* Retrieved from http://www.eld-initiative.org/index.php?id=1

ELD and UNEP. (2018). *The Economics of Land Degradation Neutrality in Asia and Africa*. Retrieved from http://www.eld-initiative.org/fileadmin/pdf/Asia_Report_EN.pdf

Fana, C., Haji, J., Jaleta, M., Ademe, A., & Gebresenbet, G. (2021). Vulnerability of farmers to crop farming risks in Ethiopia: an integrated vulnerability analysis approach using social-ecological system framework. *Sustainable Agriculture Research, 10*(3), 25. https://doi.org/10.5539/sar.v10n3p25

FAO. (2015). *World Soil Charter.* Retrieved from http://www.fao.org/3/a-i4965e.pdf

FAO. (2016a). *Negotiated territorial development in a multi-stakeholders participatory resource planning* *approach: an initial sustainable framework for the Near East region*. Land and Water Division Working Paper No. 15. Rome.

FAO. (2016b). Near East and North Africa Regional Overview of Food Insecurity 2016. Cairo, pp. 35.

FAO. (2017a). *Voluntary Guidelines for Sustainable Soil Management.* Food and Agriculture Organization of the United Nations Rome, Italy.

FAO. (2017b). *Intended national contributions: global analyses and key findings.* FAO Rome, Italy. Retrieved from www.fao.org/3/a-i6573e.pdf

FAO. (2017c). *Near East and North Africa Regional Overview of Food Insecurity 2016*. Cairo. pp. 35

FAO. (2017d). *Sustainable Land Management (SLM) in practice in the Kegara Basin*. Land and Water Division. Food and Agriculture Organization of the United Nations: Rome, Italy

FAO. (2017e). *The future of food and agriculture: trends and challenges.* Food and Agriculture Organization of the United Nations: Rome, Italy. Retrieved from http://www.fao.org/3/a-i6583e.pdf

FAO. (2018a). *Regional analyses of the Nationally Determined Contributions of countries in Southern-Eastern Europe and Central Asia: Gaps and opportunities in the agriculture sectors*. Retrieved from http://www.fao.org/3/CA2518EN/ca2518en.pdf

FAO. (2018b). *FAO Regional Conference for the Near East Thirty-fourth Session Side Event: The Challenge of Sand and Dust Storms in the Near East and North Africa Region*. Retrieved from http://www.fao.org/fileadmin/user_upload/bodies/NERC_34/NERC34_SideEvents/MW769_SE_Challenge/MW769_NERC_18_CONCEPT_NOTE_SDS_en.pdf

FAO. (2018c). *Drought characteristics and management in North Africa and the Near East*. FAO Water Reports 45. Food and Agriculture Organization of the United Nations Rome, Italy.

FAO. (2019a). *Soil erosion: the greatest challenge to sustainable soil management*. Rome. Licence: CC BY-NC-SA 3.0 IGO. p. 100. Retrieved from http://www.iamb.it/uploads/attachments/794/web_Sustainable_land_management_and_land_restoration.pdf

FAO. (2019b). *Land Resources Planning Toolbox, User's Guide*. Retrieved from http://www.fao.org/3/ca5491en/ca5491en.pdf

FAO. (2019c). *The Multi-Faced role of Soil in the Near East and North Africa Region - Policy Brief*. Rome. Licence: CC BY-NC-SA 3.0 IGO. p. 36.

FAO. (2021). *Near East and North Africa Regional Forest Resource Assessment 2020 – Extent, changes and trends. Cairo*. https://doi.org/10.4060/cb7174en

FAO and ITPS. (2015). *Status of the World's Soil Resources.* Retrieved from http://www.fao.org/3/a-i5199e.pdf

FAO and ITPS. (2017). *Voluntary Guidelines for Sustainable Soil Management*. Retrieved from http://www.fao.org/3/a-bl813e.pdf

FAO and ITPS. (2020). *Protocol for the assessment of Sustainable Soil Management*. Rome, FAO. Retrieved from http://www.fao.org/fileadmin/user_upload//GSP/SSM/SSM_Protocol_EN_006.pdf

FAOSTAT. FAO's global statistical database on food and agriculture. Retrieved from http://www.fao.org/faostat/en/#data

Fargues, P. (2017). International Migration and the Nation State in Arab Countries. *Middle East Law and Governance, 5*, 5-35. https://doi.org/10.1163/18763375-00501001

GEF. (2018). *GEF-7 Replenishment Programming Directions.* Global Environment Facility. Fourth Meeting for the Seventh Replenishment of the GEF Trust Fund. Stockholm, Sweden. Retrieved from https://www.thegef.org/sites/default/files/council-meeting-documents/GEF-7%20Programming%20Directions%20-%20GEF_R.7_19.pdf

Harari, N., Gavilano, A., & Liniger, H. P. (2017). *Where people and their land are safer: A Compendium of Good Practices in Disaster Risk Reduction*. Bern and Lucerne, Switzerland: Centre for Development and Environment (CDE), University of Bern, and Swiss NGO Disaster Risk Reduction (DRR) Platform, with Bern Open Publishing.

Hou, D. (2020). Knowledge sharing and adoption behaviour: An imperative to promote sustainable soil use and management. *Soil Use and Management, 36*(4), 557-560. https://doi.org/10.1111/sum.12648

Hou, D., Bolan, N. S., Tsang, D. C. W., Kirkham, M. B., & O'Connor, D. (2020). Sustainable soil use and management: An interdisciplinary and systematic approach. *Science of the Total Environment, 729*. https://doi.org/10.1016/j.scitotenv.2020.138961

Hussein, M. A. (2008). Costs of environmental degradation: An analysis in the Middle East and North Africa region. *Management of Environmental Quality: An International Journal, 19*(3), 305-317. https://doi.org/10.1108/14777830810866437

IPBES. (2018). Summary for policymakers of the thematic assessment report on land degradation and restoration of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. L. Montanarella, R. Scholes & A. Brainich (Eds.), *Bonn: IPBES Secretariat*. Retrieved from www.ipbes.net/assessment-reports/ldr

IPCC. (2019). *Climate Change and Land. Summary for Policy Makers.* Retrieved from https://www.ipcc.ch/site/assets/uploads/2019/08/Fullreport.pdf

Liniger, H. P., & Critchley, W., (Eds.). (2007). *Where the land is greener - case studies and analysis of soil and water conservation initiatives worldwide.* World Overview of Conservation Approaches and Technologies (WOCAT). p. 364.

Liniger, H., Harari, N., Fleiner, R., & van Lynden, G. (2018). *Achieving land degradation neutrality: the role of knowledge sharing and evidence-based decision-making*. Questionnaires on Sustainable Land Management (SLM) Technologies and Approaches: A tool to help document, assess, and disseminate SLM practices. World Overview of Conservation Approaches and Technologies (WOCAT). https://doi.org/10.1016/j.envsci.2019.01.001

Lipper, L., DeFries, R., & Bizikova, L. (2020). Shedding light on the evidence blind spots confounding the multiple objectives of SDG 2. *Nat. Plants, 6*, 1203-1210. https://doi.org/10.1038/s41477-020-00792-y

Nkonya, E., Mirzabaev, A., & von Braun, J. (Eds.). (2016). *Economics of land degradation and improvement- A global assessment for sustainable development*. Spinger Cham Heildelberg New York Dordrecht London. https://doi.org/10.1007/978-3-319-19168-3

Mcleman, R. (2017). *Migration and land degradation: Recent experience and future trends*. Global Land Outlook Working Paper. UNCCD, Bonn, Germany.

Mahmoodi-Eshkaftaki, M., Haghighi, A., & Houshyar, E. (2020). Land suitability evaluation using image processing based on determination of soil texture-structure and soil features. *Soil Use and Management, 36*(3), 351-355. https://doi.org/10.1111/sum.12572

Montgomery, D. R. (2007). Soil erosion and agricultural sustainability. *Proc Natl Acad Sci USA, 104*(33), 13268-72. https://doi.org/10.1073/pnas.0611508104

Orr, B. J., Cowie, A. L., Castillo Sanchez, V. M., Chasek, P., Crossman, N. D. … Welton, S. (2017). *Scientific Conceptual Framework for Land Degradation Neutrality.* A Report of the Science-Policy Interface. United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany. https://doi.org/10.1016/j.envsci.2017.10.011

Schwilch, G., Bestelmeyer, B., Bunning, S., Critchley, W., Herrick, J., … Winslow M. (2011). Experiences in Monitoring and Assessment of Sustainable Land Management. *Land Degradation & Development, 22*(2), 214-225. https://doi.org/10.1002/ldr.1040

Stockman, U., Minasny, B., & McBratney, A. B. (2014). How fast does soil grow? *Geoderma, 216*, 48-61. https://doi.org/10.1016/j.geoderma.2013.10.007

Sustainable Food Trust. (2015). *Moroccan agriculture: Facing the challenges of a divided system*. Retrieved from https://sustainablefoodtrust.org/articles/moroccan-agriculture-facing-challenges-divided-system/

Tuel, A., & Eltahir, A. B. (2020). Why Is the Mediterranean a Climate Change Hot Spot? *Journal of Climate, 33*(14), 5829-5843. https://doi.org/10.1175/JCLI-D-19-0910.1

World Resource Institute. (2014). *Atlas of Forest and Landscape Restoration Opportunities.* Retrieved from https://www.wri.org/resources/maps/atlas-forest-and-landscape-restoration-opportunities

UNCCD-GM. (2016). *Achieving Land Degradation Neutrality at the country level - Building blocks for LDN Target Setting*. Bonn, Germany: Global Mechanism (GM) of the United Nations Conventions to Combat Desertification (UNCCD). Retrieved from https://www.unccd.int/publications/achieving-land-degradation-neutrality-country-level-building-blocks-ldn

-target-setting

UNEP. (1992). *The Status of Desertification and Implementation of the United Nations Plan of Action to Combat Desertification*. Nairobi: UNEP.

UNFCCC. (2017). *Decision -/CP.23. Koronivia Joint Work on Agriculture.* Retrieved from http://unfccc.int/files/meetings/bonn_nov_2017/application/pdf/cp23_auv_agri.pdf

United Nations. (1992). *Agenda 21: The United Nations Programme of Action from Rio*. New York, USA.

Zdruli, P., Paglai, M., Kapur, S., & Faz Cano, A. (2010). What we know about the saga of land degradation and how to deal with it? In P. Zdruli, M. Pagliai, S. Kapur, & A. Faz Cano (Eds.), *Land Degradation and Desertification: Assessment Mitigation and Remediation* (pp. 3-15). Springer Dordrecht Heidelberg London New York. https://doi.org/10.1007/978-90-481-8657-0_1

Zdruli, P. (2014). Land resources of the Mediterranean: status, pressures, trends and impacts on regional future development. *Land Degradation & Development, 25*, 373-384. https://doi.org/10.1002/ldr.2150

Ziadat, F., Mazahreh, S., Haddad, M., Benabdelouahab, T., Attaher, S., Karrou, M., Oweis, T., & Kandakji, T. (2014). *Similarity and Suitability Analysis to Assist the Out-Scaling of Sustainable Water and Land Management Practices in West Asia and North Africa*. Research Report, 11, Beirut, ICARDA.

Ziadat, F., Berrahmouni, N., Grewer, U., Bunning, S., Bockel, L., & Oweis, T. (2015). Reversing land degradation in the drylands: scaling out and monitoring proven sustainable land management options. In J. Griffiths (Ed.), *Living land* (pp. 14-17). United Nations Convention to Combat Desertification.

Ziadat, F., De Pauw, E., Nachtergaele, F., & Fetsi, T. (2021). A Land Resources Planning Toolbox to Promote Sustainable Land Management. *Sustainable Agriculture Research, 10*(1), 73. https://doi.org/10.5539/sar.v10n1p73

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# Economic Analysis of Ginseng Based Forest Farming: a Sustainable Income Diversification Opportunity for Forest Landowners

Prabodh Illukpitiya[1], Avis Ortiz[1] & Fisseha Tegegne[1]

[1] Department of Agricultural and Environmental Sciences, Tennessee State University, 3500 John A. Merritt Blvd, Nashville Tennessee 37209, USA

Correspondence: Prabodh Illukpitiya, Department of Agricultural and Environmental Sciences, Tennessee State University, 3500 John A. Merritt Blvd, Nashville Tennessee 37209, USA. Tel: 615-963-1877. E-mail: pillukpi@tnstate.edu

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**Abstract**

While American ginseng is a complicated opportunity for forest farmers to understand, within these production systems there are many opportunities and constraints linked to production of ginseng. There are different market demands and prices paid for the various grades of dried roots depending on the system used to cultivate the plant. This study reviewed the unique benefits of producing ginseng, opportunities for forest farmers, the potential profits, as well as financial risks. The study focused on two common ginseng production systems in the southeastern region of the U.S. The specific objective of the paper is to assess economic returns of producing ginseng under different production systems. The Monte Carlo simulation was performed to analyze the profitability and risks associated with producing ginseng and performed sensitive analysis to determine the effect of uncertainty variables such as production costs, yield, and price of product on economic feasibility.

**Keywords:** economic returns, forest farming, ginseng, income diversification, Monte Carlo simulation, sensitivity analysis

## 1. Introduction

American ginseng (*Panax quinquefolius* L.) is indigenous to the southern portions of Ontario and Quebec in Canada and deciduous forests in the mid-western, southern and eastern parts of the United States (Cheng and Mitchell, 2009; Punja, 2011). American ginseng has been cultivated in the U.S. since the late 1800's and also grown in ginseng farms (Beyfuss, 1999; USFWS, n.d). Ginseng is being distributed in 35 countries around the world and there are differences by each country in the distribution volume and amount (Baeg and So, 2013). While cultivation of this plant species has taken place in North America for over 100 years, there are many challenges that need to be addressed. While ginseng is native to eastern North America, major producers of wild ginseng thrive along most of the nation's eastern seaboard, from Maine to Alabama and west to Michigan, Wisconsin and Minnesota. It still grows wild, but it was over-harvested and was subsequently defined as an endangered species in 1975 (Harrison et al., 2015; USFWS n.d; Vaughn et al., 2011).

Ginseng is unique in its several benefits for a range of health conditions.Its roots have many benefits such as helps in weight loss, preventing and managing diabetes, reduce stress and anxiety etc. Moreover, growing ginseng promises lucrative financial for the growers (Maher, 2014). For example, given favorable climatic conditions and with little capital investment, it is possible to gain up to $26,880 worth of the prized botanical on only 0.2 ha (about half an acre) woodland in 10 year cycle (Ha et al., 2017). For generations, Appalachian residents have harvested ginseng roots as a source of extra income (Hankins, 2014). Often, whole families would search the woods each fall for the distinctive three or four-pronged plant and the lucrative roots lying beneath its yellow leaves (Axtell, 2012).Ginseng is so prized for its medicinal properties that poaching and overharvesting of the plant by collectors threatens to wipe out wild Appalachian ginseng from North Carolina's forests and dried roots sell for $1,100-$1,320/kg (Axtel, 2012). Ginseng is one of the most popular holiday gifts in China. American ginseng is stamped with a 100% guarantee. Few consumers are more faithful to American products than Chinese users of ginseng: The U.S. exported $77.3 million in ginseng roots in year 2014, most of it to Hong Kong, and American ginseng fetches the highest price of any cultivated variety (Shyong, 2015).

According to the U.S. Department of Commerce, US has long history of exporting dried wild ginseng roots.

While American ginseng is a "complicated opportunity for forest farmers to understand, it can be grown in many different production systems" (Wallin, 2016). Within these production systems there are many opportunities and constraints linked to this plant. There are different market demands and prices paid for the different grades of the dried roots depending on the system used to cultivate the plant. This could provide an opportunity to learn about forest income enterprises other than timber (Wallin, 2016). Also in a survey among landowners in the southern US, nearly forty percent indicated a desire for more information on forest farming (Workman et al., 2003), and over half of the extension agents and almost 30 percent of foresters in the Mid-Atlantic states have been queried by landowners about ginseng income opportunities (Kays, 2004). Considering the above facts, the major objective of this paper is to analyze economic returns of producing ginseng under natural production systems and to determine the effect of uncertainty variables on net return using Monte Carlo simulation.

## 2. Methodology

Given the different systems of ginseng production, evaluation of profitability from each system is important for producers to identify the most appropriate choice that provide them highest income. Therefore, the economic analysis is mainly focused on the producer's point of view concerning ginseng root production under two different systems. This information is also useful for potential forest land owners who are interested in identifying least cost production system that gives highest net return in ginseng production. In ginseng, the cost of production includes commonly used cost categories from land preparation to harvesting and drying. The analysis assumes that ginseng production is on own land hence rental costs were excluded from the analysis. It should be noted that certain field operations are not performed regularly and uniformly year after year, therefore, annual costs may differ over the crop's life. From an economic point of view, the overall approach is to estimate range of outcome give various input distributions. Rational economic decision-makers are assumed to make crop production decisions by choosing crop that maximize their profits under risk and uncertainty. The landowner's overall objective is to maximize profit, which is the net return from selected enterprise. The profit function ($\pi_j$) can be represented by (Yuldashev et al., 2020):

$$\pi_j = \Sigma[(P_j * Y_j) - (Q_j * P_{Ij}) - FC_j]$$

Where $\pi_j$ represents profit of j$^{th}$ ginseng producer (\$/ha yr$^{-1}$), $Y_j$ represents yield of ginseng for the j$^{th}$ producer (kg/ha yr$^{-1}$), $P_j$ represents selling price of ginseng for the j$^{th}$ producer (\$/kg), $Q_j$ represents variable inputs applied during ginseng production such as labor for various field operations, seed, soil amendments, fertilizer, other agrochemicals; $P_{Ij}$ represents price of the $j^{th}$ input applied for ginseng production. For example, $\Sigma(Q_j * P_{Ij})$ represent total variable costs of production and $FC_j$ represents total fixed cost. Based on our data, we identified range of values for input costs, price and biomass yield, just like the triangular distribution. However, the triangular distribution may place too much emphasis on the most likely value, at the expense of the values to either side hence is limited in its ability to model real-world estimates (Palisade, n.d). Therefore we used pert distribution which is designed to generate a distribution that more closely resembles realistic probability distribution. The pert distribution constructs a smooth curve which places progressively more emphasis on values around (near) the most likely value, in favor of values around the edges. Given that many real-world phenomena are normally distributed, the pert distribution produces a curve similar to the normal curve. Depending on the values provided, the pert distribution can provide a close fit to the normal or lognormal distributions. Range of net returns were calculated based on random samples obtained from yield-price-cost distributions with the help of Monte Carlo simulation (Arnold and Yildiz, 2015; Sgroiet al., 2015). In Monte Carlo simulation, uncertain inputs (such as input costs, yield and price) in a model are represented using ranges of possible values known as probability distributions. By using probability distributions, variables can have different probabilities of different outcomes (net return) occurring. Probability distributions are a much more realistic way of describing uncertainty in variables of a risk analysis. The sensitivity analysis was performed to evaluate the effect of uncertain variables in net return.

Given limited availability of production data of ginseng, we usedmulti-method approach which encourages collecting, analyzing and integrating data from several sources. The data collected represented the different types and methods for producing ginseng mainly wood cultivated and wild simulated. Data was collected from published reports, enterprise budgets from University Extension services and producer survey.The data collected was focused on input costs from land preparation up to harvesting and drying, ginseng yields and market prices of ginseng. Specifically production data included costs for seed, labor, fertilizer, other agrochemicals, equipment such as back pack sprayers, drying equipment, security cameras etc. Market prices were used to estimate input costs of the different types of ginseng. Based on the literature, production cycle for woods-cultivated ginseng was considered as 6-8 years, and wild-simulated ginseng as 7-12 years. The data showed that the cost of production varies with quality and quantity, and form year to year based on supply and demand.

The analysis was based on the notion that average figures do not reflect range of outcome; therefore, there is a need to assess the uncertainty of variables to be identified and considered for possible range of net return under various scenarios for ginseng production. Monte Carlo simulation was performed using risk analysis software (@Risk) to measure range of outcomes by incorporating uncertainty function based on random samples generated. Monte Carlo simulation generates large number of random samples and estimate true mean, which is the average of net profit across large number of random samples.

## 3. Results

The results of the Monte Carlo simulation for wood cultivated and wild simulated ginseng production systems are discussed below.

### *3.1 Wood Cultivated Ginseng*

Figure 1-3 shows input distribution of wood cultivated ginseng. Accordingly, within 90% confidence interval, estimated yield of the wood cultivated ginseng range from 699 – 783 kg/ha with the mean yield of 741 kg/ha. The minimum potential yield was 675 kg/ha and the maximum potential yield was 807 kg/ha. There is a 90% probability that the selling price will range from $241 - $309/kg. Also under 90% confidence interval, the estimated unit cost of the wood cultivated ginseng ranges from $77 - $137/kg. The minimum potential unit cost per cycle was $71/kg and the maximum cost was $173/kg with the mean of $103/kg.

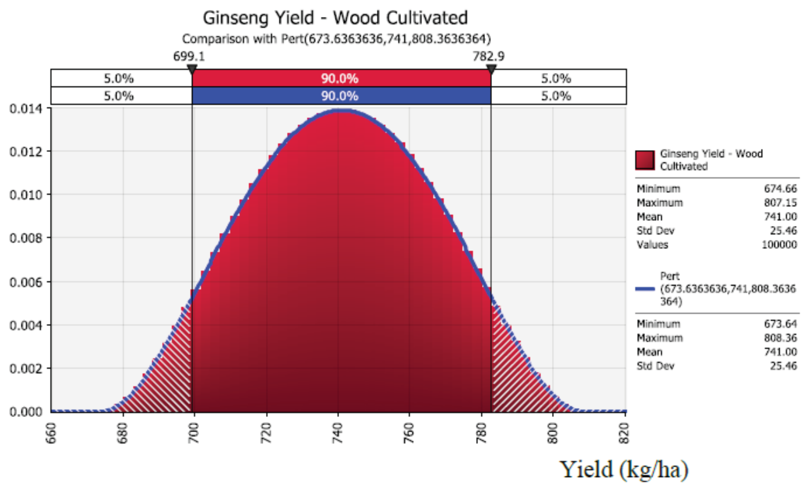


Figure 1. Potential yield distribution of wood cultivated ginseng

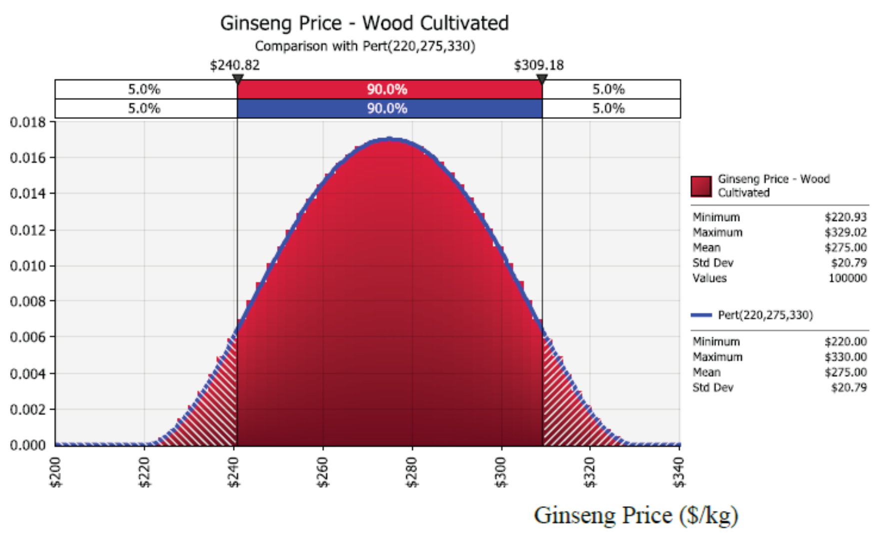


Figure 2. Potential price distribution of wood cultivated ginseng

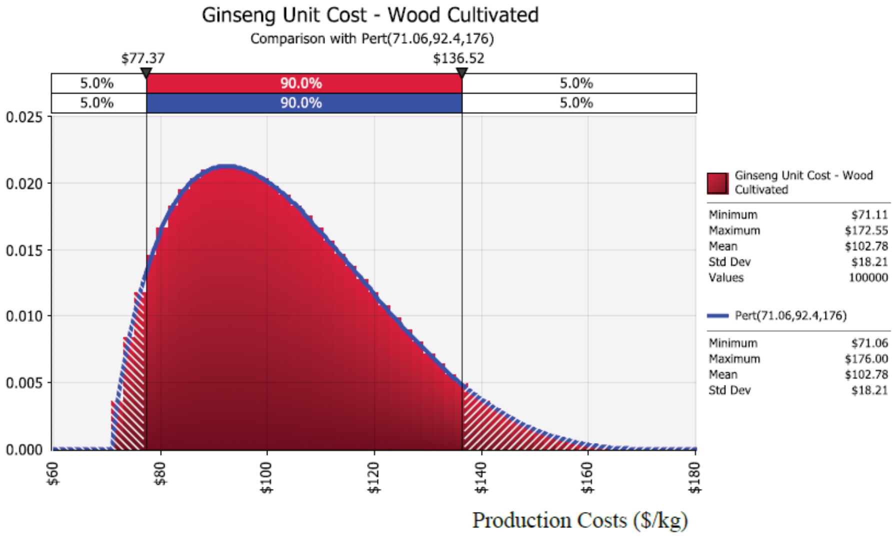


Figure 3. Potential unit cost distribution of wood cultivated ginseng

Figure 4 shows the net profit for wood cultivated ginseng, accordingly, there is high probability (0.90) that the net profit will range from $89,682 - $158,624/cycle. The estimated minimum potential net profit was $48,966 and the maximum net profit was $192,006 with the mean of $124,816/cycle.

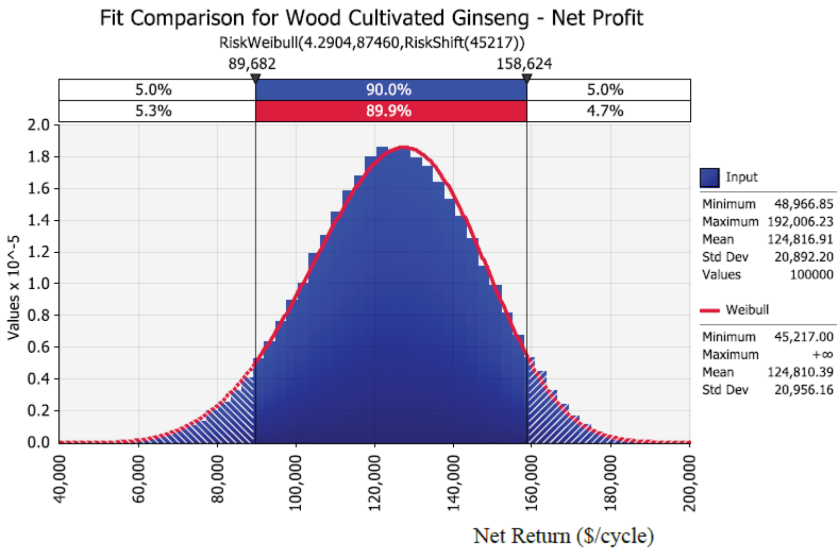


Figure 4. Distribution of net return from wood cultivated ginseng

Figure 5 shows the correlation between ginseng yield, price and unit cost to net profit. The Tornado graph (Figure 6) shows the general trend of the association between key risk variables with net return from feedstock production (Figure 5). The longer the bar or the larger the coefficient, the greater the impact that particular input has on the net return. For example, the unit production costs ($/ha) show inverse (negative) relationship with profit while ginseng yield and price show a positive relationship with net return. In tornado graph, the regression coefficients doesn't express them in terms of actual dollar value. They are scaled or normalized by the standard deviation of the output and the standard deviation of that input. For example, regression coefficient of selling price of ginseng was 0.73. This means that for every k fraction of a standard deviation (SD) increase in selling price, the net return will increase by 0.73k standard deviations. To get from that coefficient to the actual coefficient in terms of unit of price and unit of net return, we need to multiply by the SD of the net return and divide by the SD of the price.


Figure 5. Correlation between net return and stochastic variables

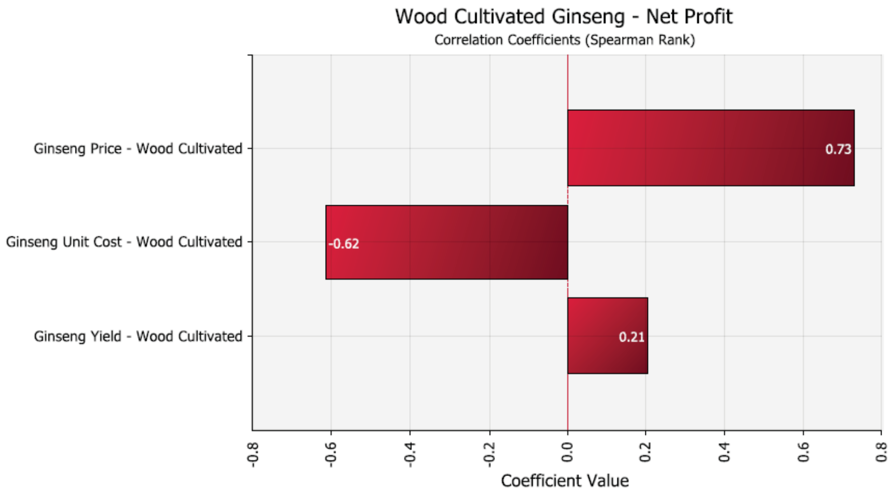


Figure 6. Tornado graph for wood cultivated ginseng

*3.2 Wild Simulated Ginseng*

Figure 7 – 9 shows input distribution of wild simulated ginseng. Accordingly, within 90% confidence interval, the estimated yield of the wild simulated ginseng ranges from 184 – 198 kg/ha with the mean of 191 kg/ha. The estimated minimum potential yield was 180 kg/ha and the maximum potential yield is 202 kg/ha. Also under 90% confidence interval, selling price of ginseng ranges from $701 - $838/kg while the estimated unit cost of the wild simulated ginseng could range from $159 - $232/kg. The minimum and maximum potential unit cost was $134 & $237/kg respectively with mean of $193/kg.

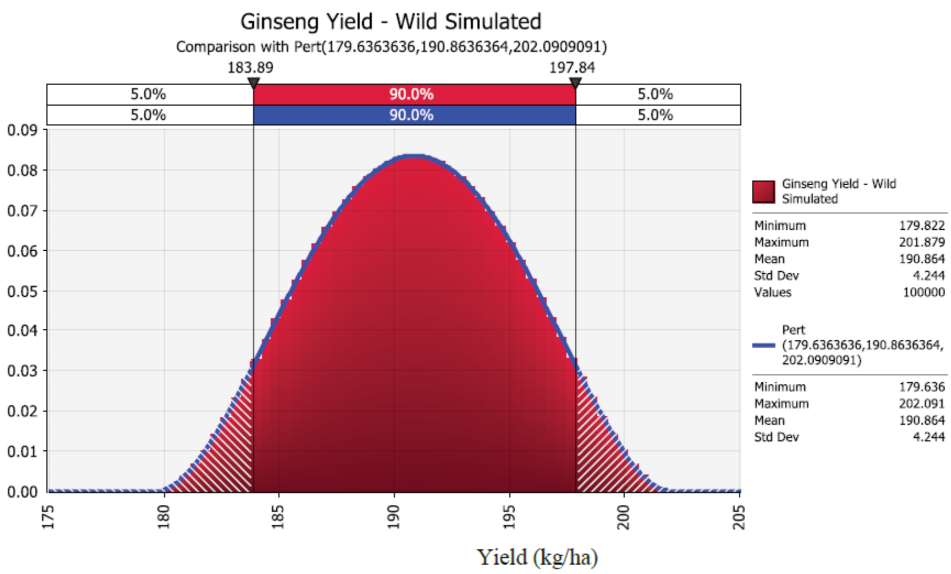


Figure 7. Potential yield distribution of wild simulated ginseng

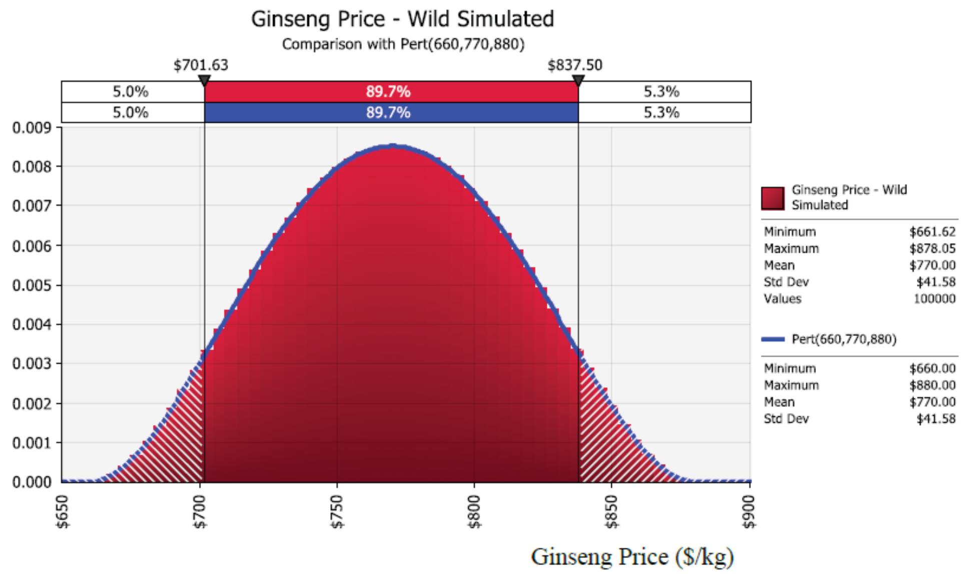


Figure 8. Potential price distribution of wild simulated ginseng

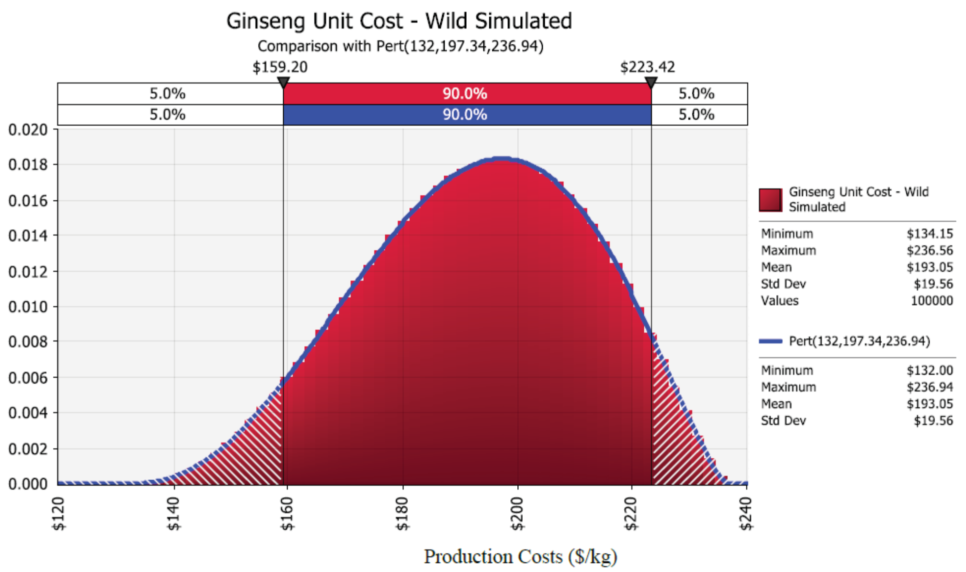


Figure 9. Potential unit cost distribution of wild simulated ginseng

Figure 10 shows the net profit for wild simulated ginseng. According to 90% confidence interval, the estimated net profit ranges from $94,200 and $124,314/cycle with the mean net return of $109,168/cycle. The minimum potential net profit was $79,967 and the maximum net profit was $141,740/cycle.

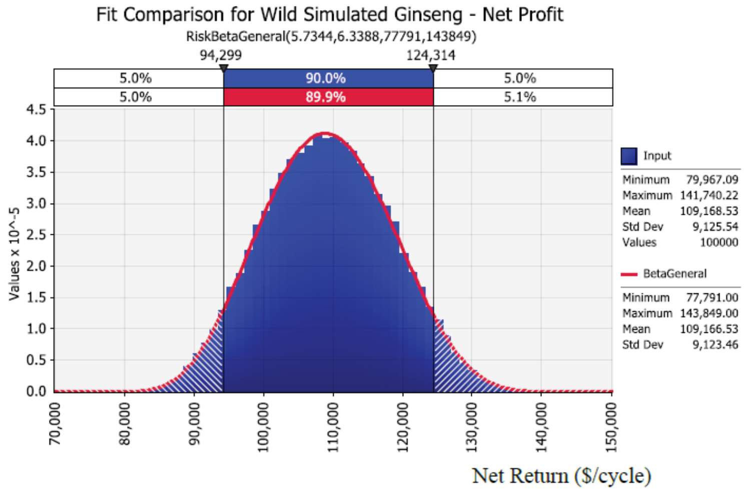

Figure10. Distribution of net return from wild simulated ginseng

Figure 11 shows the correlation between wild simulated ginseng yield, price and unit cost to net profit. Pearson correlation coefficient was 0.26, 0.87 and -0.41 respectively for yield, price and unit costs of production. Unit production costs of ginseng is negatively correlated with net profit. Moreover, negative correlation with net profit shows possibility of lower profit under low yield though lower production is theoretically associated with higher product price. The typical selling price is high at low yield, but decreased yield does not make up to recover the losses. Compared to yield, ginseng price is highly correlated to net return while higher unit costs lower the net return to the producer (Figure 12).

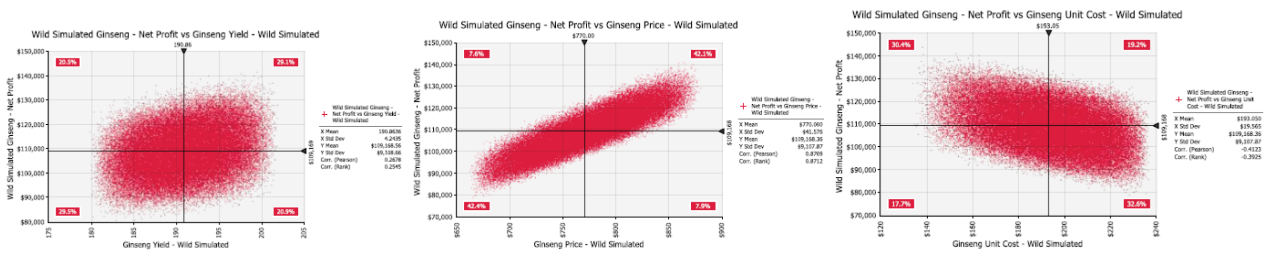

Figure 11. Correlation between net return and stochastic variables in wild simulated ginseng

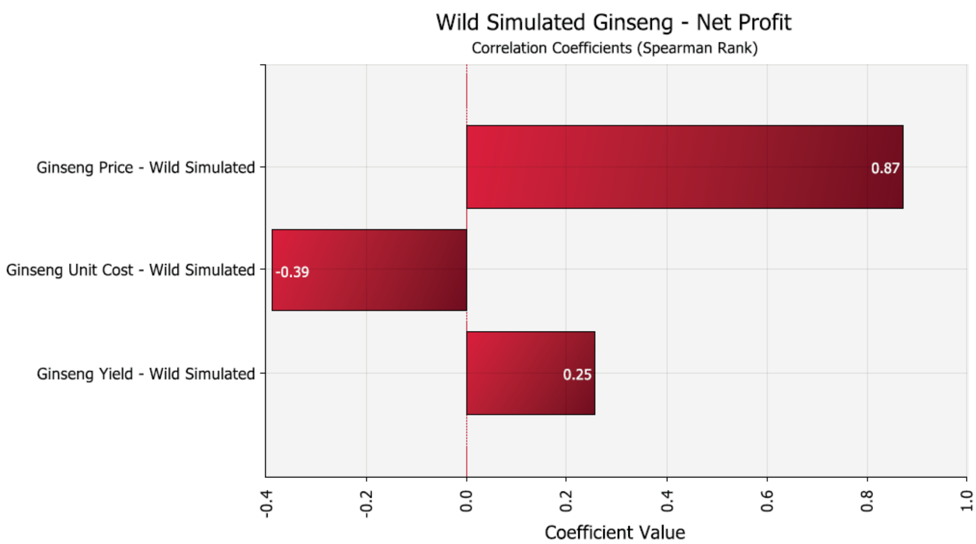

Figure 12. Tornado graph for wild simulated ginseng Conclusion

## 4. Conclusion

This study was focused on the feasibility of producing American ginseng and its unique benefits to producers. The Monte Carlo simulation was performed to assess the viability of cultivating ginseng under the different cultivating systems. The goal was to place emphasis on potential risk variables that could impact net returns namely, production costs, yields, and price of the product. Information gathered from various sources on key production inputswere used to compare and analyze the economic returns and risks associated with producing ginseng. The findings revealed that among the two production methods, the mean ginseng yield was approximately 741/kg ha$^{-1}$ and 191 /kg ha$^{-1}$in wood cultivated and wild simulated systems respectively. Although yield is comparatively low, market price of wild simulated ginseng was much higher ($770/kg) compared to wood cultivated ginseng ($275). The mean net return of wild simulated ginseng was $109,668/cycle while in wood cultivated system, the mean net return was $124,816 per cycle. These results suggest the economic feasibility of investment for ginseng as a long term forest based investment. Although production of ginseng is profitable, there are certain risks involved, and producing ginseng can be a way for forest landowners to utilize their land and subsidize their annual incomes.Most new growers of ginseng are attracted by the potential profits. Since this is a lucrative investment opportunity for forest landowners, there is a need for practical training, resource materials, and outreach materials on ginseng production. There is a need for landowners to have more education and training on the different production systems. The University outreach services could play an important role by designing training programs, demonstration sessions, pilot programs and information needed for growers. In addition, production of ginseng needs support from federal and state agencies to access technical and financial resources needed for growers. This could provide an opportunity to learn and invest on forest income enterprises such as production of ginseng

## References

Arnold, U., & Yildiz, Ö. (2015). Economic risk analysis of decentralized renewable energy infrastructures–A Monte Carlo Simulation approach. *Renewable Energy, 77*, 227-239. https://doi.org/10.1016/j.renene.2014.11.059

Axtell, N. (2012). *Forest farming key to saving wild ginseng from extinction*. Retrieved from http://www.blueridgenow.com/article/20121209/ARTICLES/121209833

Baeg, I., & So, S. (2013). The world ginseng market and the ginseng (Korea). *Journal of Ginseng Research, 27*(1), 1-7. https://doi.org/10.5142/jgr.2013.37.1

Beyfuss, R. (1999). *Economics and marketing of ginseng.* Retrieved from http://www.wvfa.org/pdf/sfi/ginseng.pdf

Cheng, L., & Mitchell, P. (2009). *Status of the Wisconsin ginseng industry.* Retrieved from https://www.aae.wisc.edu/pubs/misc/docs/Mitchell.WI.Ginseng.Industry.2009.pdf

Ha, K., Atallah, S., Benjamin, T., Fariee, L., Hoagland, L., & Woeste, K. (2017). *Costs and returns of producing wild-simulated ginseng in established tree plantations.* Purdue Extension, FNR-550-W. Retrieved from https://www.fs.fed.us/nrs/pubs/jrnl/2017/nrs_2017_ha_001.pdf

Hankins, A. (2014). *Wild-simulated forest farming for ginseng production*. Retrieved from http://www.aftaweb.org/latest-newsletter/temporate-agroforester/57-1997-vol-5/january-no-1/23-forest-ginseng-production.html

Hankins, A. (2009). *Producing and marketing wild simulated ginseng in forest and agroforestry systems.* Retrieved from http://pubs.ext.vt.edu/354/354-312/354-312.html

Harrison, H. C., Parke, J. L., Oelke, E. A., Kaminski, A. R., Hudelson, B. D., Martin, L. J., … Binning, L. K. (2015). *Ginseng.* Alternative field crops manual. Retrieved from https://www.hort.purdue.edu/newcrop/afcm/ginseng.html

Kays, J. S. (2004). Alternative income opportunities: Needs of county agents and foresters in the Mid-Atlantic region. *Journal of Extension, 42*, Article 2RIB6. Retrieved from http://www.joe.org/joe/2004april/rb6.php

Maher, K. (2014). Demand for ginseng boosts prices, tempts poachers; medicinal herb grows wildly in Appalachia and the Midwest. *Wall Street Journal.* Retrieved from http://www.wsj.com/articles/demand-for-ginseng-boostsprices-tempts-poachers-1410971637

Palisade, (n.d). *Monte Carlo simulation*. Retrieved from https://www.palisade.com/risk/monte_carlo_simulation.asp

Punja, Z. K. (2011). American ginseng: research developments, opportunities, and challenges. *Journal of Ginseng Research, 35*(3), 368-374. https://doi.org/10.5142/jgr.2011.35.3.368

Shyong, F. (2015). *American ginseng has a loyal Chinese clientele.* Retrieved from http://www.latimes.com/local/california/la-me-adv-ginseng-american-20150301-story.html

USFWS. (n.d). *American ginseng*. U.S. Fish and Wildlife Service. Retrieved from http://www.fws.gov/international/plants/american-ginseng.html

Vaughn, R., Chamberlain, J., & Munsell, J., (2011). *Growing American ginseng (Panax quinquefolius) in forestlands*. Retrieved from http://pubs.ext.vt.edu/354/354-313/354-313.html.

Wallin, C. (2016). *Ginseng: A high value crop with long term potential!* Retrieved from http://www.profitableplantsdigest.com/ginseng/#wrap

Workman, S. W., Bannister, M. E., & Nair, P. K. R. (2003). Agroforestry potential in the Southeastern United States: Perceptions of landowners and extension professionals. *Agroforestry Systems, 59*, 73-83. https://doi.org/10.1023/A:1026193204801

Yuldashev, F., Illukpitiya, P., Tegegne, F., & Ekanem, E. (2020). Techno-economic analysis of plantation biomass production and small-scale wood pellet processing for bioenergy market, *International Wood Products Journal, 11*(4), 173-188. https://doi.org/10.1080/20426445.2020.1816766

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# Crop Yield Estimation of Teff (*Eragrostis tef* Zuccagni) Using Geospatial Technology and Machine Learning Algorithm in the Central Highlands of Ethiopia

Hailu Shiferaw[1], Getachew Tesfaye[2], Habtamu Sewnet[3] & Leulseged Tamene[4]

[1] Water and Land Resource Center, Addis Ababa University, P.O.Box 7985, Addis Ababa, Ethiopia

[2] Remote Sensing Department, Earth Observation Division, Ethiopian Space Science Technology Institute (ESSTI), Addis Ababa, Ethiopia

[3] Geospatial Institute, Addis Ababa, Ethiopia

[4] International Center for Tropical Agriculture (CIAT), Addis Ababa, Ethiopia

Correspondence: Hailu Shiferaw, Water and Land Resource Center, Addis Ababa University, P.O.Box 7985, Addis Ababa, Ethiopia. E-mail: hailushi31@yahoo.com

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**Abstract**

The genus *Eragrostis tef* Zuccagni is commonly known as "Teff", is an indigenous cereal crop and is the major staple food crop in Ethiopia. It is mostly used to prepare a spongy flatbread called "*Injera*" and is consumed by more than 70% of the Ethiopian people. This study is conducted at nine Teff-dominated zones of the country to examine whether geospatial technology can serve to estimate the productivity of crop yield. For this, ground truth sample plots were used for nine zones, and geospatial technology and machine learning were applied for upscaling to the whole study area's scale. Very good correlation results were obtained from spatial predictions of Teff yield for 2015 and 2020 with ROC-AUC of 89 and 91% and $R^2$ of 0.67 and 0.73, respectively. The average predicted yields of Teff were about 1.37 t/ha and 1.99 t/ha for 2015 and 20202, respectively, indicating that such technology can offer a very good result to estimate yields for unreachable areas in the case of either during unfavorable political or other natural conditions. By doing so, we can plan to apply such technologies that can serve to save time, effort, and resources.

**Keywords:** crop yield, geospatial technology, *Injera*, machine learning, Random Forest algorithm, Teff

## 1. Introduction

The genus *Eragrostis tef* Zucc. is commonly known as "Teff" is an indigenous cereal crop of Ethiopia. Teff is one of the major crops and has the largest value in terms of both production and consumption (Nandeshwar et al., 2020; Lee, 2018; Minten et al., 2016). It is mostly used to prepare a spongy flatbread called "*Injera*" (Wato, 2019) and is consumed by more than 70% of the Ethiopian people as a staple food (Tamirat and Tilahun, 2020; Firdisa, 2016). Ethiopia is the only country that grows Teff as a major staple food crop. Teff accounts for the primary crop in area coverage and stands second in total annual production next to maize but ranks the lowest yield compared with other cereals grown in Ethiopia (Lakew and Berhanu, 2019; Tesfahun, 2018). Teff covers quite half the farmland area under cereals in Ethiopia (Habtegebrial et al., 2007), which is about 2.97 million hectares (CSA, 2014). Indeed, its production area is increasing from time to time following increased local and foreign market demands (Hailu and Seyfu, 2000). Teff is hand-broadcasted on the prepared farm field and its seeds are left uncovered (Sate and Tafese, 2016).

Besides to the seeds, farmers highly value Teff's straw as a source of animal feed, particularly during the dry season (Lakew and Berhanu, 2019; Tesfahun, 2018; Cheng et al., 2017; Redden, 2012). The straw is also used to reinforce mud and plaster the walls of *Tukuls* for local grain storage and traditional huts (Lakew and Berhanu, 2019; Amare and Adane, 2015). Currently, it has got great attention globally due to its gluten-free crop, tolerance to biotic and abiotic stress, animal feed, and erosion control quality (Tamirat and Tilahun, 2020; Sate and Tafese, 2016; Amare and Adane, 2015). Teff is one of the strategic food crops for Ethiopia and constitutes two-thirds of the daily protein intake and 11% of the per capita caloric intake of typical households of the country (Crymes, 2015). Thus, Teff is a crucial and economically superior commodity and incorporates a significant contribution to the livelihood and food security of many Ethiopians. Looking at environmental requirements, Teff can be grown over a wide range of altitudes (i.e., from near sea level to 3,000 m.a.s.l), but the crop has shown its best performance at an altitude ranging from 1,100 and 2,950 m.a.s.l (Tadesse et al., 2016). Scholars have reported that Teff is a relatively resistant crop to several biotic and abiotic stress (FAO, 2015; Seyfu, 1997). Thus, Teff could be adapted and harvested during drought years, while other crops are failed (Zhu, 2018) when food scarcity prevails and used for food in Ethiopia.

Proper estimation of crop yield at different scales is needed to enhance the realm of food production and support the food security programs at the regional and national levels. However, the crop production estimates are often based on the conventional labor-intensive surveys, which are expensive, at risk of large errors, and aren't easily scalable and readily available on time, not comprehensive. Consequently, many more remains unknown about the quantity of crop yield (particularly Teff) produced over different locations.

Very good progresses and achievements are made in crop yield estimation using remotely sensed data (Battude et al., 2016; Johnson, 2014). Basically, the goal of remote sensing, in this case, is to spectrally measure crop biophysical variables associated to crop conditions and yield, which might subsequently be converted to actual yield estimation using different forms of deterministic or regression methods (Tesfaye et al., 2021). The utilization of satellite imagery in monitoring and estimating Teff crop yield is extremely limited both at the national and local levels. But the recent advances in remote sensing science and freely availability of high-resolution earth observation data as well as geospatial analysis algorithms have brought great opportunities to estimate the crop yield of Teff (Sewnet et al., 2021; Tesfaye et al., 2021).

Many studies reveal that remote sensing-based crop yield estimation provides reliable and accurate results than the conventional one and is now becoming a growing research area (Battude et al., 2016; Johnson, 2014). The bulk of the previous research works was focused on globally recognized cereal crops (e.g., maize, wheat, rice) cultivated over large farmlands in developed countries. However, Teff is an indigenous cereal crop of Ethiopia, which grows within the smallholder farming systems, and doesn’t have international research reports.

In Ethiopia, where food production remains with subsistence farming levels, the yield estimation methods should be robust, to sufficiently signify the supply of foods and source of incomes, and should try to benefit from the advancement of high resolution data, freely available remote sensing products, and machine learning models. The main objective of this research is to estimate the yield of Teff (*Eragrostis tef*) in two time periods (2015 and 2020) using remote sensing and geospatial technologies and a robust machine learning algorithm. The specific objectives were to: (1) regress agronomic, climate, biomass, and other related factors and identify governing factors of Teff growth and production, and (2) determine the *Meher* (main) season yield of Teff using geospatial and machine learning technologies and compared with conventional estimation approach over Teff dominated areas in the nine selected zones.

## 2. Materials and Methods

### *2.1 Study Area*

The study was conducted in nine Teff cluster zones named East Shewa, West Shewa, Southwest Shewa from Oromia Regional State, and East Gojjam, West Gojjam, North Shewa, South Gonder, South Wollo, and Awi zones from Amhara Regional State (Fig. 1). These Teff clustered zones were purposively selected to evaluate Teff crop yield estimation using state-of-the-art of technologies.

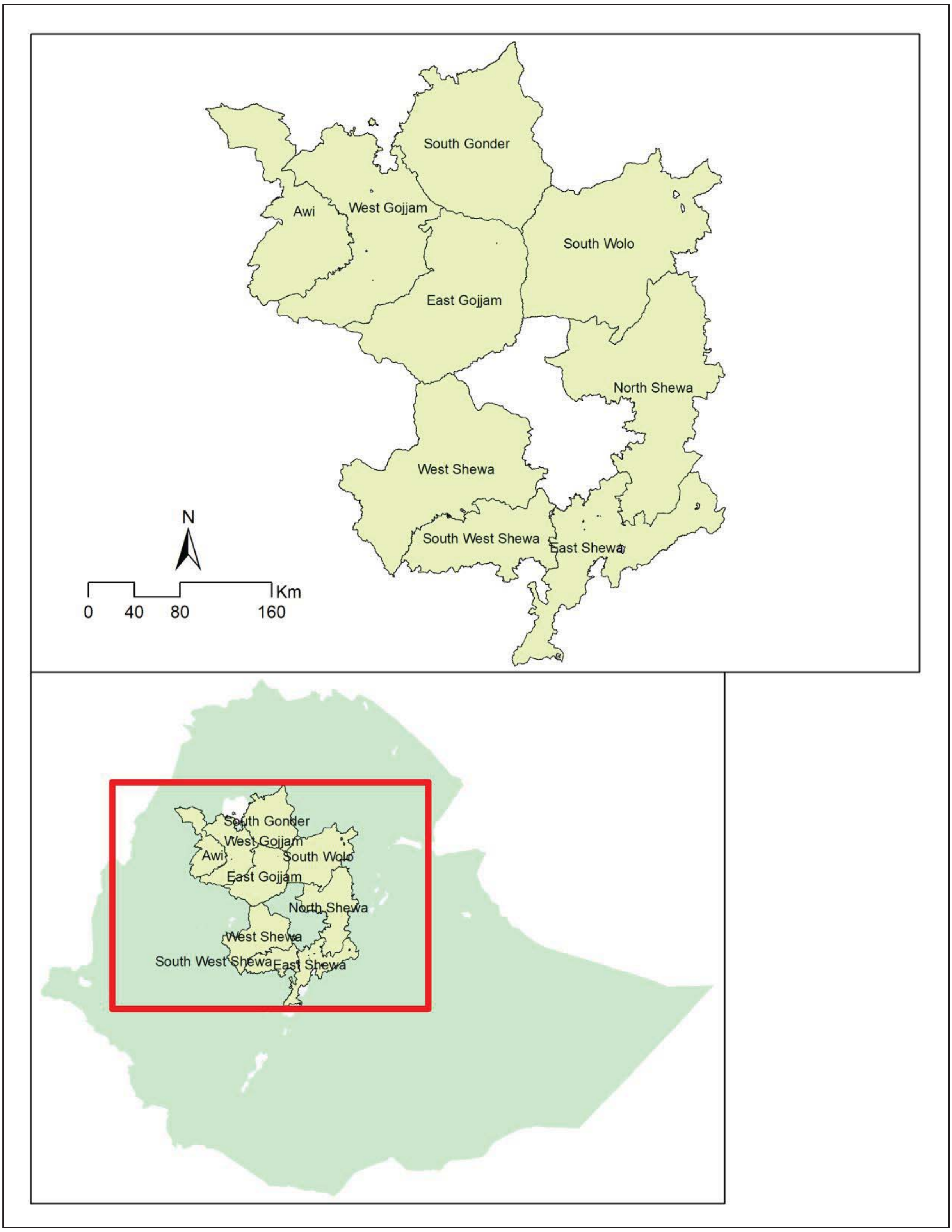


Figure 1. The study area location (the insent map is the nine zones understudy)

### *2.2 Materials*

Two major groups of datasets were used for this analysis: dependent variable and independent variables. The dependent variable is the Teff yield collected during *Meher* (main) season, which is ground truth data used for calibration and validation. *Meher* season's Teff yield statistics, collected through Agricultural Sample Survey

(AgSS) based on private peasant holdings in rural areas of the country, which were obtained from Central Statistical Agency (CSA) for 2015 and 2020 time periods. Similar periods of explanatory variables were used for this analysis. The dataset includes ground truth sample plots for 2015 and 2020 collected from nine selected Teff producing zones.

On the other hand, independent variables commonly called explanatory variables were acquired from different sources. About 20 variables were used and grouped into four major types: (1) Vegetation indices derived from MODIS images: normalized difference vegetation index (NDVI), leaf area index (LAI), fraction of photosynthesis active radiation (fPAR), net primary productivity (NPP), and soil adjusted vegetation index (SAVI) were obtained from earth explorer (https://earthexplorer.usgs.gov/); (2) Climatic data: mean monthly rainfall and temperature, length of growing periods (LGP) were obtained from Climate Hazards Group Infra-Red Precipitation with Station data (CHIRPS, https://www.chc.ucsb.edu/data/chirps); (3) Soil fertility: soil organic carbon (SOC) and organic matter (OM), and (4) Topographic factors: compound topographic index (CTI), digital elevation model (DEM) and slope of the study site.

*2.3 Data Set Preparation and Approach*

Datasets were acquired from different sources. Resampling into 30 m pixel sizes, re-projection from sinusoidal system to a local coordinate system (WGS_1984_UTM_ZONE_37), clipping into the study zones, indices calculations, and other necessary preparations were performed to arrange input datasets corresponding to the study area. Furthermore, machine learning (e.g., random forest - RF) based open source and a stand-alone system were employed for analysis. The analysis was carried out in an open-source R programming environment (R Core Team, 2019) and mapping was done using an open-source of QGIS3.8.

*2.4 Non-parametric Machine Learning Based for Teff Yield Prediction*

This part was planned to predict the yield of Teff using ground truth and RS data in a non-parametric machine learning algorithm approach. Random forest, a non-parametric machine learning algorithms were used to predict Teff yield at the selected Teff clustered areas. Teff biomass estimated from earth observation, climatic data, and agronomic factors were supposed to be used as input predictor variables whereas sampled Teff yield was used for response variable to train and validate the model developed.

Random Forest package by Laiw and Wiener (2002) in R (CRAN) was used to undertake Teff yield prediction using multivariate regression (R Core Team, 2019). RF is an algorithm for classification and regression problems and predicts well when there is missing data, avoids over-fitting problems, produces more stable results, and is less sensitive to multi-collinearity than other machine learning algorithms (e.g., Classification and Regression Tree (CART) (Lai and Tsai, 2019; Fang et al., 2020; Chen et al., 2020). RF, therefore, works by growing a large collection of de-correlated decision trees as a base learner using a fraction of observation and features (variables) randomly selected with replacement (bootstrapping). Each tree (regression) was trained using 80% of randomly selected model calibration with the remaining 20% of samples were used for validation using a method called out-of-bag (OOB) samples, serving to estimate the regression (Shiferaw et al., 2019). Finally, the majority voting or mode rule (Ghimire et al., 2010) is used to assign a pixel to a class based on the maximum number of votes that the pixel receives from the group of regression trees (Breiman, 2001). A generic non-parametric regression in the machine learning equation is presented to show how the function is implemented (equation 1).

$$J(\theta) = \frac{1}{2m}\sum_{i=1}^{m}\left(h_\theta(x^{(i)}) - y^{(i)}\right)^2 \tag{1}$$

*Where, $\theta$ is what represents the current weights of predictors, and $J(\theta)$ means the 'response for current weights', m is the number of observations, y is the real value from ground truth data, $h_\theta$ is the expected value for that predictor $x_i$ (Geitgey, 2014; URL1, 2017).*

Random forest (RF) algorithm does not need for prior data transformation or elimination of outliers but can be fitted complex nonlinear relationships (Elith et al., 2008). That is, these algorithms automatically handle interaction effects among predictors (Elith et al., 2008; Breiman, 2001). RF handles both classifications and regressions, which is an enhancement of traditional decision trees by consisting of many trees as a predictor (Breiman, 2001). Each tree votes for its preferred class and the most voted class gives the final prediction (Lorena et al., 2011).

RF was found a highly performing state-of-the-art machine learning algorithm based on an ensemble of decision trees, which compliments the findings of Rembold et al. (2015). RF has several benefits compared to traditional classifiers (maximum likelihood, for example) according to different researchers (Hastie et al., 2009; Gislason et al., 2006; Breiman, 2001). Some of its advantages are: (1) it can handle thousands of input variables and identify most significant variables so that it is considered one of the dimensionality reduction methods and also identifies importance of variables from the targeted variables, which can be a very handy feature, (2) it has an effective method for estimating missing data and maintains accuracy when a large proportion of the data are missing ("out–of-bag or bagging" system), (3) normal distribution or unimodality assumption doesn't necessary and being relatively insensitive to the number and multi-collinearity of input data (Elith et al., 2008), (4) handles high-dimensional data (many predictors), (5) it handles categorical data together with metric (numeric) data, (6) it is very efficient and reliable, mostly no need to cross-validation (Breiman, 2001), though this study had to produce validation results to produce reliable results for our purpose, and (7) no "overfitting", meaning no modelling noisy data since it uses tree branch pruning methods as a form of cross-validation (Breiman, 2001). However, the challenge of using RF requires expertise to handle programming of machine learning.

About one-fifth (20%) of the overall sample is left for validation (the out-of-bag predictions – OOB) while four-fifth (80%) was used for model calibration (Shiferaw et al., 2019). Each split of the tree is determined using a randomized subset of the predictors at each node and the final result is the average of the results of all the trees (Breiman, 2001). The number of features was set to the square root of the number of input variables, as has been done in another study (Belgiu and Drăgu, 2016). The OOB error was carefully checked for its stability with the chosen settings before applying the model.

*2.5 Important/influencing Variables*

Teff's growth and production are determined by different factors such as biotic and abiotic ones. Some predictor or influencing variables were selected with expert knowledge first and then tested their responses in non-parametric analysis. Those predictors were assumed to be very important factors to explain the dependent variable (yield). Important variables are predictors, which have relatively higher influencing weight than their batches. Natekin and Knoll (2013) defined the influence of the variable j in a single tree T. Considering that the tree has L splits, all the non-terminal nodes from the root to the L−1 level of the tree (Natekin and Knoll, 2013) (equation 2):

$$\text{Influence}_j(T) = \sum_{i=1}^{L-1} I_i^2 1(S_i = j) \tag{2}$$

This measure is based on the number of times a variable is selected for splitting, i.e., the current splitting variable $S_i$ is the same as the queried variable j. The measure also captures weights of the influence with the empirical squared improvement $I^2_i$, assigned to the model as a result of this split (Natekin and Knoll, 2013). To obtain the overall influence of the variable j in the model, this influence should be averaged overall boosted trees (as indicated in equation 3). Accordingly, the resulting influences can then be used for both forward and backward feature selection procedures.

$$\text{Influence}_j = \frac{1}{M} \sum_{i=1}^{M} \text{Influence}_j(T_i) \tag{3}$$

Finally, using highly influencing predictor variables and ground truth datasets, the Teff yield and area are then generated as a continuous layer. Furthermore, to quantify and calculate the Teff growing area, a threshold level was applied and masked out the Teff growing areas within the selected nine zones.

*2.6 Model Performance*

Model performance was assessed by calculating its accuracy based on the root-mean-square error (RMSE) and coefficient of determination ($R^2$), and the Receiver Operating Characteristics (ROC) of the area under the curve (AUC). The model performance was assessed by calculating its accuracy, coefficient of determination, and the Receiver Operating Characteristics (ROC) of the area under the curve (AUC). Moreover, we calculated the sensitivity (true positive rate - TPR) and specificity (true negative rate - TNR) of the model (Metz, 1978; Liaw and Wiener, 2002). This approach identified the minimum area where Teff is growing whilst ensuring that no localities at which the Teff has been omitted within the selected zones, i.e. omission rate of the minimum (Pearson, 2010) with a certain precision obtained from the model.

## 3. Results

### *3.1 Predictors and Predicted Teff Yield*

Random Forest results indicate that the best mtry (mtry is the number of variables randomly sampled as candidates at each split) was 2 of the other two mtry (11 and 20). Among the predictor variables, SAVI, precipitation in March, and CTI are the highest predictors (Fig. 2). The validation results indicate that the random forest algorithm achieved very good results with ROC-AUC of 89% and 91% for 2015 and 2020, respectively, and with $R^2$ of 0.67 and 0.73, respectively, with the smallest RMSE values of 2.422204 and $R^2$ of 0.44.

Considering important variables for Teff productivity, SAVI, Precipitation in July and February, SOC and CTI are the highest contributors (Fig. 2). SAVI is a soil-adjusted vegetation index, indicating the healthier environment of the area with good vegetation growth that supports potential yield. Precipitation obtained in July and February in some areas is very critical for Teff production. Rainfall in July in many parts of the country, particularly for the main season (*Meher*), and February and March precipitation is also very important for the commonly known "*Belg*" season. The "*Belg*" rainfall is mainly important for the western part of the study area (e.g. West Shewa and Southwest Shewa zones) and these areas are partly supported by "*Belg*" season productions. SOC is another very important variable that is mainly obtained from crop residue and additional organic matter applications. However, organic matter applications are not widely used for vast areas of Teff production but crop residue from previous harvest or fallow practice that support other plant species grown and produce organic matters are main sources of SOC in crop production. Hence, if the smallholder farmers either leave crop residue uncollected for fire fuel or animal feed or fallow their farmland, they will be obtained more yield from their farmland. CTI is the compound topographic index, which indicates the feature of the landscape that has highly correlation with soil moisture-holding capacity.

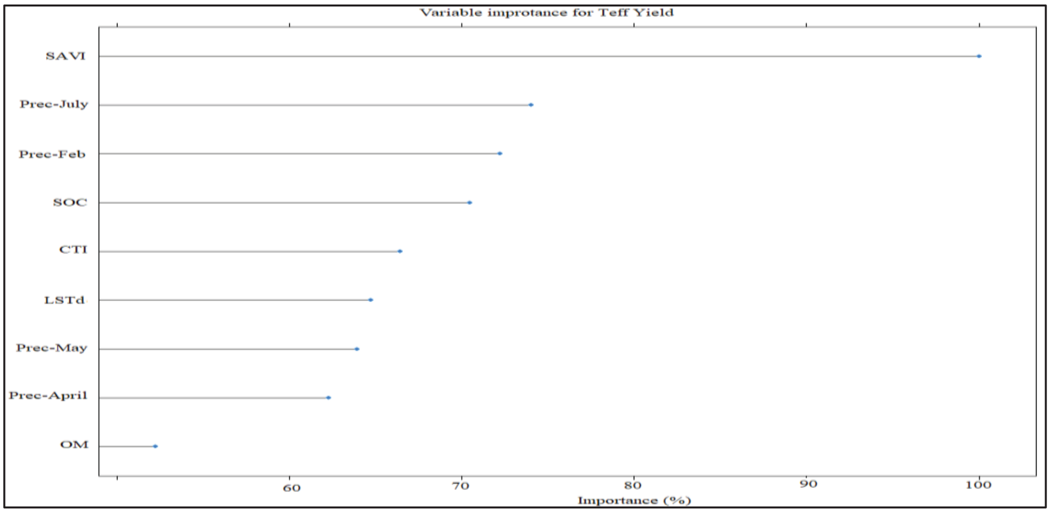


Figure 2. Important variables to predict Teff yield (x- axis is variable importance in percent)

### *3.2 Upscaling to the Study Areas from Samples*

The spatially up-scaled Teff yield probabilities in 2015 and 2020 indicate that there is little change or increase of Teff yield between 2015 and 2020 that the maximum was 1.52 t/ ha in 2015 but it was increased to 2.42 t/ha in 2020. Not only the maximum probability of productivity but the minimum was increased from 1.17 t/ha in 2015 to 1.36 t/ha in 2020 (Fig. 3). These changes are encouraging and indicating that there are huge potentials for higher productivity as it is observed that there are positive changes, particularly in the southern and eastern parts of the study area, i.e., North Shewa and South Wollo of Amhara Region. The average productivity of Teff is increased from 1.37 t/ha in 2015 to 1.99 t/ha in 2020, indicating that there are considerable changes over time though it is still below its potential as these areas as naturally suitable and known as Teff belt zones of the country.

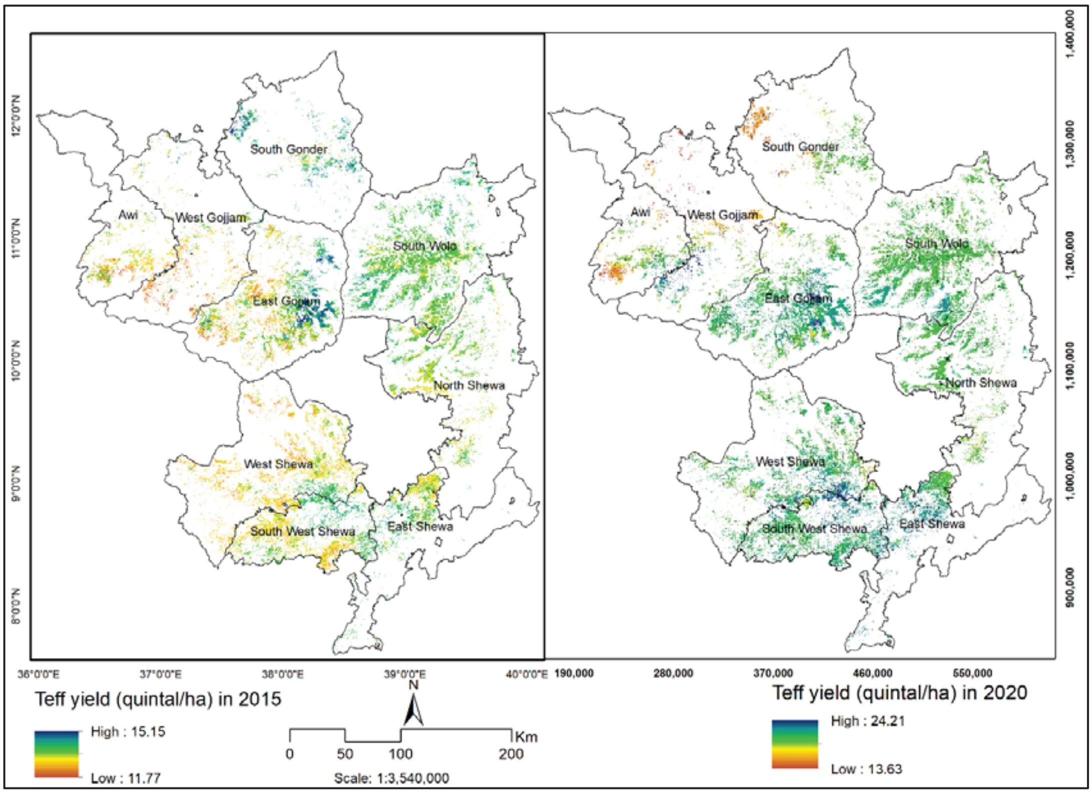


Figure 3. Teff yield in 2015 (left) and 2020 (right)

Among the nine Teff producing zones considered in this analysis, East Gojjam, West Gojjam and North Shewa of Amhara Region and East Shewa and South West Shewa of Oromia Region showed the highest Teff producing zones in both periods (Table 1). Of these, East Gojjam (Amhara Region) and South West Shewa (Oromia Region) recorded the highest Teff yield (productivity) and production in 2020.

Table 1. Teff yield prediction results summarized by zonal statistics of zone values for 2015 and 2020 using geospatial technology

| Zone | Teff Yield in 2015 | | | | Teff Yield in 2020 | | | |
|---|---|---|---|---|---|---|---|---|
| Name | Min | Max | Mean | Std | Min | Max | Mean | Std |
| Awi | 12.30 | 14.67 | 13.50 | 0.313 | 15.18 | 15.82 | 15.5 | 0.321 |
| East Gojjam | 11.60 | ***15.15*** | 13.65 | 0.436 | 22.21 | ***23.09*** | ***22.65*** | 0.435 |
| North Shewa-Amhara | 12.80 | 14.72 | 13.77 | 0.246 | 20.79 | 21.33 | ***21.06*** | 0.274 |
| South Gonder | 12.58 | 15.07 | 13.99 | 0.330 | 18.29 | 18.93 | 18.61 | 0.320 |
| South Wolo | 12.88 | 14.74 | 13.89 | 0.235 | 17.12 | 17.56 | 17.34 | 0.221 |
| West Gojjam | 11.48 | ***15.14*** | 13.48 | 0.515 | 20.00 | 20.80 | ***20.4*** | 0.398 |
| East Shewa | 12.87 | 14.56 | 13.90 | 0.213 | 20.82 | 21.38 | ***21.1*** | 0.281 |
| South West Shewa | 12.74 | 14.57 | 13.66 | 0.320 | 20.97 | ***21.55*** | ***21.26*** | 0.290 |
| West Shewa | 12.47 | 14.55 | 13.38 | 0.279 | 20.57 | 21.29 | ***20.93*** | 0.361 |
| Average | 12.41 | **14.83** | 13.69 | 0.32 | 19.55 | 20.19 | **19.87** | 0.32 |

## 4. Discussion

Proper estimation or forecasting of Teff crop yield at different scales is needed to enhance the domain of food production and support to address food security at the regional and national levels (Sewnet et al., 2021). However, the crop production estimates are commonly dependent on the conventional labor-intensive surveys, which are expensive, at risk of large errors, and do not easily scalable and not readily available on time, and not comprehensive (CSA, 2016). Consequently, much remains unknown about the quantity of Teff crop yield produced over different locations from where samples were not collected (Sewnet et al., 2021).

Many complex factors are contributing to Teff's productivity and its prediction over space. For example, crop biomass plays an important role in the global carbon cycle, which is also closely related to crop conditions and yield (Zhang et al., 2013). Biomass can be used for estimating yield even at high spatial resolution with high fragmented smallholders' plots. Yield prediction in precision farming is considered of high importance for the improvement of crop management and market planning. Once the yield is site-specifically predicted, the farm inputs such as fertilizers could be applied variably according to the expected crop, yield, and soil needs (Pantazi et al., 2016).

On the other hand, the amount of carbon available as plant materials is associated to crop yield (Tao et al., 2005), implies the variation in the accumulation of biomass for Teff crops growing at different sites of the study area (Tesfaye et al., 2021). The rate of accumulation of organic carbon and its storage in plants are affected by many factors including solar energy input, temperature, available soil moisture, the level of carbon dioxide, nutrient availability, the potential of the crop variety, crop management practices, among others (Hay, 1995; Sinclair and Muchow, 1999). All these factors affect the crop's light use efficiency, which is an important indicator of crop photosynthesis and depicts the efficiency with which crop to produce good yield (Ma et al., 2020).

The yield of Teff in 2020 was ranged from 1.36 to 2.41 t/ha with an average of 1.99 t/ha, indicating that it was very good productivity as compared to the previous results recorded in many parts of the country with an average yield of 1.48 t/ha (CSA, 2016). Our prediction results are also within the same ranges of productivity of Teff reported by CSA (CSA, 2020). This indicates that a very good yield estimation is possible using geospatial technologies with some reference ground truth data, with minimized cost and time that would take longer periods and higher costs for ground survey especially for those larger crop types of the country such as Teff, wheat, and maize.

However, the productivity of Teff is still very low as compared to some experiments conducted, for example by Tesfahun (2018), which is about 3.77 t/ha with the application of NPS fertilizer. Some of the limiting factors contributing to the low yield of Teff are low soil fertility, suboptimal use of mineral fertilizers, weeds, uneven rainfall distribution in lower altitudes, lack of high yielding cultivars, lodging, water-logging, and low moisture (Fenta, 2018; Tesfahun, 2018; Tamirat and Tilahun, 2020). Furthermore, random broadcasting of Teff sowing also contributes to the low productivity of Teff due to self-competition in space and minerals. Bekalu and Tenaw (2015) indicated that the most common way of planting Teff is by broadcasting the small seed at the rate of 25-50 kg/ha. This broadcasting reduces the amount of grain production, promotes competition among plants for resources, and causes severe lodging, which is the main cause for the low yield of Teff due to high plant density (Hundera et al., 2011). Using row planting or transplanting technology, weeding can be done easily and the lodging incidence can be reduced (Sebsebe and Assefa, 2013). Thus, it is important to develop an appropriate sowing method and balanced blended fertilizer application for enhancing the productivity of the crop and food security (Tesfahun, 2018). However, limited research has been done to elucidate the response of Teff variety to blended fertilizer applications and row planting technologies.

Furthermore, geospatial technologies and machine learning algorithms offer very good results in predicting the production and productivity of Teff with some reasonable ground truth samples. This has many advantages: (1) estimating productivity and then food security in time, (2) plan any immediate interventions in terms of agricultural produce including Teff productivity, and (3) the technology reduces cost, saves time and resources for yield estimation using conventional methods of cut and weight systems.

## 5. Summary

It is also possible to estimate crop yield and monitor crop growth using geospatial and remote sensing technology for clustered crop areas. This approach reduces costs and efforts but requires ground truth data, technology, and skill. Crop yield estimation and growth monitoring help to plan for growers, government, and crop insurance companies and contribute to the national goal of food security. However, there are some caveats for this kind of study: (1) some of the areas lack local level ground truth data for several years, (2) the approach requires further regression analyses based on selected machine learning algorithms, (3) the future analyses are based on many variables including crop factors such as climate, agronomic factors, crop factors (e.g., harvest index), among others, besides to ground truth, and (4) our assumption was to test yield estimation potential using geospatial technology in combination with machine learning algorithms at clustered areas but this requires to test further for its applicability for fragmented cropping systems.

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**References**

Amare, A., & Adane, L. (2015). *Determination of seed rate and variety on the growth and yield of Tef in the Eastern Amhara region*. A Report, Ethiopia.

Battude, M., Al Bitar, A., Morin, D., Cros, J., Huc, M., … Demarez, V. (2016). Estimating Maize Biomass and Yield over Large Areas Using High Spatial and Temporal Resolution Sentinel-2 like Remote Sensing Data. *Remote Sensing of Environment, 184*, 668-681. http://dx.doi.org/10.1016/j.rse.2016.07.030

Breiman, L. (2001). *Random forest 2001*. pp. 1-33. https://doi.org/10.1017/CBO9781107415324.004

Belgiu, M., & Drăgu, L. (2016). Random forest in remote sensing: A review of applications and future directions. *ISPRS J. Photogramm. Remote Sens, 114*, 24-31. https://doi.org/10.1016/j.isprsjprs.2016.01.011

Cheng, A., Mayes, S., Dalle, G., Demissew, S., & Massawe, F. (2017). Diversifying crops for food and nutrition security - A case of Tef. *Biological Reviews, 92*(1), 188-198. https://doi.org/10.1111/brv.12225

Crymes, R. (2015). The International Footprint of Teff: Resurgence of an Ancient Ethiopian Grain. *Arts & Sciences Electronic Theses and Dissertations, 394*. Retrieved from https://openscholarship.wustl.edu/art_sci_etds/394

CSA. (2014). *Agricultural sample survey report on area and production for major crops*. Private Peasant Holdings Meher Season. The FDRE Statistical Bulletin, General information about Teff in Ethiopia. Addis Ababa, Ethiopia,

CSA. (2020). *Agricultural sample survey report on area and production for major crops*. Private Peasant Holdings Meher Season. Addis Ababa, Ethiopia.

FAO. (2015). *Analysis of price incentives for Teff in Ethiopia Technical notes series*. MAFAP, produced by Assefa B. Demeke M., Lanos B, Rome.

Fenta, A. (2018). Effect of Teff variety and rates of nitrogen fertilizer application on growth and yield components under Jimma condition. *ARPN Journal of Agricultural and Biological Science, 13*(3), 42-43.

Firdisa, B. (2016). Determinants of smallholder farmers' participation decision in tef production: evidence from horo and Jimma geneti woreda, Ethiopia. *Developing Country Studies, 6*(10), 36-43.

Geitgey, A. (2014). *Machine Learning is Fun!* The world's easiest introduction to Machine Learning. Retrieved from https://medium.com/@ageitgey

Habtegebrial, K., Singh, B. R., & Haile, M. (2007). Impact of tillage and nitrogen fertilization on yield, nitrogen use efficiency of Teff (*Eragrostis teff*) and soil properties. *Journal of Soil Tillage Research, 94*, 56-63. https://doi.org/10.1016/j.still.2006.07.002

Hailu, T., & Seyfu, K. (2000). Production and Importance of Teff in Ethiopian Agriculture. In T. Hailu, B. Getachew & M. Sorrells (Eds.). *Narrowing the rift: Teff research and development* (pp. 3-7). Proceedings of the international work shop on Teff Genetics and Improvement, Debre Zeit, Ethiopia.

Hay, M. (1995). Harvest index: a review of its use in plant breeding and crop physiology. *Ann Appl Biol, 126*, 197-216. https://doi.org/10.1111/j.1744-7348.1995.tb05015.x

Hundera, F., Behute, B., Simons, R., & Berhe. T. (2011). *Tef Diagnostic Report: Strengthening the Tef Value Chain in Ethiopia*. Addis Ababa, Ethiopia. http://dx.doi.org/10.1111/j.1601-5223.2001.00103.x

Johnson, D. (2014). An Assessment of Pre-and Within-Season Remotely Sensed Variables for Forecasting Corn and Soybean Yields in the United States. *Remote Sensing of Environment, 141*, 116-128. https://doi.org/10.1016/j.rse.2013.10.027

Kemanian, A. R., Stockle, C., Huggins, D., & Viega, L. (2007). A simple method to estimate harvest index in grain crops. *Field Crops Research, 103*, 208-216. https://doi.org/10.1016/j.fcr.2007.06.007

Lakew, A., & Berhanu, T. (2019). Determination of seeding rate and inter-row spacing on the yield of tef (*Eragrostis tef* Zucc. Trotter) in the dryland areas of Wag Lasta, North Eastern Amhara, Ethiopia. *Archives of Agriculture and Environmental Science, 4*(1), 69-74. https://doi.org/10.26832/24566632.2019.040101

Lee, H. (2018). Teff, A rising global crop: current status of teff production and value chain. *The Open Agriculture,* *12*(1), 185-193. https://doi.org/10.2174/ 1874331501812010185

Liaw, A., & Wiener, M. (2002). Classification and Regression by randomForest. *R news, 2*, 18-22.

Ma, L., Wang, S., Chen, J., Chen, B., Zhang, L., Ma, L., Amir, M., Sun, L., Zhou, G., & Meng, Z. (2020). Relationship between Light Use Efficiency and Photochemical Reflectance Index Corrected Using a BRDF Model at a Subtropical Mixed Forest. *Remote Sens., 12*, 550. https://doi.org/10.3390/rs12030550

Metz, C. E. (1978). Basic principles of ROC analysis. *Semin. Nucl. Med., 8*, 283-298. https://doi.org/10.1016/S0001-2998(78)80014-2

Minten, B., Tamru, S., Engida, E., & Kuma, T. (2016). Feeding Africa's cities: The case of the supply chain of Teff to Addis Ababa. *Econ Dev Cult Change, 64*(2), 265-97. https://doi.org/10.1086/683843

Nandeshwar, B. C., Hirko, O., Morketa, G., Belay, G., Usman, M., Reta, F., Fufa, M., & Kinde, L. (2020). Teff (*Eragrostis tef* [Zucc] Trotter): an emerging global demanding crop. *Agriculture Observer, 1*(1), 28-33.

Pantazi, X. E., Moshou, D., Alexandridis, T., Whetton, R. L., & Mouazen, A. M. (2016). Wheat yield prediction using machine learning and advanced sensing techniques. *Computers and Electronics in Agriculture, 121*, 57-65. https://doi.org/10.1016/j.compag.2015.11.018

Pearson, R. G. (2010). Species' distribution modeling for conservation educators and practitioners. *Lessons Conserv, 3*, 54-89.

R Core Team. (2019). *R: a language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. Retrieved from http://www.R-project.org

Sate, S., & Tafese, A. (2016). Effects of sowing methods and seed rates on yield components and yield of tef in Soro Woreda, Hadya Zone, Southern Ethiopia. *Journal of Natural Sciences Research, 6*(19), 109-114.

Sebsebe, C., & Assefa, K. (2013). *The agronomy of teff*. Improved evidence towards better policies for the teff value chain conference, Addis Ababa, Ethiopia. http://dx.doi.org/10.2147/idr.s134369

Sewnet, H., Tesfaye, G., Shiferaw, H., & Tamene, L. (2021). *Phenology based Time Series LAI as a Proxy for Teff Crop Yield Estimation: A Case in Major Teff (Eragrostis) Growing Zones of Ethiopi*a. pp. 30.

Seyfu, K. (1997). *Teff. Eragrostis teff (Zucc.) Trotter. Promoting the conservation and use of underutilized and neglected crops.* Institute of plant genetics and crop plant research. Rome, Italy: Gatersleben / International Plant Genetic Resources Institute.

Shiferaw, H., Schafner, U., Bewket, W., Alamirew, T., Zeleke, G., Teketay, D., & Eckert, S. (2019). Modelling the current fractional cover of an invasive alien plant and drivers of its invasion in a dryland ecosystem. *Scientific Reports, 9*, 1576. https://doi.org/10.1038/s41598-018-36587-7

Sinclair, T. R., & Muchow, C. (1999). Radiation use efficiency. *Adv. Agron., 65*, 215-265. https://doi.org/10.1016/S0065-2113(08)60914-1

Tadesse, D., Alem, T., Wossen, T. (2016). Evaluation of improved varieties of Teff in West Belesa, Northwest Ethiopia. *Review of plant studies, 3*, 1-6. https://doi.org/10.18488/journal.69/2016.3.1/69.1.1.6

Tamirat, W., & Tilahun, N. (2020). The response of Teff [*Eragrostis teff* (Zucc.) trotter] to nitrogen fertilizer and development of Barley (Hordeum vulgare L.) at Bore district, Southern Oromia, Ethiopia. *American Journal of Life Sciences, 2*(5), 260-266. https://doi. org/10.11648/j.ajls.20140205.12

Tesfahun, W. (2018). Tef yield response to NPS fertilizer and methods of sowing in East Shewa, Ethiopia. *Journal of Agricultural Sciences - Sri Lanka, 13*(2), 162-173. https://doi.org/10.4038/jas.v13i2.8340

Tesfaye, G., Sewnet, H., Shiferaw, H, Desta, L., Abera, W., & Gudeta, K. (2021). *Tef [Eragrostis tef (Zucc.) Trotter] yield estimation based on satellite-derived light use efficiency model*. A case study in the top tef growing zones of Ethiopia. pp. 38.

Tao, F., Yokozawa, M., Zhang, Z., Xu, Y., & Hayashi, Y. (2005). Remote sensing of crop production in China by production efficiency models: models comparisons, estimates and uncertainties. *Ecological Modelling, 183*, 385-396. https://doi.org/10.1016/j.ecolmodel.2004.08.023

van Herwaarden, A. F., Farqhuar, G. D., Angus, J. F., Richards, R. A., & Howe, G. N. (1998). 'Haying-off', the negative grain yield response of dryland wheat to nitrogen fertilizer. I. Biomass, grain yield, and water use. *Aust. J. Agric. Res., 49*, 1067-1081. https://doi.org/10.1071/A97039

Wato, T. (2021). Tef [*Eragrostis tef* (Zucc)] grain yield response to nitrogen fertilizer rates in East Badewacho district, Hadiya Zone, Southern Ethiopia. *Cogent Food & Agriculture, 7*, 1-11. https://doi.org/10.1080/23311932.2021.1909203

Wato, T. (2019). Effects of nitrogen fertilizer rate and inter-row spacing on yield and yield components of teff [*Eragrostis teff* (Zucc.) Trotter] in Limo district, Southern Ethiopia. *International Journal of Plant & Soil Science, 31*(3), 1-12. https://doi.org/10.9734/ IJPSS/2019/v31i330211

Zhang, M., Wu, B., Zeng, H., & Xing, Q. (2013). *Crop estimation by integration of remote sensing and meteorological data*. Institute of Remote Sensing and Digital Earth, Chinese Academy of Science.

Zhu, F. (2018). Chemical composition and food uses of Teff (*Eragrostis tef*). *Food Chem., 239*, 402-15. https://doi.org/10.1016/j.foodchem.2017.06.101

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# Strategies to Reduce Inorganic Fertilizer Inputs in Crop Production through Integrated Crop-livestock Systems

Akim Omokanye[1, 2], Yamily Zavala[3], Dianne Westerlund[3], Liisa Jeffrey[1] & Buthaina Al-Maqtari[1]

[1] Peace Country Beef & Forage Association, Room 229 TIB, Grande Prairie Regional College, Fairview Campus, Box 3000, Fairview Alberta, T0H 1L0, Canada

[2] Department of Renewable Resources, Faculty of Agricultural, Life & Environmental Sciences, University of Alberta, 2-06 Agriculture Forestry Centre, Edmonton, AB T6G 2P5, Canada

[3] Chinook Applied Research Association, Highway 41 E, Box 690 Oyen, Alberta T0J 2J0, Canada

Correspondence: Akim Omokanye, Peace Country Beef & Forage Association, Room 229 TIB, Grande Prairie Regional College, Fairview Campus, Box 3000, Fairview Alberta, T0H 1L0, Canada. E-mail: akim@pcbfa.ca; aomokanye@gmail.com

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**Abstract**

Adequate nutrition is essential for crop growth, production, and profit potential for farmers, but chemical fertilizer costs alone can constitute a greater portion of the total variable costs for wheat and canola. The present study evaluated seven cropping treatments (CT) in a 3-year crop rotation under two different soil types. Five of the CTs consisted of a one-time application (year 1) of beef cattle manure, and growing of cover crop cocktails (CCC) for annual pasture, swath grazing, green manure, and green feed. Canola and wheat were respectively grown in years 2 and 3 of the 3-year crop rotation. In year 2, CTs impacted canola seed yield and seed protein (only at site 2). Wheat had similar protein content in year 3 at both sites. At both sites, the application of beef cattle manure in year 1 seemed to encourage higher plant tissue P at the expense of plant tissue Zn. Overall, beef cattle manure and CCCs based CTs improved soil N, P, and K, but beef cattle manure application consistently improved crop yield and significantly reduced the need for additional in-organic fertilizer application to canola and wheat in subsequent years.

**Keywords:** cover cropping, wheat, canola, integrated crop-livestock production, soil nutrients

## 1. Introduction

The study of the environmental impacts of crops, the reduced costs of production, and the balanced use of fertilization are among the main objectives of modern agriculture (Yousaf et al., 2016). In Alberta, Canada, a recent *AgriProfit*$ report showed that chemical fertilizer costs could constitute up to 30% of the total variable costs for wheat and 33% for canola (AAF, 2021) indicating that in-organic fertilizer alone could have the highest of any single input cost in wheat and canola production. Concomitant with this is that over the last four years, the costs of fertilizers have escalated by as much as 40% for urea, 37% for mono-ammonium phosphate, 22% for muriate of potash, and 9% for ammonium sulphate. The high fertilizer costs and the unstable prices of beef cattle and grains are causing producers to look for different ways to manage farming systems that will improve soil fertility and health, and reduce in-organic fertilizer application without sacrificing crop yields.

A preliminary study that examined the soil nutrient status after forage harvests of cover crop monocultures and a CCC in northern Alberta showed the potential of cover crops and their mixtures to improve soil fertility for subsequent crop production (Omokanye, 2019). Similarly, in eastern Alberta, initial evaluations of CCCs showed the potential of CCCs to provide a reduction in soil compaction, increased weed suppression and aggregation formation for the next cropping season, as well as improved biological activity (CARA, 2016), all of which will have positive impacts on crop production and overall farm profits. This further shows the need for a multifunctional low-input cropping system that includes CCCs. The benefits of CCCs are based on the multifunctional action of each crop species in the blend interacting with the soil attributes and stimulating the soil's biological activity (Barot et al., 2017).

Garrett et al. (2017) indicated that farmers' motivations for re-integrating animals into cropland are varied, but often include risk reduction through diversification, increased nutrient and land-use efficiency, and climate resilience through enhanced adaptability of management options. Yet, crop production outcomes following livestock grazing across environments and management scenarios remain uncertain and are a potential barrier to adoption, as producers worry about the effects of livestock activity on the agronomic quality of their land. Integrated crop-livestock systems investigated using a meta-analysis on three soil types reported 5% higher yields than unintegrated systems for one soil type, and no difference between integrated and unintegrated systems on the other soils (Peterson et al., 2020). Crop nutrient uptake and crop yields are the principal factors that determine optimal fertilization practices (Ju and Christie, 2011), hence the need to apply fertilizers in an efficient way to minimize loss and to improve the nutrient use efficiency (Li et al., 2009). There is, therefore, the need for more integrated forms of agriculture to restore the sustainability of agricultural systems (Bell and Moore, 2012; Hendrickson et al., 2008; Russelle et al., 2007). Crop–livestock integration pursues three aims: reducing the openness of nutrient cycles, following the rationale of industrial ecology, organizing land use and farming practices to promote ecosystem services, and increasing farm resilience to adverse climatic and economic events (Bonaudo et al., 2014; Lemaire et al., 2014; Moraine et al., 2014).

In this study, 3-year field-scale experiments were conducted at two sites with different soil types to study the effectiveness of different cropping systems, including CCCs, livestock integration, and the use of manure and bio-stimulants on subsequent canola and wheat crop production and the impact on soil characteristics.

## 2. Materials and Methods

### *2.1 Experimental Site Description*

Field experiments were conducted from 2018-2020 at two sites in Alberta, Canada. Site 1 was at Fairview Research Farm (Fairview) and site 2 was at Sedalia. The soil group at Fairview is dark gray chernozemics and brown chernozemics at Sedalia (AGRASID; GOA 2020). At the start of the project, the Fairview site had a soil pH of 5.19 (0-6”), 5.55 (6-12”) and 5.81 (12-18”), and a soil organic matter (SOM) content of 6.99% (0-6”), 3.06% (6-12”) and 2.32% (12-18”). The soil at Sedalia had a soil pH of 5.67 (0-6”), 6.59 (6-12”), and 6.80 (12-18”), while the SOM was 2.71%, 3.06%, and 2.32%, respectively from 0-6”, 6-12” and 12-18”. Both sites have a subarctic climate (also called boreal climate), which is characterized by long, usually very cold winters, and short, cool to mild summers. Fairview site was seeded to oats for greenfeed two years before the commencement of the experiment but left fallow the year before the experiment started. During the fallow period (uncultivated), the plants growing in the field were mowed down a few times during growing season. Sedalia had canola seeded the year before and combined harvested. Growing season precipitation, air temperatures, and growing degree days during the study and long-term averages for both sites acquired through the Alberta Climate Information System (ACIS, 2020) weather station are shown in Table 1.

Table 1. Monthly mean air temperature (°C), precipitation (mm), and growing degree days for the 3 growing seasons (2018, 2019 and 2020), and their long-term averages (LTA) at both sites

| | Site 1: Fairview (Northwestern Alberta) | | | | Site 2: Sedalia (Eastern Alberta) | | | |
|---|---|---|---|---|---|---|---|---|
| | 2018 | 2019 | 2020 | LTA | 2018 | 2019 | 2020 | LTA |
| Rainfall (mm): | | | | | | | | |
| May | 5.3 | 7.4 | 35.3 | 38.7 | 15 | 2.7 | 50.9 | 35.5 |
| June | 77.3 | 72.9 | 67.2 | 103 | 62.1 | 53.2 | 96.3 | 73.1 |
| July | 108.5 | 61.9 | 89.8 | 69.5 | 48.2 | 107 | 93.9 | 55.6 |
| August | 23.3 | 49.1 | 53.9 | 47.5 | 17.8 | 13.6 | 17.4 | 40.4 |
| September | 32.9 | 24.6 | 23.1 | 81.2 | 25.4 | 44.3 | 26.3 | 29.8 |
| Total | 247.3 | 215.9 | 269.3 | 339.9 | 168.5 | 220.8 | 284.8 | 234.4 |
| Air temperatures (°C): | | | | | | | | |
| May | 14.3 | 11.5 | 9.9 | 9.9 | 14.5 | 10.1 | 10.4 | 10.7 |
| June | 14.9 | 14.1 | 14 | 14 | 16.5 | 15 | 15.1 | 15.1 |
| July | 16.3 | 15.1 | 15.6 | 15.8 | 18.2 | 17.1 | 17.4 | 17.9 |
| August | 14.7 | 12.9 | 14.1 | 14.6 | 17.4 | 15.8 | 17.7 | 17.1 |
| September | 4.41 | 9.68 | 10.3 | 9.57 | 7.29 | 11.3 | 12.3 | 11.3 |
| Growing degree days (5˚C): | | | | | | | | |
| May | 272 | 210 | 158 | 161 | 183 | 152 | 161 | 183 |
| June | 297 | 273 | 272 | 269 | 304 | 292 | 292.3 | 304 |
| July | 344 | 306 | 330 | 334 | 399 | 382 | 380.3 | 399 |
| August | 293 | 248 | 283 | 298 | 375 | 331 | 394.2 | 375 |
| September | 39 | 162 | 157 | 147 | 106 | 209 | 221.5 | 196 |
| Total | 1245 | 1199 | 1200 | 1209 | 1367 | 1366 | 1449.3 | 1457 |

*2.2 Treatments and Experimental Design*

This experiment was designed to examine the effect of a one-time application of seven CTs on soil fertility, and canola and wheat production over a 3-year period at both sites. The CTs were examined (Table 2) using a randomized complete block design with three replications.

Table 2. The seven cropping treatments (CT) investigated from 2018 to 2020

| Brief description of CT | 2018 | 2019 | 2020 |
|---|---|---|---|
| Conventional rotation (control). P-C-W (control) | CDC Meadow peas (P) | Canola (C) | Wheat (W) |
| $CCC_G$ (grazed as a standing crop) - canola - wheat rotation. $CCC_G$-C-W | CCC mixture seeded. Fairview (used 6 cow-calf pairs to graze CCC) in fall. Sedalia (grazed by 5 dry cows) in fall. | Canola (C) | Wheat (W) |
| $CCC_{SG}$ (swathed and grazed) - canola - wheat rotation. $CCC_{SG}$-C-W | CCC mixture seeded. CCC swathed when oats were at the soft dough stage. Fairview (grazed by 6 cow-calf pairs) in fall. Sedalia (grazed by 5 dry cows) in fall. | Canola (C) | Wheat (W) |
| Barley (manure) - canola - wheat rotation. $B_M$-C-W | Stockpiled beef cattle manure was applied and harrowed into the soil before seeding. CDC Maverick barley was seeded. No additional chemical fertilizer was applied. | Canola (C) | Wheat (W) |
| $CCC_R$ (rolled as green manure) - canola - wheat rotation. $CCC_R$-C-W | CCC mixture seeded. CCC was rolled onto the surface soil as green manure when the oats were at the late milk-soft dough stage. | Canola (C) | Wheat (W) |
| High legume-base $CCC_F$ (40% cereals & 60% legumes for greenfeed) - canola - wheat rotation. $CCC_F$-C-W | CCC mixture seeded. Harvested for forage and removed from the field when the oats were at the late milk stage. | Canola (C) | Wheat (W) |
| Barley - canola - wheat rotation (Bio-stimulants applied yearly). $B_P$-$C_P$-$W_P$ | CDC Maverick barley seeded. Penergetic K applied at seeding. Penergetic P applied as in-crop (foliar) application. | Canola (C) + PKP | Wheat (W) + PKP |

Note.

Water and free choice trace mineralized stock salt were provided to the cows during grazing in 2018.

$CCC_G$ and $CCC_R$ consisted of oats, German millet, annual ryegrass, hairy vetch crimson clover, Winfred forage brassica, and sunflower.

$CCC_{SG}$ was made up of oat, Italian ryegrass, frosty berseem clover, peas, and Winfred forage brassica.

$CCC_F$ consisted of oats, peas, crimson clover, and hairy vetch.

For all CCCs, a substitutive approach (proportional replacement design) was used for calculating seeding rates (Omokanye et al., 2019).

No chemical fertilizer was applied to the CCCs and barley + manure ($B_M$) in 2018.

Except for $B_M$-C-W, crops were fertilized with inorganic fertilizers from 2018 to 2020.

Fairview (canola in 2018 and wheat in 2020) received half of the recommended in-organic fertilizer rates following soil test reports. Sedalia had a uniform in-organic fertilizer rate applied to all crops every year. In-organic fertilizer applications were at seeding.

At site 1, seeding dates were May 28 (2018), May 22 (2019), and May 21 (2020). Site 2 was seeded on May 25 (2018), May 27 (2019), and May 31 (2020). Plot size was about 1,102 $m^2$ with an alleyway of 1 m between plots. In 2019, a canola hybrid with Pioneer® Protector Harvest-Max CR traits (45CM39) was seeded. Canada Western Red Spring wheat (AAC Brandon wheat) was seeded in 2020. All crop monocultures from 2018 to 2020 were seeded using the desired plant population per ha (AAF, 2018). For combine harvesting, all monocultures were harvested for grain after they had reached physiological maturity stages.

*2.3 Soil Measurements*

Every year, prior to seeding, soil characteristics were measured. The soil physical properties measured were bulk density [BD: 0-15 cm soil depth, expressed as mass per unit volume of soil (g/$cm^3$)] and water-stable aggregates. Soil samples for water-stable aggregates and biological activities (0-7.5 cm and 7.5-15 cm soil depths), which included microbial activity ($CO_2$ respiration) and active carbon (AC) were analyzed at the Chinook Applied Research Association's Soil Health Laboratory using the University of Cornell Soil Health protocols (Schindelbeck et al., 2016). Total carbon (TC), total organic carbon (TOC), and total nitrogen (TN) were analyzed at the University of Alberta Natural Resources Analytical Laboratory by combustion elemental analysis (Sparks et al., 2020; Schumacher, 2002). Soil samples were transported in a cooler and stored in a fridge before analysis. Calculation of the amount of soil C density or soil organic carbon (SOC) stock (carbon t $ha^{-1}$**)** to 30-cm depth in soil was calculated using SOC concentration (%) and bulk density (g $cm^{-3}$) as per GOWA (2021).

Soil samples for soil chemical properties (at 0-15 cm soil depth) including nitrate-N, P, K, and S, and soil pH and organic matter were shipped to A&L Canada Laboratories Inc., London, Ontario for analysis. Using KCl extraction with the cadmium-reduction, nitrate-N concentration was quantified colorimetrically (Maynard et al., 2008) by an auto-analyzer (Technicon Auto-Analyzer II, Tarrytown, NY). A Mehlich III (Mehlich 1984) extraction was used for S and determination of S was by inductively-coupled plasma atomic emission spectrometry (ICP-OES). Concentration data for N, P, K, and S were converted to content (kg $ha^{-1}$).

*2.4 Plant Measurements*

For plant tissue analysis, canola and wheat plant tissue sampling was carried out as per the tissue sampling reference guide provided by A&L Analytical Experts (A&L Canada Lab., 2019). The growth stage for canola was pre-flower to 50% flower with the most recently matured leaf (5th from the top) sampled. Wheat was harvested at the bloom stage and most recently matured leaf sampled. Plant samples were sent to A & L Canada Laboratory for plant tissue analysis. The oven-dried samples were ground into a powder form and passed through a 1 mm sieve. The leaf nitrogen content (expressed as a percentage) was then measured using the Laboratory Equipment Company (LECO) FP628 nitrogen/protein analyzer that uses the total nitrogen combustion method (AOAC, 2006).

Grain yield, grain crude protein (CP), and test weight were measured for canola (year 2) and wheat (year 3). Straw yields and quality were determined for the canola (2019) and wheat (2020). Straw samples were sent to A&L Canada Laboratories for nutritive value.

*2.5 Data Analysis*

The data was analyzed on a site basis. As the experiment was designed to test the effect of a one-time application of seven CT treatments in year 1 (2018) on subsequent soil nutrients, soil biological activities, and crop grain and residue yields, the crop data in 2019 and 2020 was analyzed separately (on a yearly basis) using a pre-defined model procedure (1-way randomized block) from the CoStat – Statistics Software (version 6.2; CoStat 2005). Soil nutrients (N, P, K, and S) were analyzed using R statistical software (R-Studio, 2021) to determine the appropriate interactions, and CT and depth effects. Where ANOVA indicated significant effects, the means were separated by the least significant difference (LSD) at the 0.05 probability level. Significant differences in the text refer to $P < 0.05$.

## 3. Results and Discussion

*3.1 Canola and Wheat Grain Yields and Protein*

In year 2 of the rotation, canola yield differed significantly from prior CTs at both sites (Table 3). At both sites, $B_M$-C-W produced the highest seed yield (site 1: 2632 kg $ha^{-1}$, site 2: 2464 kg $ha^{-1}$), followed by $B_P$-$C_P$-$W_P$ with 2296-2352 kg $ha^{-1}$ at both sites. At site 1, only $B_M$-C-W and $B_P$-$C_P$-$W_P$ produced significantly higher seed yield than control (P-C-W), while at site 2, $B_P$-$C_P$-$W_P$, $B_M$-C-W, and $CCC_R$-C-W clearly showed significantly higher seed yield than control. At site 1, $B_P$-$C_P$-$W_P$ and $B_M$-C-W out-yielded other CTs by 280-1064 kg $ha^{-1}$ in canola seed yield, while at site 2, the yield differences from both $B_P$-$C_P$-$W_P$ and $B_M$-C-W over other CTs were 56-952 kg $ha^{-1}$. At site 1, $CCC_F$-C-W had the least canola seed yield. Unlike site 1, where $CCC_G$-C-W produced a similar canola yield to control, at site 2, both CTs that had CCC grazed the year before had lower canola seed yield than control. This shows that at both sites, the amounts of manure and urine from the CTs that involved grazing ($CCC_G$-C-W and $CCC_{SG}$-C-W) might not be substantial enough to provide any positive effect on the immediate subsequent crop. At site 2, four of the CTs ($B_M$-C-W, $CCC_R$-C-W, $B_P$-$C_P$-$W_P$, and $CCC_F$-C-W) produced 504-784 kg $ha^{-1}$ canola seed yield than projected canola yield for the study area (AAF, 2019). At site 1, only $B_M$-C-W and $B_P$-$C_P$-$W_P$ produced a higher canola seed yield than the projected canola yield for the area. With the reduction in inorganic fertilizer application to all CTs in year 2, $B_M$-C-W was still able to produce 448 – 784 kg $ha^{-1}$ canola seed yield between both sites.

Wheat grain yield in year 3 of the rotation was influenced significantly by CT at site 1, but this was not the case at site 2 (Table 3). $B_M$-C-W produced the highest wheat grain yield (5040 kg $ha^{-1}$). $B_M$-C-W had had similar ($P<0.05$) grain yield to both $CCC_R$-C-W and $B_P$-$C_P$-$W_P$, but differed significantly from other CT. Other than $B_M$-C-W, both $CCC_R$-C-W and $B_P$-$C_P$-$W_P$ had some form of similarity ($P<0.05$) in wheat grain yield to other CT investigated. At both sites (though treatments were not significantly different from each other at site 2), the control (P-C-W) seemed to consistently produce lower wheat grain value than other CT. The wheat grain yield from both $B_M$-C-W and $CCC_R$-C-W (though similar to control) at both sites in year 3 clearly indicates the carry-over of residual effects from year 1 from the spread of beef cattle manure and to some extent from CCC rolled as green manure ($CCC_G$-C-W). At site 1, even with the reduction in in-organic fertilizer application rates for the different CTs, all CT surprisingly produced more wheat grain yield than the projected yield estimate for the study area (AAF, 2020). $B_M$-C-W, in particular, produced ~1300 kg ha$^{-1}$ more yield than projected, followed by both $CCC_R$-C-W and $CCC_R$-C-W, each with ~875 ha$^{-1}$. At site 2, only $B_P$-$C_P$-$W_P$, $B_M$-C-W, and $CCC_R$-C-W seemed to produce some greater yield advantage than projected for the study area.

On a general note, in the present study, we used the continuous grazing method, where animals are allowed to have unrestricted, uninterrupted access to a specific unit of land throughout the entire grazing period of the treatment plots. This was thought to have accounted for the generally less impact (manure not evenly distributed) from both $CCC_G$-C-W and $CCC_{SG}$-C-W on the immediate subsequent crop (canola) and even later for wheat in year 3 of the rotation. The greater impact from $CCC_G$-C-W and $CCC_{SG}$-C-W would have been found in this study had **s**trip grazing been used for each grazed plot. Strip grazing technique involves utilizing a movable, electric fence to allot enough forage for a short time period and then moving the fence forward providing a new allocation of forage. Strip grazing can increase utilization, decrease animal selectivity and allow even distribution of manure and urine.

Canola seed crude protein (CP) was similar for all CTs at site 1, but differed significantly for CTs at site 2 (Table 3). At site 2, $B_P$-$C_P$-$W_P$ had significantly lower canola seed CP than other CTs (except for $B_M$-C-W and $CCC_R$-C-W). Why canola seed CP was lower for $B_P$-$C_P$-$W_P$ than most CTs at site 2 in this study is difficult to explain.

*3.3 Canola and Wheat Straw Yield and Nutritive Value*

At site 1, the straw yield was influenced significantly by CTs, while at site 2, canola straw was similar (P>0.05) for all CTs (Table 3). The highest straw yield came from $B_M$-C-W, followed by $B_P$-$C_P$-$W_P$ and then P-C-W at site 1 in that order. The highest straw yield from $B_M$-C-W was probably a reflection of the higher seed yield produced by these CTs.

Both canola straw CP and energy in the form of total digestible nutrients (TDN) were not significantly affected by prior cropping management implemented in year 1 (2018) in this study at the two sites. The results of canola straw CP show that when integration of crop and livestock is involved and beef cattle are grazed on canola straw, the straw CP at both sites would be adequate and in most cases would be in excess of what a beef cow requires in early pregnancy according to NASEM recommendations (NASEM, 2016). At both sites 1 and 2, the straw TDN was short of meeting the TDN requirements of a beef cow in early pregnancy as recommended by NASEM (2016).

Wheat straw yield did not differ significantly for the CTs at both sites (Tables 3 and 4). Straw CP and TDN were significantly influenced by CTs at site 1 and greatly in favour of $B_P$-$C_P$-$W_P$ (8.46% CP, 54.3% TDN) than other CTs. The straw CP at both sites (5.43-9.33% CP) seemed to be sufficient in most cases for a beef cow in early to mid-pregnancy (NASEM, 2016). The straw TDN from both sites (<55% TDN) on the other hand was generally below that suggested for a beef cow in early to mid-pregnancy (NASEM, 2016).

Table 3. Seed/grain yield and CP (DM basis), and straw yield and straw CP and TDN (DM basis) for cropping treatments investigated in year 2 (2019, canola crop) and year 3 (2020, wheat crop) at both sites 1 and 2

| Canola | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Seed yield | | Seed CP | | Straw yield | | Straw CP | | Straw TDN | |
| Cropping treatment | Site 1 Kg ha$^{-1}$ | Site 2 | Site 1 % | Site 2 | Site 1 Kg ha$^{-1}$ | Site 2 | Site 1 % | Site 2 | Site 1 % | Site 2 |
| P-C-W | 2072c[¶] | 1736bc | 24.8 | 22.1a | 2442bc | 2347 | 6.56 | 9.33 | 42.9 | 39.44 |
| $B_P$-$C_P$-$W_P$ | 2352b | 2296a | 22.8 | 17.8c | 3445ab | 2709 | 6.26 | 6.64 | 41.9 | 36.92 |
| $B_M$-C-W | 2632a | 2464a | 23.2 | 20.4abc | 3691a | 3312 | 7.17 | 7.17 | 44.2 | 36.97 |
| $CCC_G$-C-W | 2072c | 1624c | 23.8 | 21.8a | 2377c | 2339 | 6.68 | 9.21 | 40.7 | 41.64 |
| $CCC_F$-C-W | 1568d | 2184abc | 23.2 | 22.3a | 2191c | 2658 | 8.12 | 7.95 | 44.2 | 39.21 |
| $CCC_R$-C-W | NA | 2240a | NA | 18.8bc | NA | 3224 | NA | 8.12 | NA | 37.17 |
| $CCC_{SG}$-C-W | 1624d | 1512 | 24.4 | 21.4ab | 2552c | 2321 | 7.31 | 7.82 | 42.7 | 38.26 |
| CV[§], % | 4.50 | 13.7 | 5.74 | 8.04 | 24.2 | 19 | 15.6 | 11.3 | 6.55 | 6.23 |
| **Wheat** | | | | | | | | | | |
| | Grain yield | | Grain CP | | Straw yield | | Straw CP | | Straw TDN | |
| Cropping | Site 1 | Site 2 | Site 1 | Site 2 | Site 1 | Site 2 | Site 1 | Site 2 | Site 1 | Site 2 |
| treatment | Kg ha$^{-1}$ | | % | | Kg ha$^{-1}$ | | % | | % | |
| P-C-W | 4032bc | 2352 | 18.7 | 12.83 | 2597 | 1415 | 7.07c | 9.33 | 50.9c | 39.4 |
| $B_P$-$C_P$-$W_P$ | 4166bc | 2890 | 18.2 | 9.86 | 2163 | 1340 | 8.46a | 6.63 | 54.3a | 36.9 |
| $B_M$-C-W | 5040a | 3091 | 18.3 | 11.23 | 2897 | 1431 | 6.73d | 7.17 | 51.5c | 36.9 |
| $CCC_G$-C-W | 4634ab | 2486 | 19 | 10.55 | 2178 | 1184 | 5.43g | 9.2 | 45.0e | 41.6 |
| $CCC_F$-C-W | 3629c | 2755 | 18.4 | 10.8 | 2572 | 1585 | 7.40b | 7.95 | 53.6b | 39.2 |
| $CCC_R$-C-W | 4637ab | 2890 | 19 | 10.01 | 2197 | 1485 | 6.18f | 8.11 | 47.6d | 37.2 |
| $CCC_{SG}$-C-W | 3898c | 2419 | 18.6 | 10.63 | 2189 | 1260 | 6.55e | 7.82 | 51.3c | 38.2 |
| CV, % | 8.85 | 22.9 | 5.14 | 6.76 | 24.3 | 22 | 1.35 | 14.1 | 0.62 | 4.50 |

[§]CV, coefficient of variation.
[¶]Within a particular column, means followed by the same letter are not different according to LSD at P = 0.05.
‡NA, data not available.

### *3.4 Plant Tissue*

In year 2, at site 1, only canola plant tissue P, Ca, and Zn of the thirteen minerals (N, P, K, Ca, Mg, S, Zn, Mn, Fe, Cu, B, Al, Na) were analyzed for here in the present study showed significant differences for the CTs investigated, while no canola plant tissue was impacted at site 2 (full data not presented). At site 1, $B_M$-C-W had the highest plant tissue P and the lowest level of plant tissue Zn for canola. Marschner (2011) reported that increases in the levels of P in the plant tissue could lead to a decrease in Zn uptake. Both $CCC_F$-C-W and $CCC_{SG}$-C-W had similar plant tissue Ca to P-C-W, but significantly higher than others. Going by the critical nutrient levels recommended by Holmes (1980) and Schwab et al. (2007) for annual crops, at site 1, canola tissue was deficient in N (<3.99% N) for P-C-W, $CCC_F$-C-W and $CCC_{SG}$-C-W. All CCC CTs in year 2 had insufficient Cu (<4 ppm). In general, all CTs were deficient in B (<29 ppm) and K (<2.79% K). Other minerals measured here were mostly well within the critical nutrient levels for canola (year 2). For canola in year 2 at site 2, nutrients in plant tissue were as follow: Cu was deficient in all CTs (<4 ppm Cu), B was adequate only in P-C-W (control) and $CCC_G$-C-W, while Na was only deficient in $B_M$-C-W (<0.11% Na).

In year 3, only wheat plant tissue Ca, Mg and Zn differed for the CT (data not shown). $B_M$-C-W had the highest plant tissue P. P-C-W (control) had the highest K. Plant tissue Ca and Zn were higher for cropping treatments that had peas and CCC (regardless of the use of the CCC) in year 1 than both CTs that had barley seeded in year 1 ($B_P$-$C_P$-$W_P$ and $B_M$-C-W). The highest level of Zn uptake was done by the $CCC_G$-C-W cropping system regardless of the crop (canola or wheat). This seems to suggest that peas or CCC might improve Ca and Zn availability for the benefit of subsequent crop production. This observation was also reflected in year 3 with wheat plant tissue (except for Zn with $B_P$-$C_P$-$W_P$). CTs did not impact plant tissue minerals at site 2 in year 3. In year 3, the wheat nutrient uptake was adequate for all CTs but deficient for Cu (<4ppm) for P-C-W. It is important to note that the nutrient concentration that is considered adequate will change as the plant grows and matures.

### *3.5 Soil Properties*

Soil nutrients were impacted by CT x year interaction effects at both sites. In the year following application, at site 1, $B_M$-C-W produced significantly higher soil N, P, K and S than others (Figures 1-4). At site 2, $B_M$-C-W also produced the higher soil N (Figure 5), while $CCC_R$-C-W had the most soil P and K (Figures 6 and 7). Except for $B_M$-C-W and $CCC_R$-C-W (in a few cases), in general, at both sites, soil N and P availability had a pattern of increasing their availability for year 2 but decreasing to below their initial levels of year 1. The manure treatment ($B_M$-C-W) in year 3 had soil N and P levels that were similar to year 1. The generally higher soil N, P, K, and S levels observed for all CTs in year 2, particularly for soil N and P seems to suggest that soil N and P credits were most apparent to the year following the implementation of CTs examined here (bio-stimulants, manure application, CCC for green manure, and grazing of CCC) compared with the control crop rotation. At site 1, soil K availability was particularly influenced by the first year manure application treatment ($B_M$-C-W) which doubled its initial content (year 1) and remained remarkably similar for the following two years. It is important to state here that the inclusion or integration of CCC with grazing or when used for green manure reduced the amount of soil N and P depletion over the duration of this study at site 2. This shows that crop-livestock integration or the use of CCC for green manure would greatly benefit the producers in terms of reduction in-organic fertilizer application over most of the other cropping systems. As stated earlier in this paper, strip grazing would have been ideal for maximizing the impact of both grazed CCCs and the residual soil N and P would have been much more significant than obtained in the present study. Future research studies aimed at planned strip grazing to investigate yearly fertility savings and cost: benefit ratio for subsequent crop production on a short and long-term basis are needed.

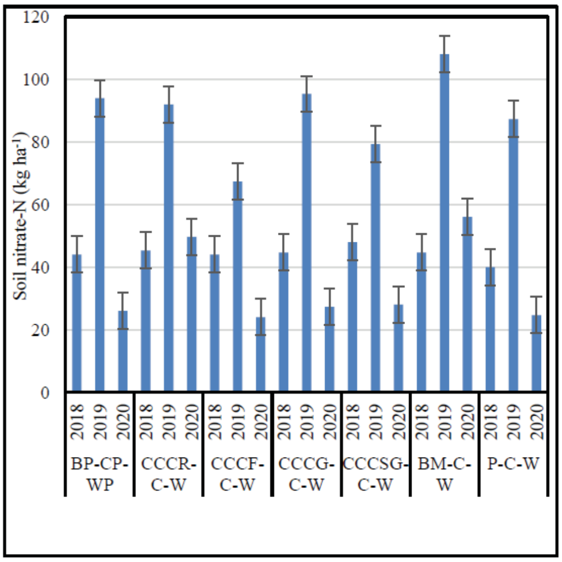


Figure 1. Soil nitrate-N for cropping treatments at site 1 for 3 years

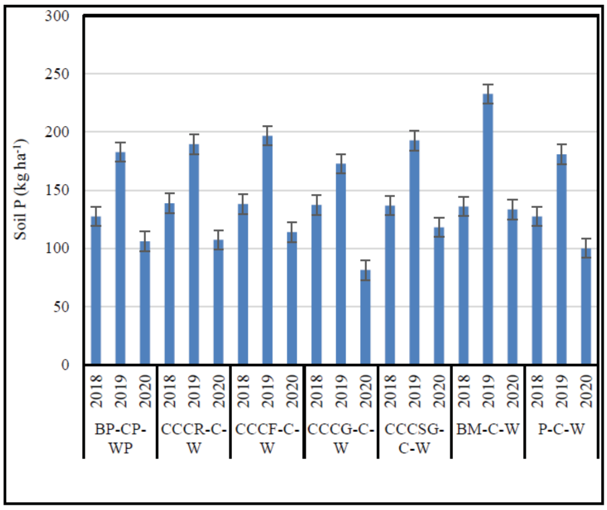


Figure 2. Soil P cropping treatments at site 1 for 3 years

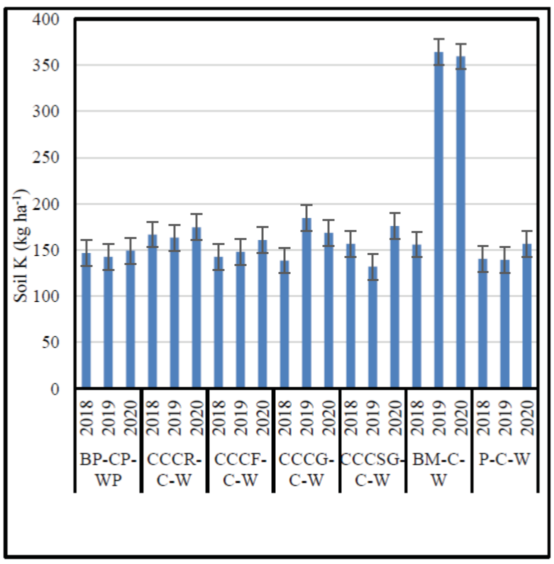


Figure 3. Soil K for cropping treatments at site 1 for 3 years

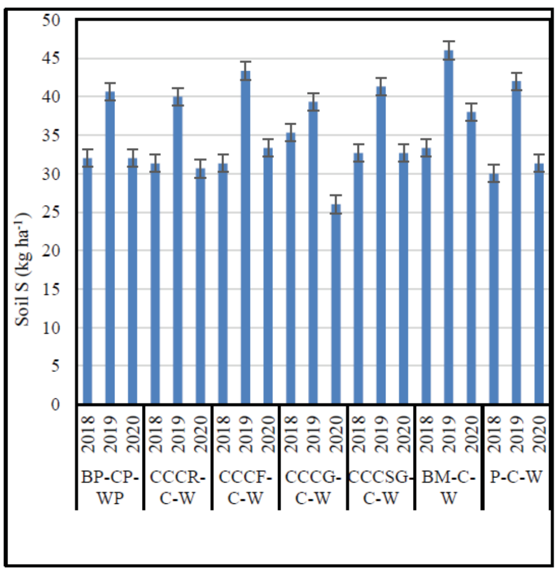


Figure 4. Soil S for cropping treatments at site 1 for 3 years

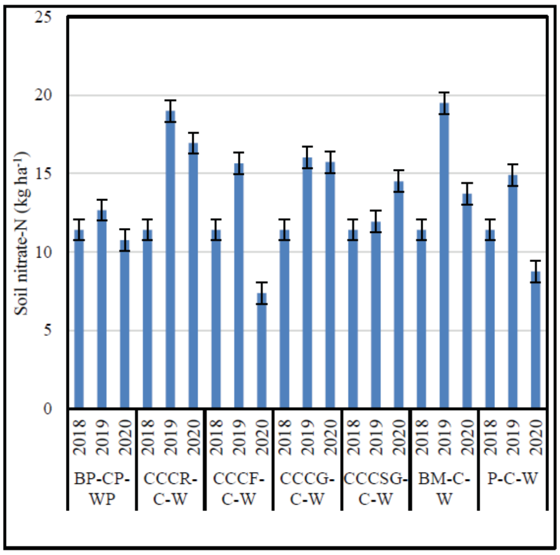


Figure 5. Soil nitrate-N for cropping treatments at site 2

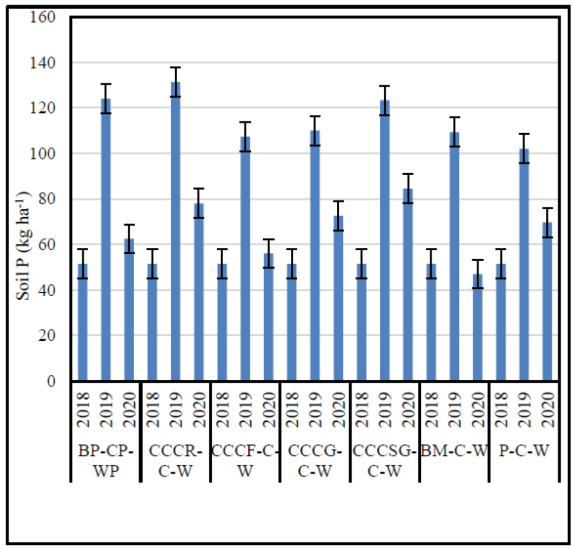


Figure 6. Soil P for cropping treatments at site 2 for 3.

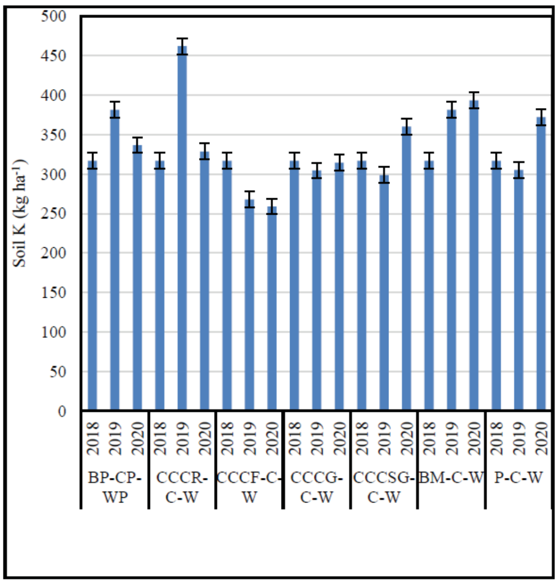


Figure 7. Soil K for CT cropping treatments at site 2 for 3 years

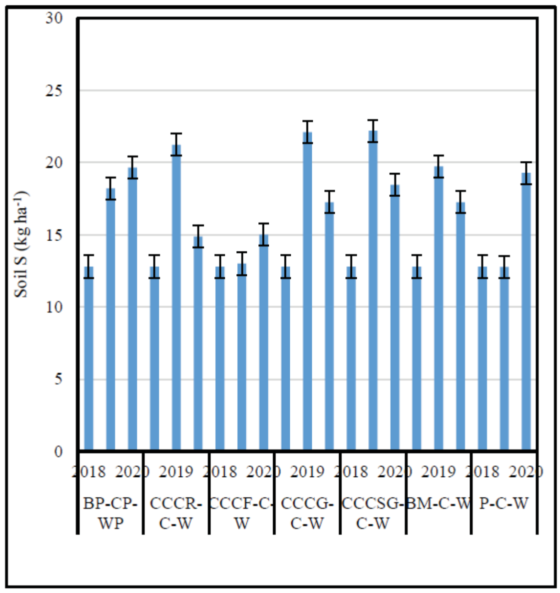


Figure 8. Soil S for cropping treatments at site 2 for 3 years

### *3.6 Soil Quality Characteristics and Biological Activities*

CT was not significantly different for surface SOM and pH, as well as all the following soil physical and biological activities: BD, SOC, TN, and TC (data not shown).

For the SWAggr, AC, and SMResp, which were examined at two soil depths (0-7.5 and 7.5-15.0 cm), there were no significant CTs by soil depths interactions at both sites. The CTs did not have significant impacts on SWAggr, AC, and SMResp at each site. However, both AC and SMResp were influenced ($P<0.05$) by soil depths at both sites, but not SWAggr in any of the sites. As expected, AC and SMResp were consistently higher at 0-7.5 cm than 7.5-15.0 cm at both sites (Table 4). The higher AC in 0-7.5 cm at both sites indicates a trend toward more SOM building up in the soil through biological activity (Hoffland et al., 2020; Obalum et al., 2017). The higher SMResp in the 0-7.5 than 7.5-15.0 cm is an indication of presence of a larger, more active soil community (Hoffland et al., 2020). Surprisingly, SMResp values were similar for both sites at each examined soil depth. With the exception of SMResp, in general, all soil characteristics measured here were higher in values at site 1 than site 2.

Table 4. Means of SWAggr, AC and SMResp for cropping treatments and soil depths for both sites 1 and 2

| Site 1 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cropping | SWAggr | | | AC | | | SMResp | | |
| treatment | 0-7.5 cm | 7.5-15 cm | Mean | 0-7.5 cm | 7.5-15 cm | mean | 0-7.5 cm | 7.5-15 cm | mean |
| P-C-W (C) | 33.5 | 30.4 | 32.0a | 472 | 385 | 429a | 0.72 | 0.48 | 0.60a |
| $CCC_G$-C-W | 29.9 | 27.8 | 28.9a | 445 | 370 | 408a | 0.7 | 0.51 | 0.61a |
| $CCC_R$-C-W | 27.1 | 28.3 | 27.7a | 482 | 335 | 409a | 0.72 | 0.44 | 0.58a |
| BM-C-W | 29.3 | 24.5 | 26.9a | 456 | 332 | 394a | 0.71 | 0.48 | 0.60a |
| $CCC_{SG}$-C-W | 27.1 | 30.5 | 28.8a | 461 | 343 | 402a | 0.74 | 0.48 | 0.61a |
| $CCC_F$-C-W | 28.6 | 31.2 | 29.9a | 410 | 315 | 363a | 0.65 | 0.46 | 0.56a |
| $B_P$-$C_P$-$W_P$ | 28.2 | 23.1 | 25.7a | 427 | 348 | 388a | 0.7 | 0.48 | 0.59a |
| Mean¶ | 29.1a | 28.0a | | 450a | 347b | | 0.71a | 0.48b | |
| **Site 2** | | | | | | | | | |
| Cropping | SWAggr | | | AC | | | SMResp | | |
| treatment | 0-7.5 cm | 7.5-15 cm | Mean | 0-7.5 cm | 7.5-15 cm | mean | 0-7.5 cm | 7.5-15 cm | mean |
| P-C-W (C) | 23.8 | 21.2 | 22.5a | 259 | 235 | 247a | 0.63 | 0.38 | 0.51a |
| $CCC_G$-C-W | 20 | 18.2 | 19.1a | 281 | 216 | 249a | 0.74 | 0.48 | 0.61a |
| $CCC_R$-C-W | 24.6 | 24.3 | 24.5a | 279 | 176 | 228a | 0.72 | 0.48 | 0.60a |
| BM-C-W | 22.2 | 22.9 | 22.6a | 232 | 147 | 190a | 0.67 | 0.68 | 0.68a |
| $CCC_{SG}$-C-W | 22 | 24.4 | 23.2a | 257 | 169 | 213a | 0.74 | 0.51 | 0.63a |
| $CCC_F$-C-W | 22.8 | 22.3 | 22.6a | 214 | 149 | 182a | 0.8 | 0.64 | 0.72a |
| $B_P$-$C_P$-$W_P$ | 21.1 | 28.6 | 24.9a | 223 | 171 | 197a | 0.6 | 0.44 | 0.52a |
| Mean¶ | 22.4a | 23.1a | | 249a | 180b | | 0.70a | 0.51b | |

¶Within a particular soil parameter, means followed by the same letter in the same row are not different according to LSD at P = 0.05.

## 4. Conclusion

The evaluation of mixed crop-livestock systems during a 3-year period gave an indication of the potentiality of these systems to minimize the use of chemical fertilizer inputs for annual crops. Canola yields were significantly influenced by prior CTs at both sites. Three of the top yields over control (P-C-W) were for treatments: $B_M$-C-W, $B_P$-$C_P$-$W_P$, and $CCC_R$-C-W. Canola straw CP and TDN can also be considered for utilization in these ecosystems. But their use will depend on what kind of livestock production is targeted. The effect of the first year was more pronounced on wheat grain yield at site 1 than site 2. At site 1, manure ($B_M$-C-W) produced high wheat grains, and was statistically similar to 2 of the CCC ($CCC_G$-C-W and $CCC_R$-C-W). Wheat grain protein for the overall study was not influenced by the cropping system. Site 1 had a higher percentage of protein (18.6%) than site 2 (10.8 %). Soil P levels at both sites for $B_M$-C-W had a higher level of soil P for year 2. A crop-livestock integration or the use of CCC for green manure would have great benefit to producers in terms of savings in fertility cost for canola and wheat production over most of the other cropping systems. More studies need to be carried out to evaluate the appropriate cropping system to target specific constraints in the soil.

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**References**

A&L Canada Laboratories Inc. (2019). *2019 A&L Tissue sampling reference guide.* A&L Canada Laboratories Inc. pp. 26. Retrieved from www.alcanada.com

AAF (Alberta Agriculture & Forestry). *(2018). Using 1,000 Kernel Weight for Calculating Seeding Rates and Harvest Losses*. Agri-Facts, Agdex 100/22-1.

AAF (Alberta Agriculture & Forestry). (2019). *2019 Cropping alternatives.* Retrieved from https://www.alberta.ca/cropping-alternatives.aspx

AAF (Alberta Agriculture & Forestry). (2020). *2020 Cropping alternatives*. Retrieved from https://www.alberta.ca/cropping-alternatives.aspx

AAF (Alberta Agriculture & Forestry). (2020). *2021 Cropping alternatives.* Retrieved from https://www.alberta.ca/cropping-alternatives.aspx

ACIS (Alberta Climate Information Service ACIS). (2020). *Current and historical Alberta weather station data viewer. Data provided by Alberta Agriculture and Forestry*. Retrieved from https://acis.alberta.ca/acis/weather-data-viewer.jsp.

AOAC Official Method 972.43. (2006). Microchemical determination of carbon, hydrogen, and nitrogen, automated method. *Off. Methods Anal. AOAC Int., 12,* 5-6.

Barot, S., Allard, V., Cantarel, A., Enjalbert, J., Gauffreteau, A., Goldringer, I., ... Porcher, E. (2017). Designing mixtures of varieties for multifunctional agriculture with the help of ecology. *A review. Agronomy for sustainable development, 37*(2), 13. https://doi.org/10.1007/s13593-017-0418-x

Bell, L. W., & Moore, A. D. (2012). Integrated crop-livestock systems in Australian agriculture: Trends, drivers and implications. *Agricultural Systems, 111*, 1-12. https://doi.org/10.1016/j.agsy.2012.04.003

Bonaudo, T., Bendahan, A. B., Sabatier, R., Ryschawy, J., Bellon, S., Leger, F., Magda, D., & Tichit, M. (2014). Agroecological principles for the redesign of integrated crop-livestock systems. *European Journal of Agronomy, 57*, 43-51. https://doi.org/10.1016/j.eja.2013.09.010

CARA (Chinook Applied Research Association), (2016). *Annual Reports.*

Ciampitti, I. A., Garcia, F. O., Picone, L. I., & Rubio, G. (2011). Soil C & P pools in field crop rotations in Pampean soils of Argentina. *Soil Sci. Soc. Am. J., 75*, 616-625. https://doi.org/10.2136/sssaj2010.0168

CoStat Statistical Software. (2005). *Cohort Version 6.2*. Monterey, CA: Costat.

Garrett, R., Niles, M. T., Gil, J. D. B., Gaudin, A., Chaplin-Kramer, R., … Assmann, A. (2017). Social and ecological analysis of integrated crop livestock systems: Current knowledge and remaining uncertainty. *Agric Syst., 155*, 136-46. https://doi.org/10.1016/j.agsy.2017.05.003

GOA (Government of Alberta). (2020). *Alberta Soil Information Viewer*. Retrieved from https://soil.agric.gov.ab.ca/agrasidviewer

GOWA (Government of Western Australia). (2021). *Measuring and reporting soil organic carbon*. Department of Primary Industries and Regional Development, Government of Western Australia. Retrieved from https://www.agric.wa.gov.au/soil-carbon/measuring-and-reporting-soil-organic-carbon

Hendrickson, J. R., Hanson, J. D., Tanaka, D. L., & Sassenrath, G. (2008). Principles of integrated agricultural systems: Introduction to processes and definition. *Renewable Agriculture and Food Systems, 23*(4), 265-271. https://doi.org/10.1017/S1742170507001718

Hoffland, E., Kuyper, T. W., Comans, R. N., & Creamer, R. E. (2020). Eco-functionality of organic matter in soils. *Plant and Soil, 455*, 1-22. https://doi.org/10.1007/s11104-020-04651-9

Holmes, M. R. J. (1980). *Nutrition of the oilseed rape crop*. Applied Science Publishers.

Ju, X., & Christie, P. (2011). Calculation of theoretical nitrogen rate for simple nitrogen recommendations in intensive cropping systems: A case study on the North China Plain. *Field Crops Research, 124*(3), 450-458. https://doi.org/10.1016/j.fcr.2011.08.002

Lal, R. (2009). *Soil C sequestration for climate change mitigation and food security.* In Souvenir, Platinum Jubilee Symp. on Soil Science in Meet the Challenges to Food Security and Environmental Quality, New Delhi. Indian Soc. of Soil Sci., New Delhi. pp. 39-46.

Lemaire, G., Franzluebbers, A., Carvalho, P. C. de F., & Dedieu, B. (2014). Integrated crop-livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. *Agriculture Ecosystem Environment, 190*, 4-8. https://doi.org/10.1016/j.agee.2013.08.009

Marschner, H. (2011). *Marschner's mineral nutrition of higher plants*. Academic press.

Maynard, D., Kalra, Y., & Crumbaugh, J. (2008). Nitrate and exchangeable ammonium nitrogen. In E. G. Gregorich & M. R. Carter (Eds.), *Soil sampling and methods of analysis* (pp. 71-77). CRC Press, Boca Raton, FL.

Moraine, M., Grimaldi, J., Murgue, C., Duru, M., & Therond, O. (2014). *Integrating crop and livestock activities at territorial level in the watershed of Aveyron river: From current issues to collective innovative solutions*. In Proceedings of 11th European IFSA Symposium, Berlin, Germany. pp. 1371-1384.

National Academies of Sciences, Engineering, and Medicine (NASEM). (2016). *Nutrient requirements of beef cattle* (8th ed.). The National Academies Press, Washington, DC. pp. 494.

Obalum, S. E., Chibuike, G. U., Peth, S., & Ouyang, Y. (2017). Soil organic matter as sole indicator of soil degradation. *Environmental monitoring and assessment, 189*(4), 176. https://doi.org/10.1007/s10661-017-5881-y

Omokanye, A. (2019). *Cover crop cocktails for livestock feed*. Presentation at Cocktail Cover Crop Workshop, Debolt Centre, Debolt, Alberta, Canada.

Peterson, C. A., Deiss, L., & Gaudin, A. C. (2020). Commercial integrated crop-livestock systems achieve comparable crop yields to specialized production systems: A meta-analysis. *PloS one, 15*(5), e0231840. https://doi.org/10.1371/journal.pone.0231840

RStudio Team. (2021). *RStudio: Integrated Development for R. RStudio, PBC, Boston, MA*. Retrieved from http://www.rstudio.com

Russelle, M. P., Entz, M. H., & Franzluebbers, A. J. (2007). *Reconsidering integrated crop-livestock systems in North America.* https://doi.org/10.2134/agronj2006.0139

Schindelbeck, R. R., Moebius-Clune, B. N., Moebius-Clune, D. J., Kurtz, K. S., & van Es, H. M. (2016). *Cornell University comprehensive assessment of soil health laboratory standard operating procedures*. Ithaca, NY: Cornell University.

Schumacher, B. A. (2002). *Methods for the determination of total organic carbon (TOC) in soils and sediments*. NCEA-C-1282, EMASC-001. United States EPA, Las Vegas.

Schwab, G. J., Lee, C. D., & Pearce, R. (2007). *Sampling Plant tissue for Nutrient Analysis, University of Kentucky Cooperative Extension service.*

Sparks, D. L., Page, A. L., Helmke, P. A., & Loeppert, R. H. (Eds.). (2020). *Methods of soil analysis, part 3: Chemical methods* (Vol. 14). John Wiley & Sons.

Yousaf, M., Li, X., Zhi Zhang, Z., Ren, T., Cong, R., Ata-Ul-Karim, S. T., Fahad, S., Shah, A. N., & Lu, J. (2016). Nitrogen fertilizer management for enhancing crop productivity and nitrogen use efficiency in a rice-oilseed rape rotation system in China. *Front Plant Sci., 7*, 1496. https://doi.org/10.3389/fpls.2016.01496

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