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Research Article

Impacts of Cropping Systems on Normalized Difference Vegetative Index and Soil Moisture in Maize-Bean Crops

Yaya Tesfa*, Jemal Bekere

Melkassa Agricultural Research Center, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia

Abstract

Maize (Zea mays L.) is one of the three leading staple cereal crops worldwide along with rice and wheat. Conservation agricultural practices (CA) may conserve the limiting natural resources especially soil moisture and soil nutrients. Optical sensor has been proven to be an effective tool for monitoring management. In season monitoring of agricultural crop conditions using normalized differentiated vegetative index (NDVI) and soil water during crop growth stage is very important. This field experiment was done at Melkassa agricultural research center during the rainy season of 2018 1nd 2019 to study the impacts of cropping systems on normalized difference vegetative index and soil moisture in maize-bean crops. Split plot treatment design with three replication was used. Two tillage levels were assigned to the main plots and four maize-legume systems were assigned to the sub plots. NDVI of maize at vegetative and tasselling stage were significantly affected by tillage types, and tillage x cropping system interaction. However, NDVI of maize at grain filling stage was significantly affected by tillage types only. At maize vegetative and tasselling stage NDVI was higher for conventional crop production practice (CP) than CA practice. At maize grain filling stage NDVI was become higher for conservational practice. Soil moisture content at different depth was greater for maize bean rotation under conservation agricultural practice.

Keywords

Soil Moisture, Normalized Difference Vegetative Index, Cropping System

1. Introduction

Water and soil are limiting factors for sustainable crop production in sem arid areas. Conservation agricultural practices may conserve the limiting natural resources especially soil moisture and soil nutrients. Conservation agriculture (CA) is known by increasing soil organic matter content which may partially replace the use of chemical fertilizers and supplemental irrigation while restoring the environment [5].

Optical sensor has been proven to be an effective tool for monitoring management. Using optical sensor techniques especially normalized difference vegetative index is better than traditional plant tissue sampling analysis in crop management monitoring. In season monitoring of agricultural crop conditions using NDVI and soil water during crop growth stage is very important. Timely assessment of declined production caused due to moisture stress, soil fertility problem, pest infestation and other natural disaster can be very critical where the economy is dependent on the final crop harvest. Early estimation and assessment of crop production reduction can be used to avert stress situation in

*Corresponding author: yaya.tesfa@gmail.com (Yaya Tesfa)

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growth and development of agricultural crops [14].

Maize (Zea mays L.) is one of the three leading staple cereal crops worldwide along with rice (Oryza sativa L.) and Wheat (Triticum aestivum L.). Maize and common bean are important crops in Ethiopia and are mostly grown by resource-poor farmers in risky farming systems. Maize is the second most important main staple and common bean is an important dietary protein source for the rural poor smallholder farmers in Ethiopia. The two crops are mutual to each other when used in rotation and intercropping systems under conventional crop production which causes degradation of soil and yield losses, especially in the semiarid regions. The conventional crop production practice (CCP) which involved intensive tillage plus repeated cereal sole cropping with residue removal which causes poor soil structure and low yield [15].

Global climate change might cause higher potential evapotranspiration, increases frequency of intensive rain and decreases precipitation [7]. This implied that water demand potential increased and water conservation practices would be improved especially for the smallholder agriculture in developing countries.

Improved maize and common bean-based cropping systems practices are important to minimize adverse impacts of poor soil structure and climate on crop production in sem arid areas of Ethiopia.

Agricultural production systems which improve soil fertility and yield through conserving soil, water, nutrient and environment, socially and economically visible was suggested for regions with poor soil and erratic rainfall. Conservation Agriculture practice is a collection of cropping elements setting for continuous increased crop yields with low negative outcome on environment-reduces crop production processes that contribute to emission of greenhouse gases, soil degradation and water pollution.

According to [9] CA has many advantages over CCP which included soil moisture retention which allows earlier planting for longer maturity varieties, soil moisture conservation, reduced soil erosion, reduced runoff, and low labour demand as well as improved crop yields. With conservational agricultural practice various soil properties such as soil organic C, low soil compaction, improved water infiltration, low penetration resistance and reduced bulk density could be improved. Effectiveness of a chosen agricultural management manner can be evaluated by the integration of crop growth, development and crop yields. Latest progresses in digital agricultural advancement have result in evolution of crop canopy optical sensor which is used to compute normalized difference vegetative index values.

Our farmers follow traditional fertilization practices or those which are based upon wide regional recommendations which fail to account for the intra-field variability and temporal variability of the crop nutrient requirement. This problem can be addressed with the help of NDVI which is a precision agriculture tool.

Knowing the relationship among moisture, soil nutrient, crop reflectance and farm variably could be used for assessment of optical sensor as a means for moisture and soil nutrient monitoring. However, there are very limited studies help to examine the role of NDVI index to examine impact of crop management on crop growth and development in Ethiopia.

Therefore, the objectives of the study were:

1) To evaluate performances of different cropping systems for soil moisture limiting areas
2) To assess in-season maize growth under contrasting crop management practices using handheld optical sensor

2. Materials and Methods

2.1. Description of the Study Site

The study was conducted at Melkassa agricultural research center which is located at about 117 Km in east of capital city of a country Addis Ababa. Melkassa is located at 8°24'N and 39°21'E with 1550 m elevation. It is categorized under arid to sem-arid agro ecological zone.

Its soil type is Andosols with PH 7 to 8.2. Its minimum and maximum temperature is 14℃ and 28.4℃ (http://www.eiar.gov.et/marc).

2.2. Description of the Experimental Materials

The on-going long-term CA experiment which was established in 2010 was used for this study. The two locally widely used open pollinated Melkassa II maize variety and Nassir common bean variety were planted (Table 1). A Green seeker hand held optical sensor unit was a tool used for collection of normalized difference vegetative index values during different development stages of maize. Moisture meter was used to measure soil moisture with a meter long access tube tool.

2.3. Treatments and Experimental Design

Combination of two types of tillage and four cropping systems were used to develop treatments. The randomized complete block design with split plot design was used. CA and CCP were the tillage types and they were randomly assigned to the main plots. Conservational Agriculture had full residue retention from previous harvest and no till, while conventional crop production practice was three times tillage pass with animal drawn local *maresha* with complete residue removal. Cropping systems were maize-common bean intercropping, maize-common bean rotation, maize-monoculture, and common bean monoculture. The treatments were replicated three times.

Table 1. *Combination of treatments for maize-common bean cropping systems at MARC.*

Trt.no	MP	SP
1	CA	Sole maize
2	CA	Sole bean
3	CA	Rotation
4	CA	Intercropping
5	CP	Sole maize
6	CP	Sole bean
7	CP	Rotation
8	CP	Intercropping

2.4. Field Management

The CP tillage was using the oxen drawn plow and tilling three times. Though depends on local climate conditions, the first and second tillage were in June and final tillage was during planting of maize crop. Maize was planted on late June, and common bean was planted at mid-July.

The cultivar Melkassa-II for maize and cultivar Nassir for common bean was used.

For maize 0.75 × 0.25 and for common bean 0.40 × 0.10 m, plant spacing was used.

Common bean was planted between each maize rows by maintaining full population of maize and 53% of common bean sole crop plant population, for the intercrop treatments. Pre planting herbicide was used once at two weeks before planting of CA treatments to control weeds and hand weeding is practiced when weed control is needed. For CCP plots was controlled using hand hoe.

2.5. Data Collected

Normalized difference vegetative index: This optical sensor readings was taken weekly at three growth stages of plant growth. These stages are vegetative, tasseling and silking for maize. Three rows from each plot were taken by green seeker hand held at a height of approximately 70 cm above the crop canopy.

Soil water: soil moisture reader was also used to record moisture content of each plot. Soil moisture was taken periodically in each growth stage of the main crop at 0 to 10, 10 to 20, 20 to 30, 30 to 40, and 40 to 50, 50 to 60 and 60 to 100Cm depths from auto moisture reader sensor.

2.6. Data Analysis

Data collected from this experiment were analyzed using statistic 10.0 computer software and mean separation was done using Fisher LSD at $p<0.05$ for significant treatment effects. Data was tested for normality using normal probability plot and ANOVA was computed following the general linear model procedure to test for statistical differences among treatments. F test for main plot effects was done using Error a, and for sub plot and its interaction done with Error B.

3. Results and Discussion

3.1. Crop Growth Performance as Measured by Normalized Differentiated Vegetative Index (NDVI)

Optical sensor has been shown to be an effective tool for monitoring cropping practices. Normalized differentiated vegetative index of maize at vegetative stage were significantly affected by tillage types, and tillage x cropping system interaction (Table 2). Thus, NDVI was higher under conventional crop production practices for main plot treatments and higher for maize-bean intercropping under both conventional and conservational agriculture practice for interaction of tillage types and cropping system.

Normalized difference vegetative index of maize at tasselling stage was also significantly affected by tillage types, interaction of tillage x cropping system. Thus, NDVI was higher under CP for tillage types, and higher for maize bean rotation under CA for interaction of tillage and cropping system.

However, normalized difference vegetative index of maize at grain filling stage was significantly affected by tillage types, but not significantly affected by both cropping system and interaction of tillage type and cropping system. Even though not significant maize bean intercropping and maize bean rotation under CA gave higher NDVI values for interaction of tillage types and cropping system.

The crop growth performance of maize measured over three growing period is presented in Table 2 in terms of NDVI. Generally, results of this trial shown that NDVI was greater with CCP for the earlier growth stage and lower with CA at earlier growth stage and became greater with CA during grain filling stage relatively. Maize bean rotation under CA and maize bean intercrop under CA and CCP recorded highest value of NDVI, but maize monoculture and maize bean rotation under CCP recorded lowest value of NDVI.

Generally, under this trial NDVI has an increasing trend with crop growing period but finally declined because of pollen dropped at maize silking stage. By considering terminal soil moisture and other crop production limiting factor it is estimated that treatment with high NDVI has better in yield and yield components. In case of this study CA has better to overcome terminal drought with highest NDVI values at grain filling stages.

Conventional tillage resulted in faster growth compared to zero tillage with residue retention at the beginning of the season.

Table 2. *The effects of T, CS, and T*CS interaction on NDVI at different maize growth stages.*

Tillage	Vegetative	Tasselling	Grain Filling
CP	64.7a	82.0a	70.7b
CA	60.3b	80.9b	75.2a
SEM+	0.27	0.0786	2.0382
CV%	27.31	8.38	13.29
T X CS	Vegetative	Tasseling	Grain Filling
CA_MBI	70.3ab	81.7b	78.0
CA_MBR	61.0b	84.7a	74.3
CA_SM	59.7c	83.3ab	73.3
CP_MBI	73.3a	80.0c	67.0
CP_MBR	49.3d	81.3b	73.0
CP_SM	61.3b	77.7d	72.0
SEM	7.7	1.6	4.3
CV	21.2	3.37	10.2

Retention of crop residue continuously will lead to improve CA crop performance by reducing soil crusting, controlling runoff and stimulating macrofauna activity [13].

NDVI is one of the apparatuses involved in measurement of crop growth and performance by indicating crops photosynthetic efficiency.

The greater NDVI with maize-bean intercrop under CCP during maize vegetative stage might be due to better growth of maize because of low N immobilization. This result is inline with [11].

For many crops, more than half of the economic yield derives from photosynthesis after flowering. Therefore, photosynthesis at the reproductive stage is more directly related to yield size. The positive correlation between leaf photosynthesis and yield is observed mostly at this stage. Obviously, one should not expect to find the correlation at all stages of crop development. It is estimated that NDVI is linearly correlated with the canopy of the crop.

Once the canopy began to close at vegetative stage, leaves from larger plants covered the leaves and whorl of smaller plants, extending further into the linear row. As these leaves began to fill the row, intersecting with and in some cases covering up leaves from smaller plants; soil coverage becomes decreased, and the amount of green vegetation visible increased, increasing NDVI. Low NDVI values are the result of sensing bare soil associated with uneven plant stands and some missing plants, and these same low spots were no longer obvious by vegetative stages.

Over this period, some of the tassels were completely visible, while others were just emerging. The light yellow-green color present in the tassels resulted in decreased NDVI readings, while plants with more immature tassels had darker green colors and higher average NDVI.

At this stage of growth, a noticeable decrease in mean NDVI values was observed consistent with the expected change in leaf color.

The ability of the by-day NDVI readings to detect the stage of growth where the maximum amount of within-row-by-plant variability was expressed is an exciting prospect.

From the tasseling growth stages, the variability in plant spacing/growth was masked due to overlapping leaves and canopy closure. After tasseling, and with more rapid senescence, sloughing off led again to recognizing the same spatial variability encountered early in the season.

3.2. Soil Moisture Content

At soil depth of 100mm soil moisture content was significantly affected by interaction of tillage types and cropping system. Thus, maize bean rotation under CA had significantly higher moisture content than other combination of tillage type and cropping system at depth of 0-100mm (Figure 2). Maize bean rotation and maize bean intercropping under CA had higher moisture content of 12.55% and 10.24% than maize monoculture under CA for this depth.

At soil depth of 200mm soil moisture was significantly affected by interaction of tillage types and cropping system. Maize bean rotation and maize monoculture under conventional crop production had significantly higher soil moisture content (Figure 1).

At soil depth of 400mm interaction of tillage types and cropping system was significantly affected soil moisture content. Thus, maize bean rotation under conventional crop production had significantly higher soil moisture content.

At soil depth of 600mm and 1000mm soil moisture content had significantly affected by cropping system only. Thus, maize bean rotation had significantly higher moisture content than other cropping system.

At crop vegetative growth stage soil moisture was found in high quantity in the soil due to minimum usage by crops at early crop growth stage. However, in this study we have observed minimum soil moisture at reproductive crop growth stage because of critical soil moisture requirements and maximum water uptake by crops at reproductive stage. Moreover, we have observed better soil moisture content for maize bean rotation system under conservation agriculture. At the first 1000mm soil depth soil moisture content in the conventional crop production was constantly below those of the conservation agricultural practice. This might be due to good soil physical property which has played a significant role on soil moisture retention. It is inline with findings by [12] who stated the significant effect of cropping system and tillage types on soil moisture content at different soil depths. He reported that maize bean rotation had contributed high soil moisture at the soil depths of 0-100, 100-200, 200-400, 400-600m and 600-1000mm which was responsible for high leave canopy coverage during crop growth stage.

Better crop growth and canopy cover due to crop rotation and CA leads reduced soil surface evaporation and high soil water availability at soil root zone. It is corroborated with [8] who reported water uptake from soil surface layers increased due to increased root density in the upper layer, thus decreasing water dissipated through evaporation.

Better soil organic matter content in CA plots may have been attributed to high moisture content in the soil through holding moisture than CCP plots. This is inline with the study done by [2] that soil rich in clay content attributed to an increase in water holding capacity and minimized evaporation.

The higher moisture content in soil on maize bean intercropping at top soil profile under CA plots may have been attributed to lower evaporation from CA plots due to residual retention. These findings corroborated the study of [18] who reported that cropping systems that offer quick surface cover promote soil water content by reducing evaporation and increasing infiltration. It has been reported that maize-soybean intercropping could save irrigation water due to better soil cover by a faster increase in leaf area index [6].

On average higher soil moisture content was recorded on CA treatments than on CCP plots. This implied that soil conservation practices attributed to good soil quality especially soil moisture. This result has similarity with the findings of [1] who stated that plot with soil water retention capacity would be used as indicator of soil physical quality. This means that areas with poor soil structure cannot be able to hold sufficient moisture for good plant growth and leads stunted plant growth due to low absorption of plant nutrients. It is also inline with the works of [10, 16] that absence of tillage and mulching was responsible for higher infiltration rates and soil moisture content.

For maize bean rotation higher stored soil water at high water demand of crop growth stages compared with other cropping system was observed. This might be due to quicker decomposition of bean plant residue than maize residue which can affected soil aggregation to improve water infiltration and reduce soil crusting. On the other side persistent residue of maize protects soil from raindrop impact and minimize evaporation [22], although rotation effect happened on both CA and CCP.

The higher moisture content in soil on MBI under CA plots might be due to lower evaporation by soil surface coverage. This is in line with the work of Steiner [18] who reported higher moisture content of soil due to reduced evaporation and improved infiltration by cropping system that allow immediate soil surface coverage. [5] also reported saved irrigation water by intercropping system due to better soil cover by increased leaf area index. [3] found that intercropping system has advantages to use water from different soil layers by the companion crops and improves total water use efficiency. Intercropping offers quick shade for the soil surface due to growth of legume canopy. Nevertheless, maize bean intercropping would assist in restoring soil organic matter which increased moisture retention in soil [17].

A study observed maize and cowpea extended their roots into the rhizosphere of each other. [4] In the maize-soybean intercropping the roots of maize also spread into the soybean strips [21].

Lower soil moisture content was observed for maize monoculture under conventional crop production practice towards the end of cropping season. This might be due to heavy surface soil disturbance by frequent tillage and excess water consumption by previous bean crop.

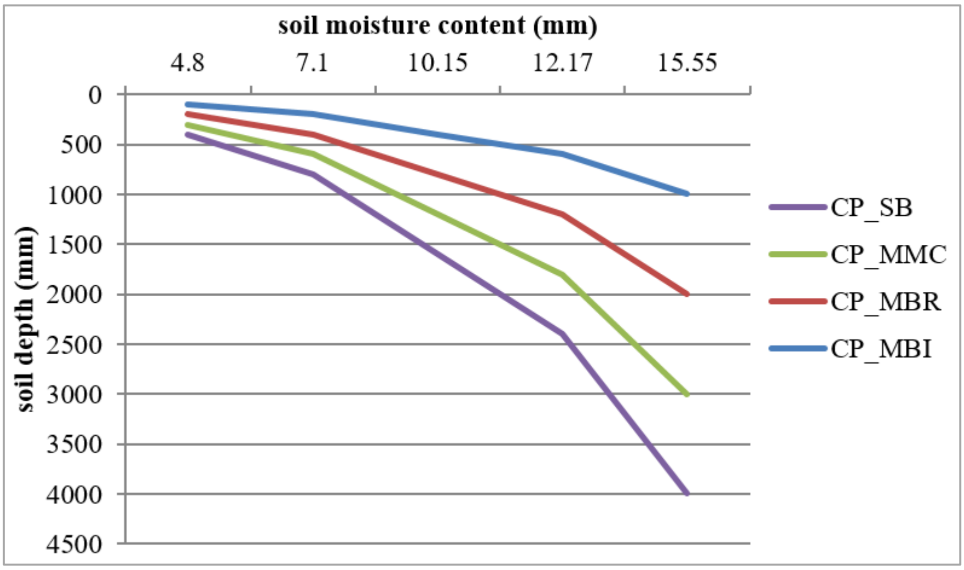

Figure 1. *Effect of CP X CS on soil moisture at different soil depth.*

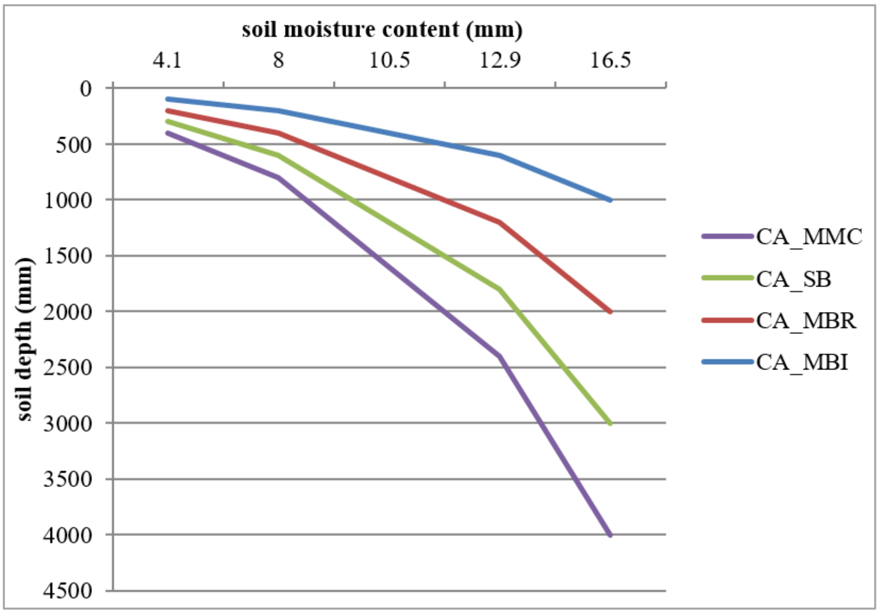

Figure 2. *Effect of CA X CS on soil moisture at different soil depth.*

At end of the season common bean fully develops its canopy which causes maximum water consumption. This has an effect on the next season maize crop as to fill soil profile more rain is needed. This implied that only low soil moisture is available for maize monoculture planted after common bean. This can clearly be seen where the maize monoculture treatment after common bean had the lowest available soil moisture. This might be until the soil profile slowly filled up again at the beginning of next cropping season with water conservational practice and towards the end of the season was one of the treatments with highest soil moisture [20].

In sole crop of maize soil moisture content in the soil was reduced dramatically due to high evapotranspiration potential, however in the sole crop of cowpea soil moisture content was dramatically increased due to low evapotranspiration potential. This means decreased evapotranspiration rate from soil surface due to canopy cover of dense legume resulted retention of soil moisture. The lower soil moisture content on the CP plot was also due to the sandy soil texture and hand weeding which causes high weed pressure. It was stated that CA plots had lower in erosion and runoff rates than conventionally ploughed plots. The amount of soil erosion caused by surface soil disturbance could be minimized by judicious use of herbicides [19].

4. Summary and Conclusion

Crop and soil management systems that helps to improve soil health parameters and reduce farmer costs are essential. Overcoming traditional mindsets about tillage by promoting farmer experimentation with this technology in a participatory way will help accelerate adoption.

Providing of appropriate equipment to assess these systems to be successfully adopted by farmers is a prerequisite for success.

In this study, CA played a vital role in terms of maize growth and yield. Rotational and intercropping under CA were very advantageous as compared to monocropping under CCP.

Maize-common bean rotation under CA improved soil moisture content and maize plant growth as compared to intercropping and monocropping systems.

NDVI which is used as measurement of crop growth and performance is significantly affected by tillage type, cropping system and interaction of tillage and cropping system. CCP was significantly higher at vegetative and tasselling stage, whereas CA was highest significantly at grain filling stage.

Optical sensor is indispensable for ecological and conservation biological applications and will play an increasingly important role in the future. For many purposes, it provides the only means of measuring the characteristics of habitats across broad areas and detecting environmental changes that occur as a result of human or natural processes.

Farmers should therefore, be encouraged to practice soil moisture conservation practices and monitoring their farm too with optical sensors.

To strongly understand role of NDVI in evaluating crop growth performance it is better to correlate it with other crop growth parameters such as LAI, LA, etc. Comparison of the various indices can be used to understand canopy vegetation biophysical properties and make easy crop management monitoring.

Abbreviations

CA	Conservation Agriculture
CPP	Conventional Crop Production

NDVI Normalized Differentiated Vegetative Index
LA Leaf Area
LAI Leaf Area Index

Conflicts of Interest

The authors declare no conflicts of interest.

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