BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND WATER RESOURCES
ENGINEERING

RESPONSE OF WATER USE AND NUTRIENT DYNAMICS TO IRRIGATION AND CONSERVATION AGRICULTURE PRACTICES UNDER SMALLHOLDER FARMING IN THE ETHIOPIAN HIGHLAND.

BY

SISAY ASRES BELAY

JUNE, 2021

BAHIR DAR
ETHIOPIA

RESPONSE OF WATER USE AND NUTRIENT DYNAMICS TO IRRIGATION AND CONSERVATION AGRICULTURE PRACTICES UNDER SMALLHOLDER FARMING IN THE ETHIOPIAN HIGHLAND.

A Dissertation
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in Partial Fulfillment of the Requirements for the Degree of
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By
Sisay Asres Belay
June 2021

A dissertation submitted to the School of Research and Graduate Studies of Bahir Dar Institute of Technology, Bahir Dar University in partial fulfillment of the requirements for the Degree of Doctor of Philosophy of Water Resources Engineering and Management administered by the Faculty Civil and Water Resources Engineering.

DECLARATION

I, the undersigned, certify that research work titled "RESPONSE OF WATER USE AND NUTRIENT DYNAMICS TO IRRIGATION AND CONSERVATION AGRICULTURE PRACTICES UNDER SMALLHOLDER FARMING IN THE ETHIOPIAN HIGHLAND." is my work. The work has not been presented elsewhere for assessment. Where material has been used from other sources, it has been properly acknowledged.

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Date of submission: June, 2021
Place: Bahir Dar University

This dissertation has been submitted for examination with my approval as the University Advisory Committee Chair.

Advisory Committee Chair: Dr. Seifu A. Tilahun

Signature: __________________________

Bahir Dar Institute of Technology-Bahir Dar
University School of research and graduate studies

Faculty of Civil and Water Resources Engineering

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Sisay Asres Belay

Student Dissertation Advisory Committee approval

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Faculty Dean	Signature	Date
Dean of Graduate studies of BiT	signature	Date

RESPONSE OF WATER USE AND NUTRIENT DYNAMICS TO IRRIGATION AND CONSERVATION AGRICULTURE PRACTICES UNDER SMALLHOLDER FARMING IN THE ETHIOPIAN HIGHLAND.

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Abstracts

Food security in sub-Saharan Africa is dependent on rainfed agriculture and is a serious issue. Irrigation is considered an important strategy to meet food insecurity. However, the limited water availability is a challenge for expanding irrigation. The application of appropriate farmland management such as conservation agriculture with different irrigation application and scheduling technologies increase the productivity of crops per drop of water and improve the soil fertility. However, the benefits of conservation agriculture under different irrigation scheduling on smallholder irrigated farms have not been adequately investigated in the Ethiopian highlands.

A 4-year irrigated conservation agriculture experiment was conducted to investigate the overall impact on irrigation water use, hydrology, and soil nutrient accumulation on vegetable farms in the Ethiopian highlands. The study area is located in Dengeshita experimental site in the headwaters of Blue Nile basin. Conservation agriculture in this study consists of no-tillage and application of grass mulch at the rate of 2 t ha^{-1}, while conventional tillage is the current farmers' practice of 4–6 tills and without mulch cover. Irrigation water amount and scheduling were managed by the researcher using estimated reference evapotranspiration (ETo) and by farmers' local practices. Finally, the research process and results of the treatments were evaluated using Agricultural Policy and Environmental eXtender model (APEX).

On-farm experimental results from irrigated vegetables (onion and garlic) in the dry monsoon phase showed that the yield and irrigation water use efficiency (IWUE) was over 40% greater under CA than conventional tillage (CT) practices. A supplementary irrigated and rain-fed experiment on pepper (*Capsicum annuum L.*) production indicated that conservation agriculture practices significantly improved water management, and reduced irrigation water use by 10% and runoff by 40% while it increased percolated water in the root zone by 27% when compared with CT practice. The study also revealed that CA practice decreased the NO_3-N and PO_4-P load in leachate by about 10% while NO_3-N and PO_4-P loads in runoff respectively, by about 159% and 50%. Besides, the yield return achieved under CA treatment was about 20% higher when compared with the CT.

Moreover, the soil organic matter, total nitrogen, and available phosphorus of soils under conservation agriculture (CA) showed an increment compared with the CT over soil depths in 4 years period. The increase in these nutrients for CT at the topsoil depth was caused by the application of fertilizer and cattle manure in both dry and wet phases of vegetable production while the higher nutrient availability in the CA was attributed to the incorporation of grass mulch combined with cattle manure, fertilizer, and no-tillage over 4-years of irrigated vegetable production.

Since field research over large areas can be unreasonably costly and time-consuming to study at a large spatial scale, the Agricultural Policy/Environmental eXtender (APEX) model was run to evaluate the effect of conservation agriculture practices on water and nutrient loads in runoff under small on-farm experimental plots. In this regard, APEX model performed well in simulating the CA and the CT practices for different response variables under irrigated and supplementary irrigated vegetable production systems. It has shown a 15% decrease in simulated ET, 70% decrease in runoff, 23% decrease in nitrogen load of runoff, and 54% decrease in phosphorus loads of runoff while it showed a 20% increase in root zone soil water and 59% increase in percolated water under CA compared with the CT treatment. The reason for the different responses of the simulated variables to CA and CT practices was obviously due to the combined use of grass mulch cover and no-tillage practices under CA treatment. APEX simulations indicated the contribution of such practices to the reductions in ET and runoff, which was the main reason for higher water-saving observed during the dry irrigation phases of various vegetable production under CA treatment.

Keywords: Irrigated agriculture, conservation agriculture, organic matter, and soil nutrients, Ethiopian highlands, APEX

አህፅሮት

ከሰሃራ በታች ባሉ የአፍሪካ አገራት የምግብ ዋስትናው በከፍተኛ ሁኔታ በዝናብ እርሻ ላይ ጥገኛ በመሆኑ አሳሳቢ እየሆነ መጥቷል ። በመሆኑም የምግብ ዋስትናን ለማረጋገጥ መስኖ እንደ አንድ አስፈላጊ ስትራቴጂ ተደርጎ ተወስዷል ። ሆኖም ግን በውሃ እጥረት ምክንያት የመስኖ እርሻን ለማስፋፋት ፈታኝ እየሆነ መጥቷል። ይህን ችግር ለመቅረፍ ተገቢውን የእርሻ መሬት አያያዝ ውሃ ቆጣቢ በሆኑ የመስኖ ቴክኖሎጂዎች በመጠቀም የሰብሎችን ምርታማነት ከፍ ማድረግና የአፈር ለምነትን ማሻሻል ይችላል ። የጥብቅ ግብርና በአነስተኛ መስኖ እርሻዎች ላይ ከተለያዩ የመስኖ አሰራሮች ጋር እንደ ዋና የእርሻ አያያዝ ወይም አስተዳደር ሊሰጥ የሚችለው ከፍተኛ ጥቅም በኢትዮጵያ የደጋ አካባቢዎች ውስጥ በበቂ ሁኔታ ጥናት እና ምርምር አልተደረገበትም።

የጥብቅ ግብርናን መሰረት ያደረገ የመስኖ ምርምር በኢትዮጵያ ደጋማ አካባቢዎች በሚገኙ አነስተኛ የአትክልት እርሻዎች ላይ በመስኖ ውሃ አጠቃቀም፣ በሃይድሮሎጂ እና በአፈር ለምነት ላይ ያለውን አጠቃላይ ተፅእኖ ለመመርመር የ 4 ዓመት ሙከራ ተደርጓል። ጥናቱ የተከናወነው በዳንግላ ወረዳ በደንገሽታ የሙከራ ጣቢያ በብሉ ናይል ተፋሰስ ውስጥ ነው ። የጥብቅ ግብርና 2 ቶን በሄክታር ማሳን ማልበስ እና ማሳን ያለማረስ ያካተተ ሲሆን የተለመደው እርሻ ደግሞ የተለመደው የአርሶ አደሮች አስተራረስ (ከ4-6 ድግግሞሽ) እና ማሳ ያለማልበስ ልምድን ያጠቃልላል። የመስኖ የውሃ መጠን እና መርሃግብር በተመራማሪው ስሌት እና የአርሶ አደሮችን ልምዶች በመጠቀም ነበር ። በመጨረሻም ስነ-ቀመር (ሞዴል) በመጠቀም የምርምር ሂደት እና ውጤቶችን መገምገም ተችሏል።

በደረቅ ወቅት በመስኖ በሚለሙ አትክልቶች (ሽንኩርት እና ነጭ ሽንኩርት) በእርሻ ላይ የተደረገው የሙከራ ውጤት እንደሚያሳየው ከተለመደው እርሻ ይልቅ በጥብቅ ግብርና የምርት እና የመስኖ ውሃ አጠቃቀም ውጤታማነት (IWUE) ከ 40% በላይ እንደሚበልጥ ታይቷል። በዚህ ጥናት ውስጥ በተጨማሪ መስኖ እና በዝናብ ወቅት በበርበሬ አትክልት ላይ የተደረገ

ሙከራ የጥብቅ ግብርና አሰራሮች የውሃ አያያዝን በእጅጉ አሻሽለዋል፣ እናም የመስኖ ውሃ አጠቃቀምን በ 10% እና የማሳ ጎርፍን በ 40% ቀንሷል ። እንዲሁም ከተለመደው አሠራር ጋር ሲነፃፀር ስርገትን በ 27% ጨምሯል። ጥናቱ እንደሚያመለክተው የጥብቅ ግብርና በስርገት ውሃ ውስጥ የናይትሬትና የፎስፈረስ ክለትን በ 10% ገደማ ሲቀንስ በጎርፍ ውስጥ ደግሞ በቅደም ተከተል በ 159% እና በ 50% ያህል ቀንሶታል ። በተጨማሪም ፣ በጥብቅ ግብርና የተገኘው ምርት መጠን ከተለመደው እርሻ ጋር ሲወዳደር 20 በመቶ ከፍ ያለ ሆኗል።

በ 4 ዓመት ጊዜ ውስጥ በአፈር ውስጥ ያለው ኦርጋኒክ ንጥረ ነገር ፣ አጠቃላይ ናይትሮጂን እና ለዕጽዋት እድገት ቅርብ የሆነ ፎስፎረስ ከተለመደው እርሻ ጋር ሲነፃፀር በጥብቅ ግብርና ከፍተኛ ጭማሪ አሳይቷል ። በተለመደው እርሻ በአፈር ውስጥ የእነዚህ ንጥረ ነገሮች መጨመር የተከሰተው በማዳበሪያ እና በከብት ፍግ አጠቃቀም የተነሳ ሲሆን በጥብቅ ግብርና ውስጥ ያለው የንጥረ ነገሮች መጨመር ደግሞ ከ ማዳበሪያና ከከብት ፍግ ጋር ተዳምሮ የሣር ልባስ መበስበስን ከ 4-ዓመታት በላይ በማካተቱ ነው ።

የመስክ ሙከራ ጥናት በሰፊ ቦታዎች ላይ ማከናወን ምክንያታዊ ያልሆነና ከፍተኛ ወጪ የሚጠይቅ እና ጊዜ የሚወስድ በመሆኑ ፣ በጥብቅ እና በተለመደው ግብርና አሰራሮች ላይ በውሃ እና በንጥረ ነገሮች መመናመን ላይ ምን ተጽእኖ እንዳላቸው ለመገምገም (APEX) ሞዴልን ተጠቅመናል ። በዚህ ረገድ የ APEX ሞዴል በመስኖ እና በዝናብ አትክልት ምርት ስርዓቶች ስር ብዙ መረጃዎችን በተመለከተ በተለመደው እርሻ እና በጥብቅ ግብርና አሰራሮች ላይ ያሳዩትን ልዩነቶች በመገምገም ጥሩ አፈፃፀም አሳይቷል ። በመሆኑም ሞዴሉ ትነትን በ 15% ፣ አማካይ ጎርፍን በ 70% ገደማ በጥበቃ እርሻ መቀነሱን አሳይቷል ፣እንዲሁም በጎርፍ የሚታጠብ ናይትሮጂንን በ 23% በጎርፍ የሚታጠብ ፎስፈረስን በ 54% የጥብቅ ግብርና ምርምር ትግበራ መቀነሱን አሳይቷል ። ለዚህም መሰረታዊ ምክንያቱ በጥብቅ ግብርና የሣር ሽፋንና እርሻ አለማረስ ልምዶች በአንድ ላይ በመከወናቸው ነው ።

ቁልፍ ቃላት- የመስኖ እርሻ ፣ ጥብቅ ግብርና ፣ ኦርጋኒክ ንጥረ ነገሮች፣ የአፈር ንጥረነገሮች ፣ የኢትዮጵያ ደጋማ አካባቢዎች፣ ሞዴል

BIOGRAPHICAL SKETCH

Mr.Sisay Asres Belay was born in a rural area of Kilil Rufael in 1970 in the then province of Gondar near the city of Gondar, Ethiopia. He attended his elementary (1-6) studies at Azezo Atse Fasil Elementary school, his junior (7-8) studies at Azezo Junior secondary High School, and his high school (9-12) studies at Azezo senior secondary high school in the city of Azezo. He joined Alemaya University of Agriculture (AUA) in 1990 and award his BSc degree in Agricultural engineering in 1994 G.C. Later he joined the **C**ommission for Sustainable Agriculture and Environmental Rehabilitation for Amhara Region (CO-SAERAR) in 1996 and worked for 9 years as a soil and water conservation structures design engineer.

During organizational restructuring with the Bureau of Water Resources in 2005, he joined the Bureau of Water Resource Development (BoWRD) and worked for about 2 years as an irrigation design engineer, and 4 years as director of irrigation design and construction division, and 1 year as the director of Water Resource management division under the same bureau. After working three years in BoWRD, Sisay continued attending his Masters of Science study in Water Resources Engineering specialization in Engineering Hydrology and was awarded his M.Sc degree in 2012 from Bahir Dar University. He finally joined Gondar University in 2014 and transferred to Bahir Dar University under the college of agriculture and environmental sciences in the department of irrigation water management.

Again in the restructuring of the irrigation department and curriculum merging, he joined Bahir Dar Institute of Technology (BIT) of the Faculty of civil and water resource engineering in 2015 and still working there as a lecturer and researcher. He then continued his PhD study in 2016 in the field of water resource engineering and management (WREM) at Bahir Dar University, Bahir Dar Institute of Technology (BIT).

Dedication

Dedicated to my Father, my Mother and My Wife.

My Father, You are the symbol of work and a real Engineer. Your determination remains in my mind forever!

My Mother, you are the symbol of patience and silence. Your compassion remains in my mind forever!

My Wife, you are the symbol of Caring, We will not forget you all the time!

"May God Bless Your Souls"

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LIST OF SYMBOLS

f	depletion fraction
g	grams
Ha	Hectare
K	Potassium
Kg	kilogram
mm	millimeter
mg/l	milligram per litre
N	nitrogen
P	phosphorus

LIST OF ACRONYM AND SYMBOLS

ALMANAC	Agricultural Land Management Alternatives with Numerical Assessment Criteria model
ANOVA	Analysis of Variance
APEX	Agricultural Policy Environmental eXtender (APEX) model
BMP	Best management practices
CA	conservation agriculture
CEC	cation exchange capacity
CREAM	Chemicals, Runoff, and Erosion from Agricultural Management Systems model
CT	conventional tillage
DAP	Diammonium phosphate
EPIC	Environmental Policy Integrated Climate mode
Eta	actual evapotranspiration
Etc	crop evapotranspiration
Eto	reference evapotranspiration
FC	field capacity
GLEAMS	Groundwater Loading Effects of Agricultural Management Systems model
IWUE	irrigation water use efficiency
Kc	crop coefficient
LSD	list significant difference
NO_3-N	nitrate nitrogen
NSE	Nash Sutcliffe efficiency
OM	organic matter
PO4-P	phosphate phosphorus
Ppm	parts per millennium
PRK	percolation
PWP	permanent wilting point
QN	nitrogen in runoff

QP	phosphorus in runoff
RZSW	root zone soil water
TAW	total available water
TDR	time domain reflectometry
TN	Total Nitrogen
WFD	wetting front detector

Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Rainfed agriculture accounts for as much as 80% of the world's cultivated land, and contributes about 60% of the total crop production, while the corresponding figure for sub-Saharan Africa is almost 95% of cultivated land contributing about 90% of the total crop production (Wani et al. 2009). About 11% of the world's population and about 19% of Africa's population is not still food secured (Molden D. 2013, Wani et al. 2009). To meet the food needs of therising population, rainfed production should be supported with irrigation. Although irrigation uses over 70%)of water (Wisser et al. 2008) and most of which is lost through evaporation, the rapid increases in agricultural products are expected to come from irrigation. Hence irrigation remains as one of the most critical systems of agriculture in the future to increase production and productivity.

Irrigation allows farmers to grow often high-value crops such as fruits and vegetables that are more sensitive to water stress if grown in a rainfed system. However, irrigation expansion in dry monsoon phases in many sub Saharan African countries has faced limited water availability (Postel et al. 1996, Wallace et al. 2000, Morison et Al. 2007) due to more water stresses in the region. The knowledge already exists to at least double yields by combining both rainfed and irrigated agriculture, even where water poses a particular challenge. In addition to this, agriculture is often hindered first by the depletion of soil nutrients and organic matter by erosion through surface runoff and percolating water during the rainy phase (Rockstrom et al. 2009, Bosch et al. 2005, Tomer et al. 2016, Grandy et al. 2006, Bekele et al. 2007), and second by the scarcity of water during dry phase (Bekele et al. 2007, Rockstrom et al. 1999). Added to these, inefficient use of the available water and less integrated resource management system has increased the extent of the problem in the irrigation sector. In response to such challenges of crop production, the integrated use of various rainfed, irrigation and conservation agriculture (CA) practices, and promote research works in the area could help for future agricultural sustainability (Bekele et al. 2007, Enciso et al. 2007).

Conservation agriculture (the combined use of no-tillage, soil cover, and crop rotation) on large commercial agricultural areas has increased water productivity (Nyborg et al. 1995), promoted soil health (Limon-Ortega et al. 2000) and sustained agricultural resources (Giller et al.

2011, Friedrich et al. 2009, Giller et al. 2009), without compromising the crop yield. The increase in water productivity can also be related to more saving of water which has meaningful implications to increase water access to most farmers in water-limited areas (Serra et al. 2002), thereby allowing more irrigated acreage (Ward et al. 2008). This also encourages more smallholders to participate in the irrigation sector (Pretty et al. 2010, Jat et all. 2013, Govaerts et al. 2009, Corbeels et al. 2015). However, only few studies using CA have been carried out on fields of smallholder farmers in sub-Saharan Africa, including Ethiopia (Bekele et al. 2007, Berihun et al. 2011, Levidow et al. 2014, Assefa et al. 2018).

In addition to water-saving, conservation agriculture can curb the negative impact of runoff and percolated water and improves water availability (Bosch et al. 2005), which ultimately protects the deterioration of the water quality of wells, reservoirs and lakes. In addition to improving water and crop productivity (Nyborg et al. 1995, Assefa et al. 2019, Belay et al. 2019, Belay et al. 2020, Assefa et al. 2020), CA improves soil organic matter and consequently soil fertility through a biological process (Limon-Ortega et al. 2000), and without affecting the environment. Hence, the current approach of agricultural systems which promotes the use of more chemical fertilizers (Pretty et al. 2011) for vegetable production, shows an indication of a wider expansion of the above risks (Pretty et al. 2011, Matson et al. 1997, Logan et al. 1993, Heathwaite et al. 1996). Conversely, CA promotes the non-removal of crop residues from fields (Powell et al. 1996, Solomon et al. 2002). Besides, organic matter addition to farms in the form of compost and other organic mulches facilitate the release of nutrients to the soil for plant use (Richardson and Simpson, 2011).

In the sub-humid areas of Ethiopia, conventional agricultural practices often continue throughout the year under irrigated and rainfed systems. As a result, farmlands are frequently exposed to climatic and anthropogenic factors and the associated removal of nutrients from the soil profile occurred (Araya et al. 2011, Bationo et al. 2007). A high rainfall erosivity (Nyssen et al. 2005), and long-term conventional agricultural activities such as tillage practices, (Berakhi et al., 1998, Assefa et al. 2018) employed a strong pressure on the soil fertility, particularly in the northern parts of Ethiopia. The potential benefit of CA practice (no-tillage, mulch cover, and crop rotations) has been tested in Ethiopia recently through experimental evaluation and biophysical modeling (Assefa et al. 2018a, Assefa et al. 2019, Yimam et al. 2020). The contribution of CA in irrigation water saving, soil moisture storage and yield in irrigated cropping have not been studied in this region. The impact of CA on runoff, leachate and the associated nutrient flow under supplementary irrigated and rainfed phases of crop production (Figure 1-1) has not been investigated in the Ethiopian highlands in general and in the upper Blue Nile basin in particular and information is still lacking.

On the other hand, the increasing need for crop production for the growing population of Ethiopia has pushed to the rapid expansion of irrigation throughout the country since the 1960s. Severe water scarcity caused by climate variability (either inadequate rainfall or uneven distribution) presents the single biggest production challenge to Ethiopia's future food production (Figure 1-1). Though irrigation has helped many countries boost agricultural yields and outputs and stabilized food production (Anon 2012), it has to be through efficient methods and techniques that can maximize water productivity all over the country. Therefore, the main objective of this research was to evaluate the response of water use and nutrient dynamics to irrigation and conservation agriculture practices under smallholder farming in the Ethiopian highland. The main objective of the study is covered by addressing four specific objectives which include to: a) evaluate the impact of conservation agriculture on water and crop productivity, b) evaluate the response of water and nutrient dynamics, and crop yield to conservation agriculture, c) evaluate the effect of conservation agriculture on soil nutrients and organic matter content, and d) evaluate APEX model and apply the model to evaluate changes in unmeasured variables due to conservation agriculture practices (Figure 1-1).

In this study, CA consists of no-tillage and application of grass mulch at the rate of 8 t ha^{-1} twice per irrigation period, while conventional tillage is the current farmers' practice of 4–6 tills plus hoeing, and without mulch cover. The study was conducted on experimental plots owned by smallholder farmers (Figure 1-1).

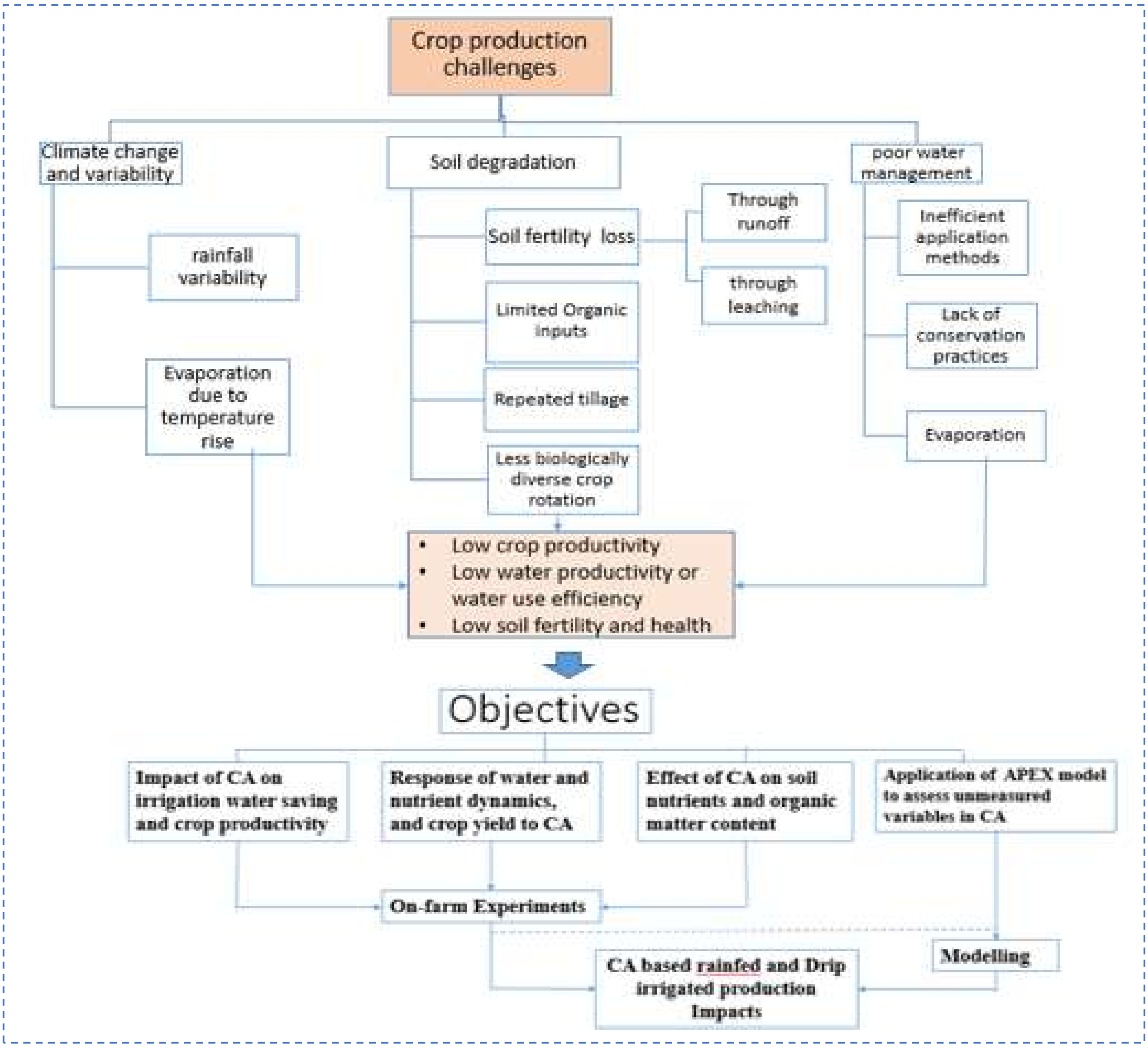

Figure 1-1: Conceptual framework diagram showing problems to be addressed and objectives to achieve through field on-farm conservation agriculture (CA) experiments and modelling under vegetable production

The contents of this dissertation are organized under four main chapters. In chapter 2, two irrigation crops (onion and garlic) were used for analysis to evaluate the impact of conservation agriculture and conventional tillage on water and crop productivity and water savings in the dry monsoon phase (1st objective in Figure 1-1). Results were properly compared using a paired - t design.

Chapter 3 covers the response of water and nutrient dynamics, and crop yield to conservation agriculture and conventional tillage (2nd objective in Figure 1-1). We used two years of experimental data of pepper production in the second season under rain phases (March to August-irrigation was supplemented with rain) in the study area.

Chapter 4 covers the impact of conservation agriculture and conventional tillage on soil physicochemical properties including soil nutrients and organic matter comparing continuous irrigated and rain-fed vegetable production (3rd objective in Figure 1-1) on the smallholder farmers In the 4 year period.

Chapter 5 dictates for investigations on how modeling water and nutrient dynamics in response to conservation agriculture practices comes in a close argument with the observed data using the 3-years continuous irrigated and rainfed vegetable production (4th objective in Figure 1-1) on the smallholder farmers. The main water, crop growth, yield and nutrient dynamics variables and the responses to conservation agriculture were simulated using APEX model and compared with the results of conventional tillage practices. APEX model was evaluated using the observed data and then some of the unmeasured variables have been investigated and compared with observed field data.

REFERENCE

Araya, T., Cornelis, W., Nyssen, J., Govaerts, B., Bauer, H., Gebreegziabher, T., Oicha, T., Raes, D., Sayre, K. D., Haile, M., 2011. Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia. Agri. Water Mant. , 27, 404-414

Assefa, T.; Jha, M.; Reyes, M.; Worqlul, A., 2018. Modeling the Impacts of Conservation Agriculture with a Drip Irrigation System on the Hydrology and Water Management in Sub-Saharan Africa. Sustainability , 10, 4763.

Assefa, T., JHA, M., Reyes, M., Worqlul, A., Doro, L. & Tilahun, S., 2020. Conservation agriculture with drip irrigation: Effects on soil quality and crop yield in sub-Saharan Africa. Journal of Soil and Water Conservation , .75, 209-217.

Assefa, T.; Jha, M.; Reyes, M.; Tilahun, S.; Worqlul, A.W., 2019. Experimental evaluation of conservation agriculture with drip irrigation for water productivity in Sub-Saharan Africa. Water , 11, 530.

Bekele, S.; Tilahun, K., 2007. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. Agric. Water Manag. , 89, 148–152, doi:10.1016/j.agwat.2007.01.002.

Belay, S. A., Assefa, T. T., Prasad, P., Schmitter, P., Worqlul, A. W., Steenhuis, T. S., Reyes, M. R. & Tilahun, S. A., 2020. The Response of Water and Nutrient Dynamics and of Crop Yield to Conservation Agriculture in the Ethiopian Highlands. Sustainability, 12, 5989.

Belay, S.A.; Schmitter, P.; Worqlul, A.W.; Steenhuis, T.S.; Reyes, M.R.; Tilahun, S.A., 2019. Conservation agriculture saves irrigation water in the dry monsoon phase in the Ethiopian highlands. Water , 11, 2103.

Berihun, B., 2011. Effect of mulching and amount of water on the yield of tomato under drip irrigation. J. Hortic. For., 3, 200–206.

Bosch, D.D.; Potter, T.L.; Truman, C.C.; Bednarz, C.W.; Strickland, T.C., 2005. Surface runoff and lateral subsurface flow as a response to conservation tillage and soil-water conditions. Trans. ASAE , 48, 2137–2144.

Corbeels, M.; Thierfelder, C.; Rusinamhodzi, L., 2015. Conservation agriculture in sub-Saharan Africa. In Conservation Agriculture; Springer: Berlin, Germany, pp. 443–476.

Enciso, J.; Jifon, J.; Wiedenfeld, B., 2007. Subsurface drip irrigation of onions: Effects of drip tape emitter spacing on yield and quality. Agric. Water Manag., 92, 126–130, doi:10.1016/j.agwat.2007.05.017.

Friedrich, T.; Kassam, A.; Taher, F., 2009. Adoption of Conservation Agriculture and the role of policy and institutional support. Presented at the International Consultation on No-Till with Soil Cover and Crop Rotation: A Basis for Policy Support to Conservation Agriculture for Sustainable Production Intensification, Astana-Shortandy, Kazakhstan, 8–10 July 2009.

Giller, K.E.; Corbeels, M.; Nyamangara, J.; Triomphe, B.; Affholder, F.; Scopel, E.; Tittonell, P., 2011. A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field Crop. Res., 124, 468–472.

Giller, K.E.; Witter, E.; Corbeels, M.; Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crop. Res., 114, 23–34.

Govaerts, B.; Sayre, K.D.; Goudeseune, B.; De Corte, P.; Lichter, K.; Dendooven, L.; Deckers, J., 2009. Conservation agriculture as a sustainable option for the central Mexican highlands. Soil Tillage Res., 103, 222–230, doi:10.1016/j.still.2008.05.018.

Grandy, A.S.; Loecke, T.D.; Parr, S.; Robertson, G.P., 2006. Long-term trends in nitrous oxide emissions, soil nitrogen, and crop yields of till and no-till cropping systems. J. Environ. Qual., 35, 1487–1495.

Heathwaite, A.L.; Johnes, P.J., 1996. Contribution of nitrogen species and phosphorus fractions to stream water quality in agricultural catchments. Hydrol. Process., 10, 971–983.

Jat, M.L.; Gathala, M.K.; Saharawat, Y.S.; Tetarwal, J.P.; Gupta, R.; Yadvinder, S., 2013. Double no-till and permanent raised beds in maize–wheat rotation of north-western Indo-Gangetic plains of India: Effects on crop yields, water productivity, profitability and soil physical properties. Field Crop. Res., 149, 291–299, doi:10.1016/j.fcr.2013.04.024.

Limon-Ortega, A.; Sayre, K.D.; Francis, C.A., 2000. Wheat nitrogen use efficiency in a bed planting system in northwest Mexico. Agron. J., 92, 303–308.

Levidow, L.; Zaccaria, D.; Maia, R.; Vivas, E.; Todorovic, M.; Scardigno, A., 2014. Improving water-efficient irrigation: Prospects and difficulties of innovative practices. Agric. Water Manag., 146, 84–94, doi:10.1016/j.agwat.2014.07.012.

Logan, T.J., 1993. Agricultural best management practices for water pollution control: Current issues. Agric. Ecosyst. Environ., 46, 223–231.

Matson, P.A.; Parton, W.J.; Power, A.G.; Swift, M.J., 1997. Agricultural intensification and ecosystem properties. Science, 277, 504–509.

Molden, D. ed., 2013. Water for food water for life: A comprehensive assessment of water management in agriculture. Routledge.

Morison, J.; Baker, N.; Mullineaux, P.; Davies, W., 2007. Improving water use in crop production. Philos. Trans. R. Soc. B Biol. Sci., 363, 639–658.

Nyborg, M.; Solberg, E.; Izaurralde, R.; Malhi, S.; Molina-Ayala, M., 1995. Influence of long-term tillage, straw and N fertilizer on barley yield, plant-N uptake and soil-N balance. Soil Tillage Res., 36, 165–174.

Postel, S.L.; Daily, G.C.; Ehrlich, P.R., 1996. Human appropriation of renewable freshwater. Science, 271, 785–788.

Powell, J., Fernandez-Rivera, S., Hiernaux, P. & Turner, M., 1996. Nutrient cycling in integrated rangeland/cropland systems of the Sahel. Agricultural Systems, 52, 143-170.

Pretty, J.; Toulmin, C.; Williams, S., 2011. Sustainable intensification in African agriculture. Int. J. Agric. Sustain., 9, 5–24, doi:10.3763/ijas.2010.0583.

Rockström, J.; Kaumbutho, P.; Mwalley, J.; Nzabi, A.; Temesgen, M.; Mawenya, L.; Barron, J.; Mutua, J.; Damgaard-Larsen, S., 2009. Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. Soil Tillage Res., 103, 23–32.

Richardson, A. E. & Simpson, R.., 2011. Soil microorganisms mediating phosphorus availability update on microbial phosphorus. Plant Physiol., 156, 989-96.

Rockström, J., 1999. On-farm green water estimates as a tool for increased food production in water scarce regions. Phys. Chem. Earth Part B Hydrol. Oceans Atmos., 24, 375–383.

Serra, A.-D.B.; Currah, L., 2002. Agronomy of onions. Agronomy of onions. In Allium Crop Science: Recent Advances; CABI: Wallingford, UK, pp. 187–232.

Solomon, D., Lehmann, J., MAMO, T., Fritzsche, F. & ZECH, W., 2002. Phosphorus forms and dynamics as influenced by land use changes in the sub-humid Ethiopian highlands., 105, 21-48.

Tomer, M.; Moorman, T.; Kovar, J.; Cole, K.; Nichols, D., 2016. Eleven years of runoff and phosphorus losses from two fields with and without manure application, Iowa, USA. Agric. Water Manag., 168, 104–111.

Wallace, J., 2000. Increasing agricultural water use efficiency to meet future food production. Agric. Ecosyst. Environ., 82, 105–119.

Wani, S.P., Sreedevi, T.K., Rockström, J. and Ramakrishna, Y.S., 2009. Rainfed agriculture–past trends and future prospects. Rainfed agriculture: Unlocking the potential, pp.1-35.

Ward, F.A.; Pulido-Velazquez, M., 2008. Water conservation in irrigation can increase water use. Proc. Natl. Acad. Sci., 105, 18215–18220.

Wisser, D., Frolking, S., Douglas, E.M., Fekete, B.M., Vörösmarty, C.J. and Schumann, A.H., 2008. Global irrigation water demand: Variability and uncertainties arising from agricultural and climate data sets. Geophysical Research Letters, 35(24).

Yimam, A. Y., Assefa, T. T., Adane, N. F., Tilahun, S. A., Reyes, M. R., 2020. Experimental Evaluation for the Impacts of Conservation Agriculture with Drip Irrigation on Crop Coefficient and Soil Properties in the Sub-Humid Ethiopian Highlands. Water, 12, 947.

CHAPTER 2

CONSERVATION AGRICULTURE SAVES IRRIGATION WATER IN THE DRY MONSOON PHASE IN THE ETHIOPIAN HIGHLAND[1]

Abstract: Water resources in sub-Saharan Africa are more overstressed than in many other regions of the world. Experiments on commercial farms have shown that conservation agriculture (CA) can save water and improve the soil properties. Nevertheless, its benefits on smallholder irrigated farms have not been adequately investigated, particularly in the dry monsoon phase in the Ethiopian highlands. We investigated the effects of conservation agriculture and conventional tillage on hydrological dynamics on smallholder farms in the Ethiopian highlands. Irrigated onion and garlic were grown on local farms. Two main factors were considered: the first factor was conservation agriculture versus conventional tillage, and the second factor was irrigation scheduling using reference evapotranspiration (ETo) versus irrigation scheduling managed by farmers. Results showed that for both onion and garlic, the yield and irrigation water use efficiency (IWUE) was over 40% greater for CA than conventional tillage (CT). The soil moisture after irrigation was higher in CA compared to CT treatment while CA used 49 mm less irrigation water. In addition, we found that ETo-based irrigation was superior to the farmers' irrigation practices for both crops. IWUE was lower in farmers' irrigation practices due to lower onion and garlic yield responses to over-irrigation and greater water application variability.

Keywords: conservation agriculture; conventional tillage; irrigation scheduling; farmers practice; irrigation water use efficiency

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[1] Belay, S.A., Schmitter, P., Worqlul, A.W., Steenhuis, T.S., Reyes, M.R. and Tilahun, S.A., 2019. Conservation Agriculture Saves Irrigation Water in the Dry Monsoon Phase in the Ethiopian Highlands. Water, 11(10), p.2103.; **https://doi.org/10.3390/w11102103**

2.1. Introduction

Water resources in sub-Saharan Africa are limited and overstressed more than in many other regions of the world. Farmers grow one or two rain-fed crops per year, nevertheless, production is not sufficient to feed the current population. As a result, irrigation remains important to meet the needs of the people by increasing production volume and productivity of lands. However, when more irrigation water is required in area where there is limited water availability, irrigation expansion in dry monsoon phases becomes a challenge (Postel et al. 1996, Wallace et al. 2000, Morison et Al. 2007). In addition using water saving irrigation technologies, irrigation in combination with conservation agriculture has been used to save water and reduce offsite transport of soil nutrients thereby increasing crop and water productivity. Scholars agreed that one way to increase irrigated production is to use the available water more efficiently through the combined application of different irrigation and conservation agriculture (CA) practices (Bekele et al. 2007, Enciso et al. 2007). Conservation agriculture involves maximum ground cover, minimum tillage, and the use of proper crop rotation (Pretty et al. 2011).

Recent studies on large commercial agricultural areas found that conservation agriculture increased water productivity (Nyborg et al. 1995) and promoted soil health (Limon-Ortega et al. 2000) and sustained agricultural resources (Giller et al. 2011, Friedrich et al. 2009, Giller et al. 2009), without compromising the crop yield. Few studies revealed that smallholder farmers can benefit more by combining conservation agriculture and irrigation practices. For example, Jat et al. (2013) and Shock et al. (1999) reported that irrigated cereals used less water under the combined or separate use of no-tillage, mulching, and crop rotation. However, in experiments using components of CA separately, scholars often saved minimum water compared to the complete CA system (Jat et al. 2013). Apart from high water-saving, the combined use of all components of conservation agriculture has been shown to increase yield by about 30% (Friedrich et al. 2011). Saving water is especially important in water-limited areas (Serra et al. 2002) and would allow increasing the irrigated acreage (Ward et al. 2008) and more smallholders to participate in the irrigation sector (Pretty et al. 2010, Jat et all. 2013, Govaerts et al. 2009, Corbeels et al. 2015).

Only a few studies have been carried out on fields of smallholder farmers in sub-Saharan Africa, including Ethiopia (Bekele et al. 2007, Berihun et al. 2011, Moges et al. 2011, Levidow et al. 2014, Assefa et al. 2018). Although these initial efforts were promising to increase sustainable crop and water productivity (Levidow et al. 2014), more research is needed in conservation agriculture-based irrigation practices in the dry phase in the Ethiopian highland. The objective of this study is therefore to explore the combined impact of conservation agriculture and irrigation water management practices on water-saving, soil water dynamics, and related soil variables.

2.2 Materials and methods

2.2.1 Study area Description

The study area is located in Dangila woreda in a particular kebele known as Dengeshita in the headwaters of Blue Nile in the Northern Ethiopian highlands (around 11.32° N and 36.85° E at an altitude of 2042 m above sea level), 80 km south of Bahir Dar. It is found in Amhara national regional state in Awi administrative zone.

The average rainfall during the main phase (June to September) is 1300 mm and during the dry phase (October to May) is 360 mm. The average monthly rainfall of Dangila metrological station in the area for 7 recent years is shown in figure 2-1 below. The mean annual minimum and maximum temperature are in the range of 5-12 °C and 18-29°C.

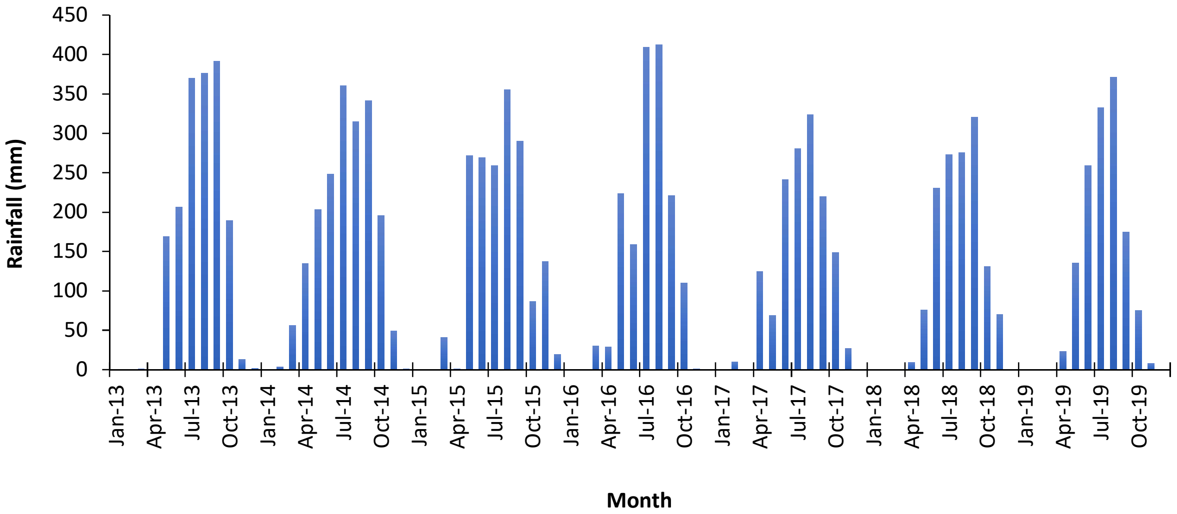


Figure 2- 1: Monthly rainfall (2013-2019) of Dangila meteorological station

The study area is exclusively used for traditional agricultural purposes, primarily crop production and cattle rising. Since most farmers live from subsistence agriculture, almost all types of farming are found on every family farm. Each farmer has a few pieces of land where he cultivates dominantly maize, finger millet and teff. A smaller area is also devoted to cattle raising, dominantly dairy cattle. The land used for the production of cereal crop and other crops is often fragmented into small plots. Maize crop is grown dominantly for commercial purposes and millet mainly for home consumption. The area is characterized by natural and manmade eucalyptus vegetation that include bushes and woody trees. The general soil of the study area is mainly characterized by red clay or nitosols which are well drained soils in the region suitable for most of the crops in the Ethiopian highlands.

2.2.2 Experimental site features

.A total of 34 plots of 10 m by 10 m were established on farms to conduct an investigation on irrigated conservation agriculture (CA) during the dry phase from October 2016 to March 2018. Using random selection, 17 plots were assigned for conservation agriculture and 17 for conventional tillage (CT). The plots were selected based on the availability of a productive shallow well adjacent to the irrigable land, and farmers' willingness to participate. Onion and garlic were grown during the dry phase while hot pepper was grown using supplementary rain and is not considered here.

The plots have slopes ranging from two to five percent. The texture of the top 30 cm soil was a loam soil and inter-plot variation was insignificant using analysis of variance (Table 2-1). The texture of the 30–60 cm soil layer was generally a clay loam and, in some plots, the soil texture consisted of sandy loam. Soil depth was divided into two based on the effective root depth of the local vegetables and cereals. The top 0-30cm as the effective root depth of local onion and garlic varieties where CA is expected to have an impact. The next soil depth (30-60cm) is considered effective root zone for millet and maize. The soil was slightly acidic with a pH level of 6. Field capacity, permanent wilting point, bulk density, total nitrogen, available phosphorus, and available potassium in the top 30 cm were 0.31 cm^3 cm^{-3}, 0. 22 cm^3 cm^{-3}, 1.1 g cm^{-3}, 0.93 g kg^{-1}, 9.57 mg kg^{-1}, and 191 mg kg^{-1}, respectively.

Table 2- 1: Mean and standard deviation of physical and chemical properties of the soil from samples collected in 30 plots and at two depths of the experimental plots.

Soil Parameter	**Soil Depth**	
	0–30 cm	**30–60 cm**
pH (H_2O) 1:2.5	6.0 ± 0.7	5.7 ± 0.7
Cation Exchange Capacity CEC, cmol kg^{-1}	25.0 ± 4.7	24.0 ± 4.7
Available phosphorus P, mg kg^{-1}	20.0 ± 14.1	6.9 ± 3.0
Available potassium K, g kg^{-1}	1.0 ± 0.6	0.7 ± 0.4
Total Nitrogen, TN, g kg^{-1}	0.2 ± 0.1	0.2 ± 0.1
Field Capacity FC, cm^3 cm^{-3}	31.0 ± 3.5	28.0 ± 1.4
Permanent wilting point PWP, cm^3 cm^{-3}	22.0 ± 4.2	21.5 ± 2.3
Clay, g kg^{-1}	39.0 ± 18.0	16.3 ± 4.4
Silt, g kg^{-1}	25.0 ± 4.9	23.3 ± 3.1
Sand, g kg^{-1}	36.0 ± 19.0	60.3 ± 6.1
Bulk Density, g cm^{-3}	1.1 ± 0.1	1.1 ± 0.2

Rainfall was recorded manually each morning at 6 A.M using a simple rain gauge installed near the experimental site (Figure 2-1). The remainder climate data used for calculating the reference evapotranspiration (ETo) with the FAO Penman–Monteith equation (Walter et al. 2000) were obtained from Dangila weather station between 1995 and 2016. We excluded the years 1998–2000 from the period because of the large number of missing data. The climate data processed for the purpose include temperature (maximum and minimum), relative humidity, sunshine hours, and wind speed.

Crop water use (ETc) was determined by multiplying ETo by the crop coefficient (Allen 1998) for initial, development, mid-season, and end stages (Table 2-1). Irrigation water to be applied to onion and garlic was determined at an allowable constant soil moisture depletion fraction (*f* = 0.25) of the total available soil water (TAW), where TAW was determined from the permanent wilting point, field capacity, root depth, and bulk density variables. The depth of water applied during each irrigation event was the net irrigation requirement between irrigation events, plus that needed for inefficiencies in the irrigation system. In this experiment, considering application losses, an irrigation efficiency of 80% was assumed and added to each plot.

2.2.2 Experimental Design

Two main factors were considered: the first factor was conservation agriculture versus conventional tillage practices, and the second factor was irrigation scheduling using reference evapotranspiration (ETo) versus irrigation scheduling managed by farmers' practices. Conservation agriculture consists of no-tillage and application of grass mulch at the rate of 2 t ha^{-1}, while conventional tillage is the current farmers' practice of 4–6 tills and without mulch cover. Irrigation water amount and scheduling managed by estimated reference evapotranspiration (ETo) here refer to the use of calculated crop water requirement (ETc) estimated from ETo. Accordingly, the treatments were:

T_1: conservation agriculture with irrigation water amount and scheduling managed by estimated evapotranspiration; T_2: conventional tillage with irrigation water amount and scheduling managed by estimated evapotranspiration and, T_3: conservation agriculture with irrigation water amount and scheduling managed by farmers' practices.

The three treatments were conducted with onion crop in 2016/2017 replicated 17 times on 17 on-farm plots (Figure 2-1), and with garlic in 2017/2018 replicated 14 times (Figure 2-1). In 2016/2017, treatments T_1 and T_2 received similar irrigation volume and scheduling practice while in 2017/2018, the two treatments were irrigated differently. Treatments T_1 and T_2 were on the same plot where half was for T_1 and half for T_2 with pair-t design. The amount of irrigation applied was measured by counting the number of known volume buckets (or watering cans) per application.

On all plots, a similar rotation of onion, green pepper, and garlic was followed: onion was planted on 20/12/2016 and harvested on 25/3/2017. It was followed by green pepper from 1/5/2017 to 10/9/2017 and then garlic from 18/10/2017 to 26/2/2018. Since pepper was grown partially in rain and dry phase, it was excluded from this paper. The location of the distribution of the plots for each treatment is shown in Figure 2-2.

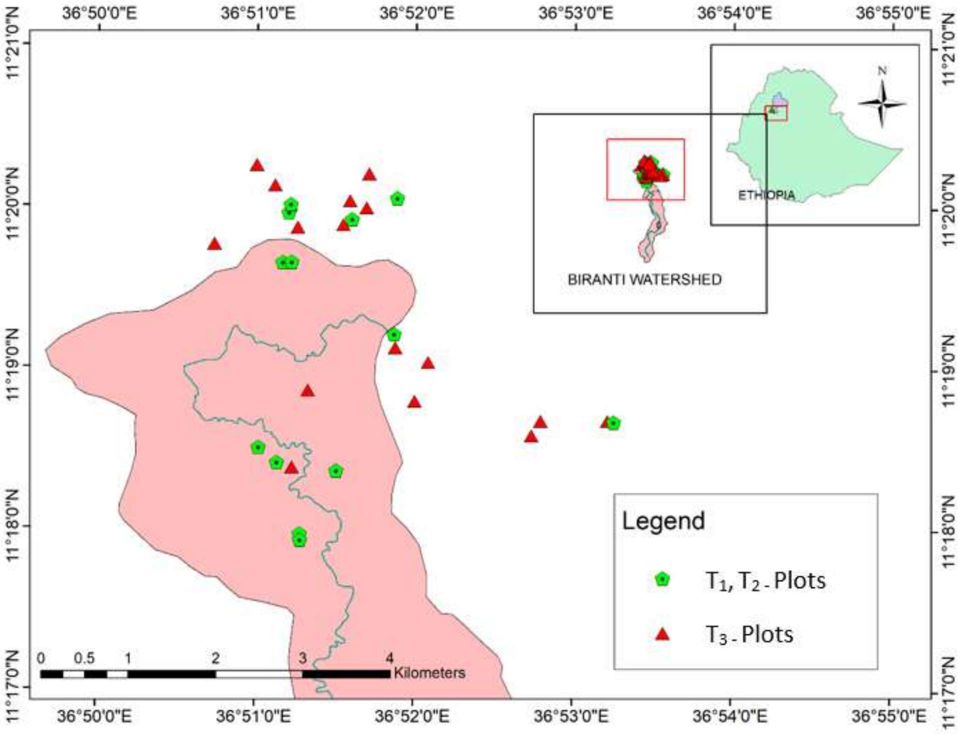


Figure 2- 2: The location and geographical distribution of on-farm experimental plots in Dengeshita Kebele (administrative unit smaller than district), in Northwestern Ethiopia, the state of Amhara. Some of the plots are within the Biranti watershed and the rest outside the watershed. The plots are located near the farmers' homes (Source: Ethiopian Mapping Agency).

2.2.3 Crop Variety and Management Information

Adama Red Onion (Allium cepa L.) variety in 2016/2017 and garlic (Allium Sativium L.) local variety in 2017/2018 were transplanted or planted respectively on 20/12/2016 and 18/10/2017, at a spacing of 20 cm between rows and between plants (Fatideh et al. 2012, Belay et al. 2015, Fabeiro et al. 2003). Onion seedlings were transplanted at the age of 50 days. Crop coefficients are shown in Table 2-2, and the management activities for growing onion and garlic vegetables are shown in Table 2-3.

Table 2- 2: Crop stages, length of the growing period in days, and crop coefficients (Allen et. Al., 1998).

Year	Crop Type	Crop Parameters	Growth Stages			
			Initial	Development	Mid-Season	End
2017	Onion	Length of growth (days)	20	45	35	20
		Crop coefficient (Kc)	0.7	0.7–1.05	1.05	0.7
2018	Garlic	Length of growth (days)	20	50	30	20
		Crop coefficient (Kc)	0.7	0.7–0.95	0.95	0.7

Table 2- 3: Experimental onion and garlic varieties, management activities, date of operation, and method of cultivation performed at the study site (2016 to 2018 years) over the growing seasons.

Year	Crop	Activities	Date (Day/Month/Year)	Method
2016/2017	Adama Red Onion (Allium cepa L.)	Seedling	2/11/2016	Manual
		Tillage*	25/9/2016–30/3/2016	Oxen and Manual
		Transplanting	20/12/2016	Manual
		Mulch application**	5/1/2017	Manual
		Irrigation	20/12/2017–20/3/2017	watering-Can
		weeding/hoeing*	20/1/2017,29/2/2017,16/3/2017	Manual
		Harvesting	22/3/2017–25/3/2017	Manual
2017/2018	Local garlic (Allium Sativium L.)	Tillage*	9/10/2017–14/10/2017	Oxen and Manual
		Planting	18/10/2017	Manual
		Mulch application**	27/10/2017	Manual
		Irrigation	27/10/2017–26/1/2018	watering-Can
		weeding/hoeing*	27/11/2017,29/12/2017,16/1/2018	Manual
		Harvesting	26/2/2018	Manual

* = For conventional tillage treatment, tillage was practiced but no grass-mulch was used; ** = For conservation agriculture no-tillage and grass-mulch were practiced.

Each experimental plot was equally treated with urea fertilizer (46-0-0) at a rate of 200 kg ha^{-1} and applied according to local management practices. Local seed free grass species were harvested and dried for mulching in order to prevent conservation agriculture plots from weed infestation. The grass mulch was applied to CA plots twice at the rate of 2 t ha^{-1} in each experimental period. Crop phenological variables such as height and number of leaves were measured every 10 days by randomly selecting nine plants from each plot. The onion was harvested on 22–25 April 2017 while garlic was harvested on 18 February 2018.

2.2.4. Soil Moisture Data

In 2017/2018 in garlic, soil moisture at the top 20 cm depth was monitored using time domain reflectometry (TDR) probes (TDR 200 Spectrum Technology Inc.). The TDR was not installed type. Rather, two agricultural extension agents were trained to measure the soil moisture each time by inserting a pair of 20 cm length TDR rods into the soil. TDR measurement was conducted before and after an irrigation event (3 times a week) for only T_1 and T_2 treatments because our interest was to compare the effect of conservation agriculture (T_1) and conventional tillage (T_2) on soil moisture content. In addition to TDR measurement, the soil moisture over the top 10, 20, and 30 cm soil depth were monitored using gravimetric method once every 10 days. TDR probes were calibrated using gravimetric soil moisture determination technique to increase the data quality. Irrigation was ceased 2 weeks before harvest to prevent both onion and garlic tubers from rotting and sprouting (Kumar et al. 2007). Irrigation water use efficiency (IWUE) in kg m^{-3} was estimated by dividing fresh yield of onion or garlic by the volume of irrigation water applied to grow each of the vegetables.

2.2.5. Data Analysis

All data are presented with arithmetic means and were statistically analyzed using analysis of variance (ANOVA) after checking the normality using Jarque–Berra methods (Huang et al. 2017). All the results shown in tables and figures are means of treatment plots. Mean values were compared for any significant differences using the least significant difference (LSD) method. LSD was calculated from data, where the differences among means were tested at $\alpha = 0.05$.

2.3. Results and Discussion

2.3.1. Irrigation Water Applied

The total irrigation water applied to the onion crop was 520 mm for both T_1 and T_2. Irrigation in these treatments was managed by replacing the water lost in crop evapotranspiration

(ETc) three times per week assuming an 80% irrigation efficiency (Table 2-4). The total irrigation water used in T_3 was 548. Irrigation water amount in this treatment was determined by farmers' practice. Water used in T_3 was much greater than T_1 or T_2 though the difference was insignificant ($P < 0.05$). Similarly, a significantly greater amount of water was used for garlic crop in the T_3 treatment (Table 2-4). In both crops, the total irrigation water applied to T_1 was the smallest while it was the highest for T_3. The total water applied for garlic was 14% and 45% less in T_1 compared to T_2 and T_3, respectively.

Irrigation water applied at the initial stage to onion was 136 mm in T_1 and 157 mm in T_3. However, irrigation water applied to the initial stage of garlic was, respectively, 48, 55, and 70 mm for T_1, T_2, and T_3 treatments. Due to the season of transplanting, onion received greater irrigation water application than the garlic crop. The onion was transplanted during a much drier month on 20/12/2016, while garlic was planted during a much wetter month on 10/10/2017 (Table 2-3). Correspondingly, the soil moisture after the end of the rainy season was higher in garlic production period, and hence less irrigation water was applied. Water applied at the initial stage of onion was 46% less in T_1 or T_2 compared with T_3 treatment. Similarly, there was 15% and 31% less water used for garlic in T_1 compared with T_2 and T_3 treatments, respectively. Less irrigation water was used for garlic in conservation agriculture (T_1) than conventional tillage (T_2) treatment. The reason was attributed to grass mulch cover and no-tillage practices in T_1 treatment. The depth of irrigation applied at initial stage of onion and the development stage of garlic was significantly ($P < 0.05$) higher in T_3 compared with T_1 and T_2 treatment. On the other hand, in similar conservation agriculture treatment (T_1 and T_3), farmers scheduling practice (T_3) used more water particularly at initial and mid-season stages for onion and at all stages for garlic compared to estimated evapotranspiration irrigation scheduling (T_1).

Table 2- 4: Applied water (mm) to each growth stages of onion and garlic vegetables and the variations using analysis of variance ($\alpha = 0.05$) *.

Treatment*	**Crop stages**				
	Initial	**Development**	**Mid-Season**	**End**	**Total**
			Onion in 2016/2017		
T_1	136^{a*}	219^{a**}	122^{a}	42^{a}	520^{a}
T_2	136^{a}	219^{a}	122^{a}	42^{a}	520^{a}
T_3	157^{b}	213^{a}	141^{b}	36^{a}	548^{a}
P-value	0.04	0.80	0.09	0.50	0.40
LSD$_{(\alpha = 0.05)}$	20.80s	35.4ns	23.0ns	19.2ns	66.8ns
			Garlic in 2017/2018		
T_1	48^{a}	120^{a}	59^{a}	33^{a}	260^{a}
T_2	55^{ab}	142^{ab}	73^{ab}	39^{ab}	309^{ab}
T_3	70^{b}	194^{c}	86^{bc}	50^{bc}	420^{c}
P-value	0.0025	0.0004	0.017	0.015	0.00095
LSD $_{(\alpha = 0.05)}$	15.14	15.14	22.52	15.91	87.72

* Numbers followed by same letters under same heads in a column are statistically non-significant at $\alpha = 0.05$ significant level; T_1: conservation agriculture with irrigation water amount and scheduling managed by estimated evapotranspiration; T_2: conventional tillage with irrigation water amount and scheduling managed by estimated evapotranspiration and; T_3: conservation agriculture with irrigation water application managed by farmers' practices.

The irrigation interval in T_1 and T_2 was 2 days for the onion crop and 3 days for the garlic crop (Table 2-5). The recommended irrigation amount per application was similar in T_1 and T_2 for onion crops. The irrigation interval under farmers' scheduling practices (T_3) varied between 1 and 4 days (Table 2-5). A greater amount of water was also applied per irrigation (Figure 2-3). The variability in farmers' irrigation practice (T_3) was primarily governed by labor availability, and therefore the depth of water applied per application was different (Figure 2-3).

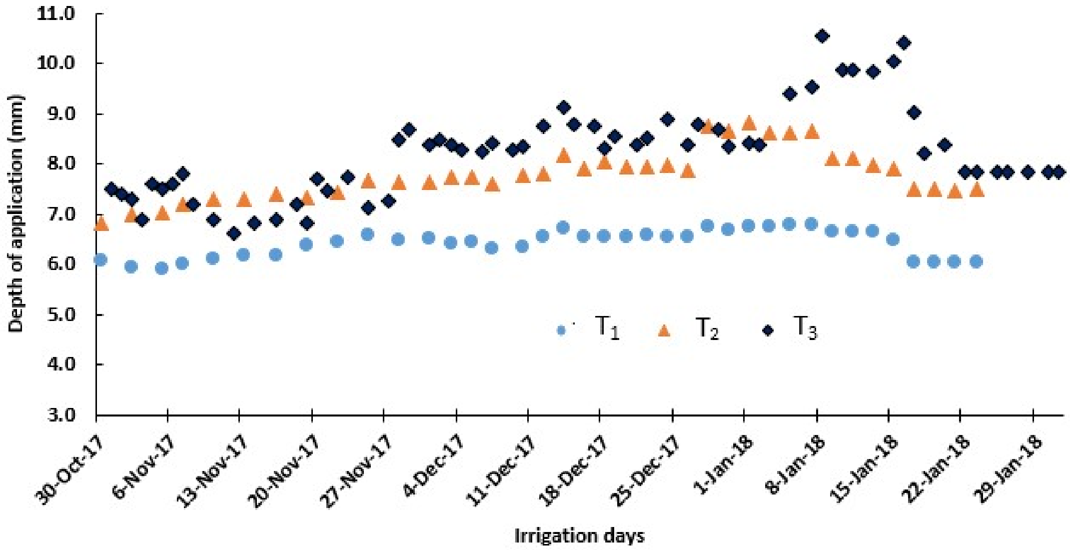


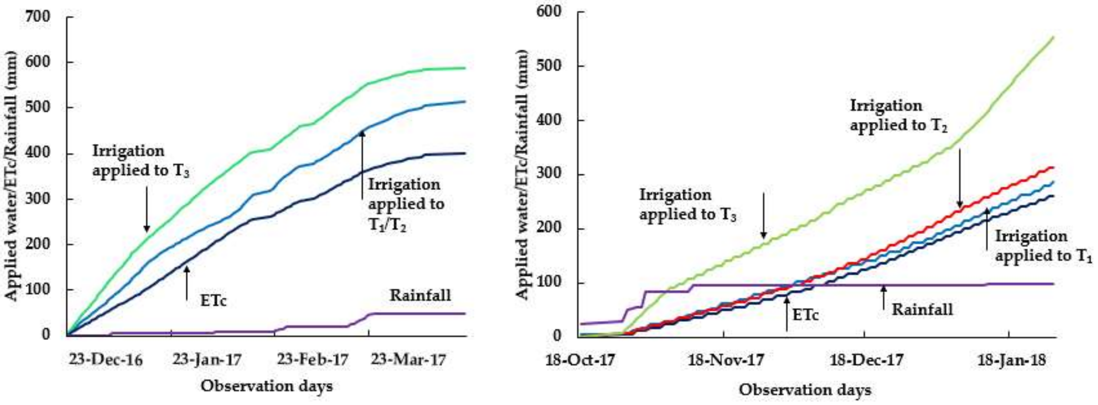
Figure 2- 3: Average depth of irrigation per application for garlic crop since planting for the three treatments (T_1, T_2, and T_3). The treatments T_1, T_2, and T_3 are described in Table 2-4.

Table 2- 5: Irrigation interval, depth of water application, and the total number of irrigations practiced for onion and garlic production.

Treatment	Irrigation Interval (days)	Irrigation Depth per Application (mm)	Number of Irrigations
		Onion—2016/2017	
T_1*	2	5–8	80–70
T_2	2	5–8	80–70
T_3	1–4	4–10	90–60
		Garlic—2017/2018	
T_1	3	6–8	40
T_2	2	8–10	45
T_3	2–4	5–13	50

*T_1: conservation agriculture with irrigation water amount and scheduling managed by estimated evapotranspiration; T_2: conventional tillage with irrigation water amount and scheduling managed by estimated evapotranspiration and; T_3: conservation agriculture with irrigation water amount and scheduling managed by farmers' practices.

Cumulative irrigation water used in each treatment, cumulative estimated evapotranspiration (ETc) used in T_1 and T_2, and cumulative rainfall during the growing season of the two crops was depicted in Figure 2-4. It shows that T_3 (farmers' practice) received a significantly greater amount of water at any stage compared with T_1 and T_2 treatments (estimated evapotranspiration-ETc). In both crops, the irrigation water used for the treatments was only slightly greater than the estimated ETc. Onion received less rainfall than garlic after transplanting (Figure 2-4a, b).



(a) Onion **(b)** Garlic

Figure 2- 4: Cumulative estimated evapotranspiration (ETc), depth of irrigation application, and rainfall for (a) onion (2016/2017), and (b) garlic (2017/2018) vegetables ; * T_1: conservation agriculture with irrigation water amount and scheduling managed by estimated evapotranspiration; T_2: conventional tillage with irrigation water amount and scheduling managed by estimated evapotranspiration and; T_3: conservation agriculture with irrigation water amount and scheduling managed by farmers' practices.

2.3.2. Soil Moisture Dynamics Responses

The soil moisture in T_1 and T_2 treatments was monitored using TDR probes for only the garlic crop period and is shown in Figure 2-5. It was not measured for the onion crop in 2016/2017. Soil moisture was measured only under T_1 and T_2 treatments because we wanted to compare conventional tillage (T_2) with conservation agricultural (T_1) practices. In Figure 2-5, soil moisture before and after irrigation is shown by dashed and solid blue lines under conservation agriculture treatment (T_1), while it is also shown by dashed and solid red lines under conventional tillage (T_2). Correspondingly, the available soil moisture after irrigation in T_1 is indicated by the area bounded by the blue lines and is shaded by vertical lines. Similarly, the area bounded by red lines and colored yellow represents the available soil moisture after irrigation in T_2. Region A indicates the soil moisture gained in T_1 over T_2 after irrigation, Region B is the common soil moisture for the two treatments after irrigation, and Region C indicates the soil moisture deficit under T_2 before irrigation. This difference (significant at $P < 0.05$) in soil moisture was attained in conservation agriculture (T_1) over conventional tillage (T_2) while it received 49 mm less applied water than conventional tillage treatment (T_2) due to reduced evaporation of the grass mulch cover (Kabir et al. 2013).

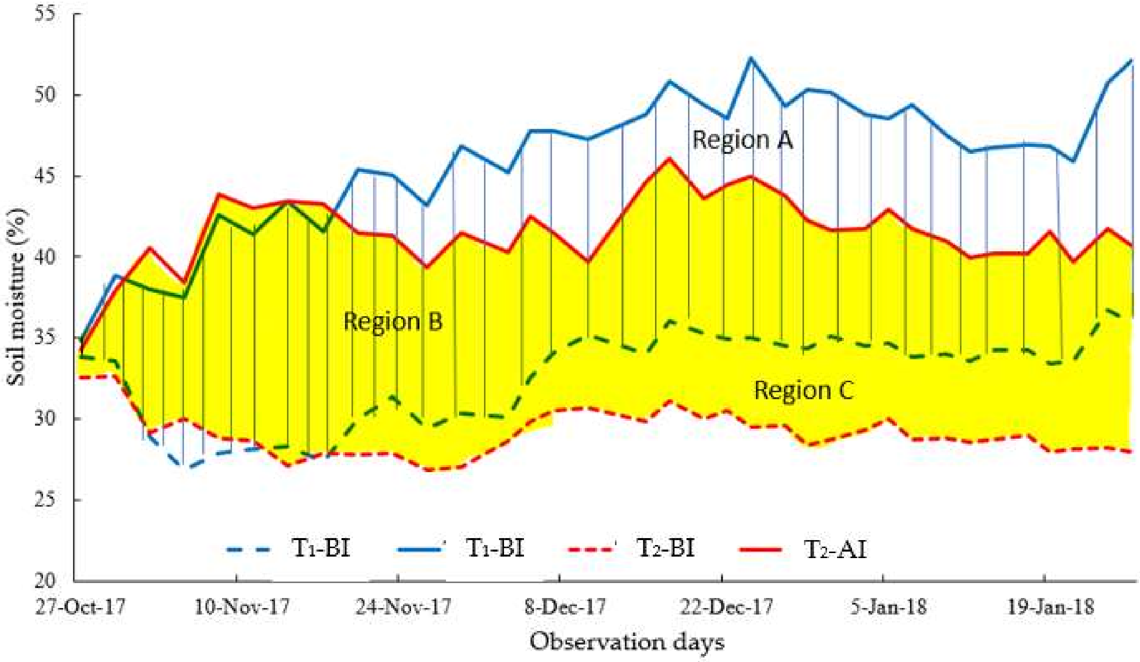


Figure 2- 5: Soil moisture of T_1 and T_2 treatments for garlic crop measured at the top 20 cm soil layer before and after irrigation water application. Region A indicates the soil moisture gained in T_1 over T_2 after irrigation, Region B is common for the two treatments, and Region C indicates the soil moisture deficit of T_2 before irrigation. * T_1: conservation agriculture with irrigation water amount and scheduling managed by estimated evapotranspiration; T_2: conventional tillage with irrigation water amount and scheduling managed by estimated evapotranspiration. T_1-BI = soil moisture (%) before irrigation for (T_1) treatment; T_1-AI = soil moisture (%) after irrigation T_1 treatment. T_2-BI = soil moisture (%) before irrigation for (T_2) treatment; T_2-AI = soil moisture (%) after irrigation $_{T2}$ treatment.

In addition to the TDR measurements, we took gravimetric soil moisture contents at 10, 20, and 30 cm depth by taking soil samples seven times during garlic growing season for the T_1 and T_2 treatments (Figure 2-6). Figure 2-5 shows that the soil moisture (%) in treatment T_1 (solid line) was greater than T_2 (dashed line) during the garlic growing period. The greatest difference in soil moisture variation was observed in the surface 10 cm (T_1-10 and T_2-10) soil layer and the smallest in the lowest 30 cm (T_1-30 and T_2-30) soil layer (Figure 2-6). This shows that despite less irrigation water was applied to T_1, the soil moisture in T_1 was greater compared with T_2.

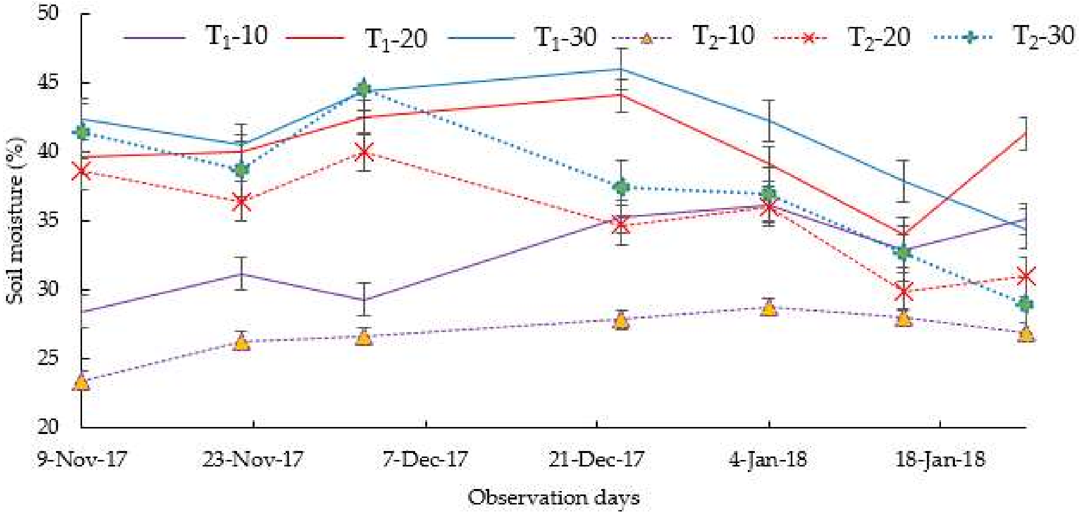


Figure 2- 6: Soil moisture dynamics at 10 cm, 20 cm, and 30 cm soil depths for T_1 and T_2 treatments under garlic crop experiment. T_1-10, T_1-20, and T_1-30 indicate soil moisture measurements at 10 cm, 20 cm, and 30 cm depth for conservation agriculture (T_1); and T_2-10, T_2-20, and T_2-30 indicate soil moisture measurements at 10 cm, 20 cm, and 30 cm for conventional tillage (T_2), monitored once every 10 days after planting of garlic.

2.3.3. Yield and Productivity

The yield of onion and garlic was greater and statistically significant ($P < 0.05$) in conservation agriculture (T_1) compared with conventional tillage practices (T_2) (Table 2-6). The yield of onion was 24, 18, and 15 t ha^{-1} respectively for T_1, T_2, and T_3 treatments (Table 2-6). A high yield of onion in T_1 is associated with improved soil moisture due to grass mulch cover (Figures 2-5 and 2-6). Moreover, it was observed that grass mulch cover prevented the emergence and regrowth of weeds. It, therefore, reduced the competition for water and nutrients.

Table 2- 6: Average irrigation water applied yield, productivity, and irrigation water use efficiency (IWUE) values for each treatment. Significant and mean differences among treatments were performed using analysis of variance ($\alpha = 0.05$) and Tukey Least Significant Difference (LSD) method*.

Treatments	**Applied Water (mm)**	**Yield (kg/plot)**	**Yield ($t\ ha^{-1}$)**	**IWUE ($kg\ m^{-3}$)**
		Onion 2016/2017		
T_1	520^a	54.7^a	24.3^a	4.42^a
T_2	520^a	40.1^b	17.9^b	3.24^b
T_3	548^a	65.1^c	14.9^b	2.40^b
P-value	0.4	<0.01	0.12	0.00004
LSD (0.05)	66.8	8.5	3.4	0.77
		Garlic 2017/2018		
T_1	260^a	15.2^a	5.3^a	1.9^a
T_2	309^{ab}	11.0^{bc}	3.8^a	1.2^{bc}
T_3	420^c	12.6^{ac}	3.8^a	1.3^c
P-value	0.00095	<0.01	0.187	0.006
LSD (0.05)	87.7	3.1	1.7	0.5

* Numbers followed by same letters under same heads in a column are statistically non-significant by LSD test at $P < 0.05$. T_1: conservation agriculture with irrigation water amount and scheduling managed by estimated evapotranspiration; T_2: conventional tillage with irrigation water amount and scheduling managed by estimated evapotranspiration and; T_3: conservation agriculture with irrigation water amount and scheduling managed by farmers' practices.

In the CA treatment, the yield in T_3 was lower compared with T_1. The reason for the yield reduction was related to suboptimal irrigation intervals for T_3 that caused either overwatering or under-watering (Table 2-5). Treatment T_3 received only slightly higher irrigation water application (548 mm) in onion production than T_1 and T_2 (520 mm), however, excess water was applied at the initial stage, and most of it was lost through percolation. In addition, we observed that the thick grass mulch cover made it difficult for the farmers to identify the soil wetness. Hence, they over- or under-irrigated their fields. Our results are in agreement with the findings of other experiments in Bangladesh (Kabir et al. 2013) that irrigation water application affects crop growth by influencing the availability of water and nutrients, and therefore, it needs to be managed carefully

(Awulachew et al. 2005). The results were also consistent with the findings reported by Patel et al. (2013). The recommendation of Shock et al. (2000) indicated that the water availability during the vegetative development stage is directly linked with the most important stage to maximize canopy formation and yield. These results agree with onion yields reported by Bekele et al. (2007) under on-station drip research conducted in the semi-arid region of Ethiopia.

Similarly, the yields of garlic were 5.3, 3.8, and 3.8 t ha^{-1}, respectively, for T_1, T_2, and T_3 treatments (Table 2-6). The reason for the significantly higher yield of garlic in T_1, compared with T_2, was similar to that discussed above for onion. In similar CA treatment, the yield in T_3 was lower compared with T_1. The reason for the garlic yield reduction in T_3 could be associated with much longer or shorter irrigation intervals that caused overwatering or underwatering (Table 2-5). In other words, the distribution of soil moisture in T_3 was not uniform and led to a decrease in yield. The results are in agreement with the findings of an experiment in Bangladesh (Kabir et al. 2013). Moreover, the result of Awulachew et al. (2009) agrees with this study. Water and other inputs interact with each other and their improper combination could reduce yield as reported by Adekpe et al. (2007). Shock et al. (2000) recommended that the vegetative development stage is the most important stage to maximize canopy formation and yield. Similar garlic yield results were also reported Kabir et al. (2013) under zero tillage and water hyacinth mulch combination. Adekpe et al. (2007) reported garlic yield results for Africa which is in harmony with this study. Under a similar region of this study, onion yield was reported by scholars in Ethiopia (Abrha et al. 2015, Yeshiwas et al. 2018, Ayalew et el. 2015, Ahmed et al. 2017). All the results discussed earlier slightly vary due to many experimental factors. Slight variations were noted due to the type of experiment (on-station or on-farm), size of the experiment (smallholder or large commercial), crop intensity, and local management differences.

2.3.4. Crop Growth Dynamics and Responses

Greater bulb weights and higher crop height were achieved with conservation agriculture (T_1) than with conventional tillage practices (T_2) in both experimental years. In 2016/2017, onion bulb weight obtained from T_2 was smaller (30 to 60 g) in size than T_1 treatment (40 to 80 g). The bulb weight difference was related to higher soil moisture content (Figure 2-6). The grass mulch cover under CA solves water deficiency and adequately recharged the onion root zone as reported by Woldetsadik et al. (2003). This also agrees with the findings of Shock et al. (1999) and Fatideh et al. (2012). In 2017/2018, greater garlic bulb weights were also obtained in T_1 (60 to 80 g) compared with T_2 (30 to 40 g) treatment. These results are in agreement with the findings by Faradonbeh et al. (2013) where larger garlic bulbs were obtained in water hyacinth mulch than non-mulch practices. The work in Adekpe et al. (2007) is also consistent with the results of this study.

The onion bulb height was highest in T_1 and lowest in T_3 treatment (Figure 2-7). Onion yield was directly proportional to the onion bulb height which is also in agreement with Reference Doorenbos et al. (1979). Similarly, the garlic bulb height was the highest in T_1 and the lowest in T_2 (Figure 2-8). In both crops, the bulb height in T_1 was almost higher than T_2 and T_3 at any observation day. The variation between T_1 and T_2 treatments was also statistically significant ($p < 0.05$). This result is also consistent with the results so far reported (Abrha et al. 2015, Yeshiwas et al. 2018, Ayalew et al. 2015, Ahmed et al. 2017).

The difference in bulb weight and height could be associated with a conducive environment within the soil by CA practices. The grass mulch cover under CA kept the water needed by the crop consistent in time (Figures 2-5 and 2-6) and adequately recharged the onion root zone as reported by Al-Jamal et al. (2001). This explanation agreed well with the findings of Berihun et al. (2011) and Kumar et al. (2007). These findings strengthen the role of conservation agriculture to solve sudden water stress for better yield of onion and garlic.

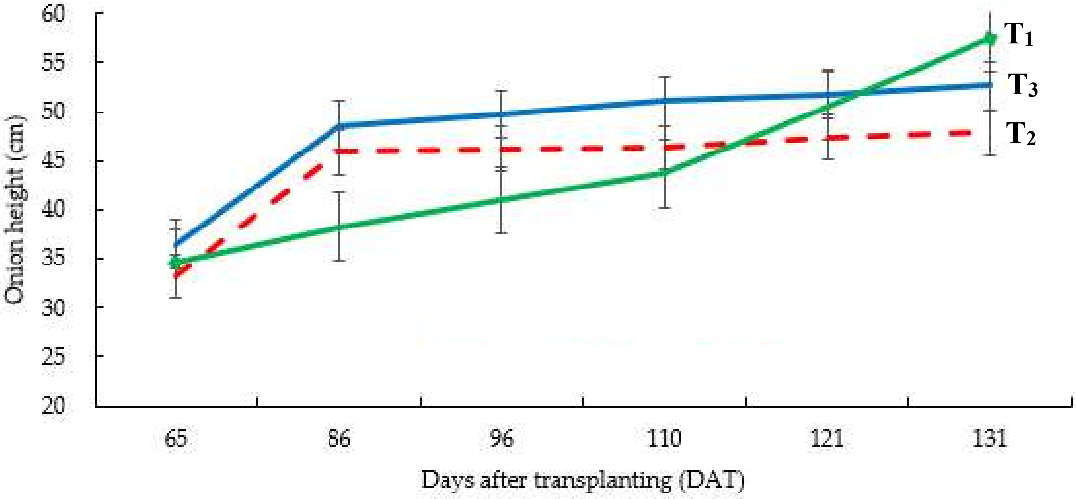


Figure 2- 7: Onion height measured at 10-day intervals after transplanting and responses to conservation agriculture among treatments. *T1: conservation agriculture with irrigation water amount and scheduling managed by estimated evapotranspiration; T2: conventional tillage with irrigation water amount and scheduling managed by estimated evapotranspiration and; T3: conservation agriculture with irrigation water amount and scheduling managed by farmers' practices.

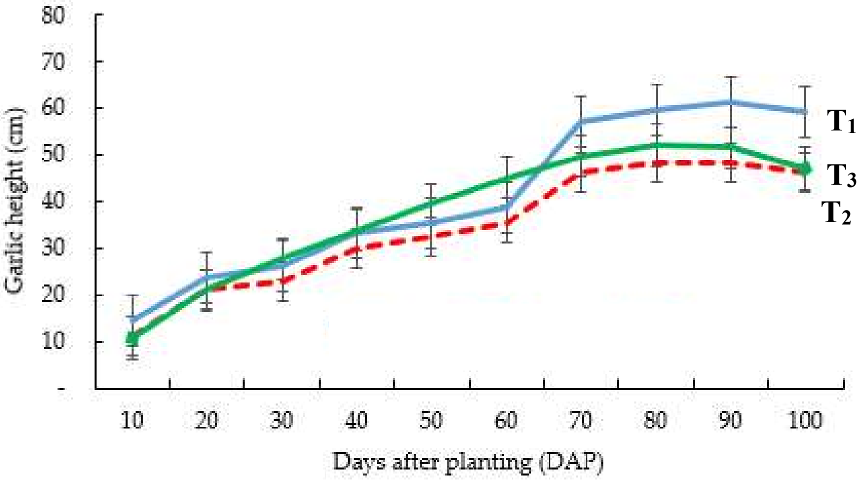


Figure 2- 8: Garlic height measured at 10-day intervals after transplanting and responses to conservation agriculture among treatments. *T1: conservation agriculture with irrigation water amount and scheduling managed by estimated evapotranspiration; T2: conventional tillage with irrigation water amount and scheduling managed by estimated evapotranspiration and; T3: conservation agriculture with irrigation water amount and scheduling managed by farmers' practices.

2.3.5. Irrigation Water Use Efficiency (IWUE)

Irrigation water use efficiency (IWUE) for onion and garlic vegetables was increased in conservation agriculture (T_1) compared to conventional tillage (T_2) (Table 2-6). IWUE of onion was 4.4, 3.2, and 2.4 kg m^{-3}, respectively, in T_1, $T_{2,}$ and T_3 treatments. This shows that IWUE in T_1 treatment was 44% higher than T_2 and 76% higher than T_3 treatment. The difference in IWUE between T_1 and T_2 was also statistically significant at $\alpha = 0.05$ significant level with LSD = 0.77 (Table 2-6).

Similarly, IWUE of garlic was 1.9, 1.2, and 1.3 kg m^{-3}, respectively, in T_1, $T_{2,}$ and T_3 treatments. It implies that IWUE in T_1 treatment was 57% higher than T_2 and 49% higher than T_3 treatment (Table 2-6). T_1 was significantly different ($p < 0.05$) from the other two treatments. Due to lower yield response to higher irrigation water application at initial stages, IWUE was the lowest in T_3 for onion while IWUE for garlic was the lowest in T_2. Al-Jamal (2001) in New Mexico reported the IWUE of sprinkler and furrow irrigated onion experiment. However, the results are significantly higher than our results probably because of the high level of nutrient provision. IWUE results of this study are also consistent with the results reported under furrow irrigated experiments in Texas (Enciso et al. 2015). In harmony with our results, IWUE results were reported in the surface drip on-station onion experiment in India (Patel et al. 2013). Similar IWUE results were reported under a greenhouse pot experiment conducted in Turkey (Kadayifsi et al. 2005). Moreover, IWUE was also reported under low head drip-irrigated onion experiments in the semiarid region of Ethiopia (Bekele et al. 2007). A low-level IWUE was found in a drip-irrigated onion experiment in southern Ethiopia (Enchalew et al. 2016).

Generally, the IWUE results of this study under onion and garlic vegetables were comparable to other reported values in similar regions (Table 2-7). It showed that the IWUE shown in Table 2-7 were within the range of 2.2–17.5 kg m^{-3} for onion and in the range of 1.1–3.9 kg m^{-3} for garlic depending on the differences in climate and fertilizer management. The yield results in this study lay within these ranges.

Table 2- 7: Comparisons of experimental findings in applied irrigation water (mm), yield (t ha−1), and IWUE (kg m−3) under irrigated onion and garlic experimental studies.

References*	Location	Type of Experiment	Experimental Crop	Treatment Type	Irrigation Method	Applied Water (mm)	Yield (t ha^{-1})	IWUE (kg m^{-3})
[1]	Los Ebanos, Texas, USA	commercial	onion	irrigation methods	surface drip	359	62.9	17.5
[1]	Los Ebanos, Texas, USA	commercial	onion	irrigation methods	furrow	677	28.7	4.2
[2]	Arkansas, USA	commercial	onion	irrigation methods	furrow	640	35.0	5.5
[3]**	Sekota, Ethiopia	station	onion	irrigation scheduling	Drip	278	25.0	9.0
[4]	Abohar, Punjab, India	station	onion	deficit irrigation	Micro-sprinkler	275	19.0	6.9
[4]	Abohar, Punjab, India	station	onion	deficit irrigation	Micro-sprinkler	467	36.0	7.7
[5]	India	station	onion	deficit irrigation	Subsurface	563	44.4	7.9
[5]	India	station	onion	deficit irrigation	Subsurface drip	328	28.1	8.6
[6]	Los Ebanos, Texas, USA	station	onion	deficit irrigation	Subsurface drip	389	42.0	10.8
[6]	Los Ebanos, Texas, USA	station	onion	deficit irrigation	Subsurface drip	292	39.0	13.4
[7]	Turkey	GH pot[1]	onion	deficit irrigation	sprinkler	190–680	4.4–27	2.2–5.6
[8]	Jima, Ethiopia	On-farm	onion	Variety	Drip	315	6.9	2.2
[9]	California, USA	On-farm	Garlic	Irrigation Interval	1 week	350	21.3	6.1
[9]	California, USA	On-farm	Garlic	irrigation interval	1.5 week	300	19.1	6.4
[10]	Mymensingh, Bangladesh	station	Garlic	CA	drip	446	7.8	1.7
[10]	Mymensingh, Bangladesh	station	Garlic	CA	drip	546	6.8	1.2
[11]	Kadawa, Nigeria	station	Garlic	planting spacing	drip	425	15.3	3.6
[49]	Pune, India	station	Garlic	Deficit irrigation	Micro sprinkler	249	7.5	3.0
[49]	Pune, India	station	Garlic	Deficit irrigation	sprinkler	374	10.8	2.9
[49]	Pune, India	station	Garlic	Deficit irrigation	Micro sprinkler	498	12.9	2.6

*1=Enciso et al. 2006, 2=Ells et al. 1993, 3=Bekele et al. 2007, 4= Kumar et al. 2007, Patel et al. 2013, 6=Enciso et al. 2009, 7=Kadayifci et al. 2005, 8=Enchalew et al. 2016, 9= Hanson et al. 2003, 10=Kabir et al. 2013, 11=Adekpe et al. 2007, 12= Sankar et al. 2008. ** 10 kg ha^{-1} mm^{-1} = 1.0 kg m^{-3}; [1] GH = greenhouse.2.4. Conclusion

2.4 Conclusion

Water use, crop yield and yield parameters (height and tuber weight), soil moisture dynamics, and irrigation water use efficiency of conservation agriculture and conventional tillage were compared for irrigated onion and garlic in the highlands of Ethiopia. The amount of water added was determined by farmers practice and calculated climatic data. Compared with conventional tillage, in conservation agriculture, lower irrigation water use wasrequired. Similarly, the soil moisture content was higher, and crop yield was greater. On the other hand, farmer scheduled irrigation used approximately twice the amount of water than the climate data-based scheduling under conservation agriculture. Onion and garlic yields were approximately 40% greater in conservation agriculture over conventional tillage. The yield of onion from climate data-based scheduling treatment was 63% greater than the farmer's irrigation practice, while it was about 41% higher for garlic bulb production. Similarly, for onion 44% and garlic 57% greater irrigation water use efficiency was obtained in conservation agriculture than conventional tillage treatment. In both years, there was lower irrigation water use efficiency under farmers' practice due to the low yield of onion and garlic as a result of over-irrigation at the initial stages. Due to greatly increased yields and water savings under conservation agriculture in smallholder plots, we recommend farmers to apply grass mulch and used no-tillage practices while irrigating production of both onion and garlic. Adoption of conservation agriculture by smallholder farmers during the dry phase has social and economic benefits because less labor was required for tillage and irrigation water application. However, additional research is needed in grass mulch availability and pest occurrence under conservation agriculture if these benefits can be achieved in a large-scale implementation.

References

Abrha, H.; Gebremedhin, Y., 2015. Evaluating local garlic (Allium sativum L.) accessions using multivariate analysis based on agro-morphological characters in Southern Tigray, Ethiopia. J. Nat. Sci. Res., 5, 211–215.

Adekpe, D.; Shebayan, J.; Chiezey, U.; Miko, S., 2007. Yield responses of garlic (Allium sativum L.) to oxadiazon, date of planting and intra-row spacing under irrigation at Kadawa, Nigeria. Crop Prot., 26, 1785–1789.

Ahmed, I.; Khan, M.A.; Khan, N.; Ahmed, N.; Waheed, A.; Saleem, F.Y.; Khan, S.; Aslam, S., 2017. Impact of plant spacing on garlic rust (Puccinia allii), bulb yield and yield component of garlic (Allium sativum). Pak. J. Agric. Res., 30, 380–385.

Al-Jamal, M.; Ball, S.; Sammis, T., 2001. Comparison of sprinkler, trickle and furrow irrigation efficiencies for onion production. Agric. Water Manag., 46, 253–266.

Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FaoRome, 300, D05109.

Assefa, T.; Jha, M.; Reyes, M.; Worqlul, A., 2018. Modeling the Impacts of Conservation Agriculture with a Drip Irrigation System on the Hydrology and Water Management in Sub-Saharan Africa. Sustainability, 10, 4763.

Awulachew, S.B.; Lemperiere, P.; Tulu, T., 2009. Training Manual on Agricultural Water Management; International Livestock Research Institute: Nairobi, Kenya.

Awulachew, S.B.; Merrey, D.; Van Koopen, B.; Kamara, A., 2005. Roles, constraints and opportunities of small-scale irrigation and water harvesting in Ethiopian agricultural development: Assessment of existing situation. In Proceedings of the ILRI workshop, Morogoro, Tanzania, 7–9 March, pp. 14–16.

Ayalew, A.; Tadesse, D.; Medhin, Z.G.; Fantaw, S., 2015. Evaluation of Garlic (Allium sativum L.) Varieties for Bulb Yield and Growth at Dabat, Northwestern Ethiopia. Open Access Libr. J., 2, 1.

Bekele, S.; Tilahun, K., 2007. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. Agric. Water Manag., 89, 148–152, doi:10.1016/j.agwat.2007.01.002.

Belay, S.; Mideksa, D.; Gebrezgiabher, S.; Seifu, W., 2015. Yield Components of Adama Red Onion (Allium cepa L.) Cultivar as Affected by Intra-row Spacing Under Irrigation in Fiche Condition. Sci. Publ. Group, 3, 75–79.

Berihun, B., 2011. Effect of mulching and amount of water on the yield of tomato under drip irrigation. J. Hortic. For., 3, 200–206.

Corbeels, M.; Thierfelder, C.; Rusinamhodzi, L., 2015. Conservation agriculture in sub-Saharan Africa. In Conservation Agriculture; Springer: Berlin, Germany, pp. 443–476.

Doorenbos, J.; Kassam, A., 1979. Yield response to water. Irrig. Drain. Pap., 33, 257.

Ells, J.; McSay, A.; Soltanpour, P.; Schweissing, F.; Bartolo, M.; Kruse, E., 1993. Onion irrigation and nitrogen leaching in the Arkansas Valley of Colorado 1990–1991. HortTechnology, 3, 184–187.

Enchalew, B.; Gebre, S.; Rabo, M.; Hindaye, B.; Kedir, M., 2016. Effect of Deficit Irrigation on Water Productivity of Onion (Allium cepal.) under Drip Irrigation. Irrig. Drain. Sys. Eng., 5, 2.

Enciso, J.; Jifon, J.; Anciso, J.; Ribera, L., 2015. Productivity of Onions Using Subsurface Drip Irrigation versus Furrow Irrigation Systems with an Internet Based Irrigation Scheduling Program. Int. J. Agron., 1–6, doi:10.1155/2015/178180.

Enciso, J.; Jifon, J.; Wiedenfeld, B., 2007. Subsurface drip irrigation of onions: Effects of drip tape emitter spacing on yield and quality. Agric. Water Manag., 92, 126–130, doi:10.1016/j.agwat.2007.05.017.

Enciso, J.; Wiedenfeld, B.; Jifon, J.; Nelson, S., 2009. Onion yield and quality response to two irrigation scheduling strategies. Sci. Hortic., 120, 301–305.

Fabeiro, C.C.; Martn, d.S.O.F.; Lopez, U.R., 2003. Production of garlic (Allium sativum L.) under controlled deficit irrigation in a semi-arid climate. Agric. Water Manag., 59, 155–167.

Faradonbeh, M.M.; Mashhadi, A.A.; Bakhshandeh, A.; Jalal-abadi, A.L., 2013. Evaluation of the effects of different mulch material on quantity and quality yield of garlic populations (Allium sativum L.). Int. J. Agric. Crop Sci., 5, 2660.

Fatideh, M.M.; Asil, M.H., 2012. Onion yield, quality and storability as affected with different soil moisture and nitrogen regimes. South Western J. Hortic. Biol. Environ., 3, 145–165.

Friedrich, T.; Kassam, A.; Taher, F., 2009. Adoption of Conservation Agriculture and the role of policy and institutional support. Presented at the International Consultation on No-Till with

Soil Cover and Crop Rotation: A Basis for Policy Support to Conservation Agriculture for Sustainable Production Intensification, Astana-Shortandy, Kazakhstan, 8–10 July 2009.

Giller, K.E.; Corbeels, M.; Nyamangara, J.; Triomphe, B.; Affholder, F.; Scopel, E.; Tittonell, P., 2011. A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field Crop. Res., 124, 468–472.

Giller, K.E.; Witter, E.; Corbeels, M.; Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crop. Res., 114, 23–34.

Govaerts, B.; Sayre, K.D.; Goudeseune, B.; De Corte, P.; Lichter, K.; Dendooven, L.; Deckers, J., 2009. Conservation agriculture as a sustainable option for the central Mexican highlands. Soil Tillage Res., 103, 222–230, doi:10.1016/j.still.2008.05.018.

Hanson, B.; May, D.; Voss, R.; Cantwell, M.; Rice, R., 2003. Response of garlic to irrigation water. Agric. Water Manag., 58, 29–43.

Huang, J.; Xu, C.-c.; Ridoutt, B.G.; Wang, X.-c.; Ren, P., 2017. Nitrogen and phosphorus losses and eutrophication potential associated with fertilizer application to cropland in China. J. Clean. Prod., 159, 171–179.

Jat, M.L.; Gathala, M.K.; Saharawat, Y.S.; Tetarwal, J.P.; Gupta, R.; Yadvinder, S., 2013. Double no-till and permanent raised beds in maize–wheat rotation of north-western Indo-Gangetic plains of India: Effects on crop yields, water productivity, profitability and soil physical properties. Field Crop. Res., 149, 291–299, doi:10.1016/j.fcr.2013.04.024.

Kabir, M.; Rahim, M.; Majumder, D.; Iqbal, T., 2013. Effect of mulching and tillage on yield and keeping quality of Garlic (Allium sativum, L.). Bangladesh J. Agric. Res., 38, 115–125.

Kadayifci, A.; Tuylu, G.İ.; Ucar, Y.; Cakmak, B., 2005. Crop water use of onion (Allium cepa L.) in Turkey. Agric. Water Manag., 72, 59–68.

Kumar, S.; Imtiyaz, M.; Kumar, A., 2007. Effect of differential soil moisture and nutrient regimes on postharvest attributes of onion (Allium cepa L.). Sci. Hortic., 112, 121–129.

Levidow, L.; Zaccaria, D.; Maia, R.; Vivas, E.; Todorovic, M.; Scardigno, A., 2014. Improving water-efficient irrigation: Prospects and difficulties of innovative practices. Agric. Water Manag., 146, 84–94, doi:10.1016/j.agwat.2014.07.012.

Limon-Ortega, A.; Sayre, K.D.; Francis, C.A., 2000. Wheat nitrogen use efficiency in a bed planting system in northwest Mexico. Agron. J., 92, 303–308.

Moges, G.; Hengsdijk, H.; Jansen, H., 2011. Review and quantitative assessment of ex situ household rainwater harvesting systems in Ethiopia. Agric. Water Manag., 98, 1215–1227.

Morison, J.; Baker, N.; Mullineaux, P.; Davies, W., 2007. Improving water use in crop production. Philos. Trans. R. Soc. B Biol. Sci., 363, 639–658.

Nyborg, M.; Solberg, E.; Izaurralde, R.; Malhi, S.; Molina-Ayala, M., 1995. Influence of long-term tillage, straw and N fertilizer on barley yield, plant-N uptake and soil-N balance. Soil Tillage Res., 36, 165–174.

Patel, N.; Rajput, T., 2013. Effect of deficit irrigation on crop growth, yield and quality of onion in subsurface drip irrigation. Int. J. Plant Prod., 7, 417–436.

Postel, S.L.; Daily, G.C.; Ehrlich, P.R., 1996. Human appropriation of renewable freshwater. Science, 271, 785–788.

Pretty, J.; Toulmin, C.; Williams, S., 2011. Sustainable intensification in African agriculture. Int. J. Agric. Sustain., 9, 5–24, doi:10.3763/ijas.2010.0583.

Sankar, V.; Lawande, K.; Tripathi, P., 2008. Effect of micro-irrigation practices on growth and yield of garlic (Allium sativum L.) var. G. J. Spices Aromat. Crop., 17, 230–234.

Serra, A.-D.B.; Currah, L., 2002. Agronomy of onions. Agronomy of onions. In Allium Crop Science: Recent Advances; CABI: Wallingford, UK, pp. 187–232.

Shock, C.; Jensen, L.; Hobson, J.; Seddigh, M.; Shock, B.; Saunders, L.; Stieber, T., 1999. Improving onion yield and market grade by mechanical straw application to irrigation furrows. HortTechnology, 9, 251–253.

Shock, C.C.; Feibert, E.B.; Saunders, L.D., 2000. Onion storage decomposition unaffected by late-season irrigation reduction. HortTechnology, 10, 176–178.

Wallace, J., 2000. Increasing agricultural water use efficiency to meet future food production. Agric. Ecosyst. Environ., 82, 105–119.

Walter, I.A.; Allen, R.G.; Elliott, R.; Jensen, M.; Itenfisu, D.; Mecham, B.; Howell, T.; Snyder, R.; Brown, P.; Echings, S., 2000. ASCE's standardized reference evapotranspiration equation. In Proceedings of the Watershed management and operations management, Fort Collins, CO, United States, 20–24 June 2000; pp. 1–11.

Ward, F.A.; Pulido-Velazquez, M., 2008. Water conservation in irrigation can increase water use. Proc. Natl. Acad. Sci., 105, 18215–18220.

Woldetsadik, K.; Gertsson, U.; Ascard, J., 2003. Shallot yield, quality and storability as affected by irrigation and nitrogen. J. Hortic. Sci. Biotechnol., 78, 549–553.

Yeshiwas, Y.; Negash, B.; Walle, T.; Gelaye, Y.; Melke, A.; Yissa, K., 2018. Collection and characterization of garlic (Allium sativm L.) germplasm for growth and bulb yield at Debre Markos, Ethiopia. J. Hortic. For., 10, 17–26.

CHAPTER 3

THE RESPONSE OF WATER AND NUTRIENT DYNAMICS AND CROP YIELD TO CONSERVATION AGRICULTURE IN THE ETHIOPIAN HIGHLAND[2]

Abstract: Smallholder agriculture constitutes the main source of livelihood for the Ethiopian rural community. However, soil degradation and uneven distribution of rainfall threatened agriculture nowadays. This study is aimed at investigating the impacts of conservation agriculture on irrigation water use, nutrient availability in the root zone and crop yield under supplementary irrigation conditions. Conservation agriculture (CA), which is defined as minimum soil disturbance, grass mulch cover and crop rotation, was practiced and compared with conventional tillage (CT). We used 2 years (2018 and 2019) experiment under paired-t design in the production of a local variety of green pepper (*Capsicum annuum L.*). The result showed that conservation agriculture practices significantly improved water management ($\alpha = 0.05$), and has reduced irrigation water use (10%) and runoff (29 to 51%) while it increased percolated water in the root zone (21% to 33%) when compared with CT practice under the supplementary irrigation phase. On the other hand, CA practice has decreased the NO_3-N (10%) and PO_4-P (10%) load in leachate while nutrient loads in runoff under CA showed about 159% decrease in NO_3-N load and an increase in PO_4-P load in the range of 40% to 60%. Besides, the yield return achieved under CA treatment was 30% higher in 2018 and 10 % higher in 2019 when compared with the CT. Relatively higher nitrogen nutrient dynamics in runoff and leachate were observed in CT management compared to CA due to frequent soil disturbance and minimum soil cover during therainy period. Correspondingly, greater phosphorus load in the leachate and lower phosphorus load in runoff were found under CA. In general, higher nitrogen removal was observed with the leachate under the CT while higher phosphorus removal was observed with the leachate under the CA management. Moreover, inorganic N-fertilizers applied in-situ were highly open to the leaching losses when compared to the losses with runoff.

.**Keywords:** Conservation agriculture; leachate; conventional tillage; nutrient dynamics; supplementary irrigation

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[2] Belay, S.A., Assefa, T.T., Prasad, P.V., Schmitter, P., Worqlul, A.W., Steenhuis, T.S., Reyes, M.R. and Tilahun, S.A., 2020. The Response of Water and Nutrient Dynamics and Crop Yield to Conservation Agriculture in the Ethiopian Highlands. Sustainability, 12(15), p.5989; https://doi.org/10.3390/su12155989.

3.1. Introduction

Water and soil nutrients remain the most limiting resource bases for agriculture. However, rainfed and irrigated agriculture is often hindered by the depletion of soil nutrients through surface runoff and percolating water during rainy phase (Rockstrom et al. 2009, Bekele et al. 2007), and by the scarcity of water during dry phase (Bekele et al. 2007, Rockstrom et al. 1999). Surface runoff adversely affects the availability of water (Rockstrom et al. 1999, Lanckriet et al. 2012, Bosch et al. 2005), soil nutrients (Bosch et al. 2005, Tomer et al. 2016, Grandy et al. 2006), and soil organic matter for the plant (Assefa et al. 2018, Bot et al. 2005). Percolated water can also affect water and nutrient availability to some extent (Bosch et al. 2005). Agricultural activities exacerbate the removal of nutrients by either of the processes (Carpenter et al. 1998). Nutrients that are removed by surface runoff are permanently lost before reaching the root zone of the plant while nutrients that are leached below the root zone are at least temporarily lost from the root system. Concurrently, the nutrient and water components of surface runoff and percolation may also deteriorate the water quality of wells, reservoirs and lakes (Logan et al. 1993). Thus, the nutrients often removed by water dynamics contribute not only to water quality deterioration but also imply an economic loss of soil fertility to the farmer. The current approach of agricultural systems which promotes the use of more chemical fertilizers (Pretty et al. 2011), particularly for vegetable production, shows an indication to a wider expansion of the above risks, and nowadays become a serious concern of environment (Pretty et al. 2011, Matson et al. 1997, Heathwaite et al. 1996).

Hence, there is a need for a paradigm shift to improve smallholder agriculture systems that could promote sustainable intensification, which encourages an increase in crop productivity with minimum inputs and saving the environment at the same time (Pretty et al. 2011). Smallholder vegetable production at home gardens is one approach of localized strategy to improve the livelihood and nutrition of farmers in many developing countries (Assefa et al. 2018, Assefa et al. 2019). Smallholder vegetable production may also be optimized by applying conservation agriculture (CA) practices that would improve productivity with minimum inorganic inputs and minimized adverse effects on the environment. The CA system (minimum soil disturbance, complete soil cover, and proper crop rotation) has been used to improve irrigation water use efficiency and crop productivity while controlling soil nutrient losses caused by various factors

(Assefa et al. 2019, Lal Bhardwaj R. 2013). No-tillage, despite the minor adverse effect of its separate application (Giller et al. 2011), reduces runoff (Lanckriet et al. 2012, Araya et al. 2010, Tesfaye et al. 2011), increase percolation and enhanced water holding capacity of soils (Grandy et al. 2007, Romic et al. 2003, Thierfelder et al. 2009, Radford et al. 2011), when combined with grass mulch cover and proper crop rotation. The biological decomposition of grass mulch has improved the soil quality (adding up to soil nutrients) and soil structure while no-till practice combined with complete soil cover reduce the soil compaction in the long-term (Blanco-Canqui et al. 2009), particularly in drier regions or dry irrigation phase (Grandy et al. 2007, Radford et al. 2011). The yield of cereal crops has been increased in CA systems while infiltration increases under rainfed phases of production (Grandy et al. 2007, Araya et al. 2010, Thierfelder et al. 2009, Ghosh et al. 2015). Water use efficiency and yield of vegetables significantly increase under CA in dry irrigation phases of production compared with the conventional practices (Assefa et al. 2018, Assefa et al. 2019, Belay et al. 2019).

Most of the previous studies evaluated the impacts of CA practices mainly on cereal crops and on either rainfed or irrigated systems. There are few studies on the impacts of CA on water saving and yield of some vegetables in the sub-humid Ethiopian highlands (Assefa et al. 2018, Belay et al. 2019, Assefa et al. 2019, Assefa et al. 2020). However, experimental study on water and nutrients dynamics and associated pepper yield are missing particularly for the highland systems of Ethiopia.. Moreover, previous studies on vegetableswere limited to dry season irrigation production. Thus, the objective of this study was to investigate the impacts of CA on water dynamics (runoff, percolation, irrigation water use) and soil nutrient (nitrate and phosphorous removals) contributing to improving crop productivity under supplemental irrigation for rainfed cropping of pepper. The results from this study would contribute to the comprehensive evaluation of the CA system for improving, productivity, and livelihood and ecosystem services.

3.2. Materials and Methods

3.2.1. Experimental design and layout

The location and site details of the area are as described in chapter 2. A total of 10 experimental plots were established on 100 m^2 in size, where 50 m^2 was randomly assigned for conservation agriculture (CA) and another 50 m^2 for conventional tillage (CT) practice under supplementary irrigated phase (Figure 3-1 a and b). The experimental plots were initially selected based on the availability of productive shallow groundwater wells adjacent to irrigable farms and farmers' willingness to participate in the experiment. CA consists of no-tillage (here only bed preparation) and application of grass mulch at the rate of 2 t ha^{-1}, while CT is the current farmers' practice of 4–6 tillage frequencies (tillage depth 15-25 cm) and without mulch cover. A paired 't' design was used to examine the impacts of CA on water use, runoff, leachate, nutrient use and crop yield as compared to CT treatment. Irrigation water was managed by estimated reference evapotranspiration based on the methods explained by Babalola et al. (2007). The crop rotation (onion- pepper-garlic-pepper-onion-pepper) was the same for both CA and CT agricultural practices, however, only the pepper production period was used for this paper. Drip irrigation was used for both 2018 and 2019 experimental years (from March to mid of June). Each treatment subplot was subjected to an equal amount of irrigation water for a week to ensure uniform recovery of transplanted seedlings.

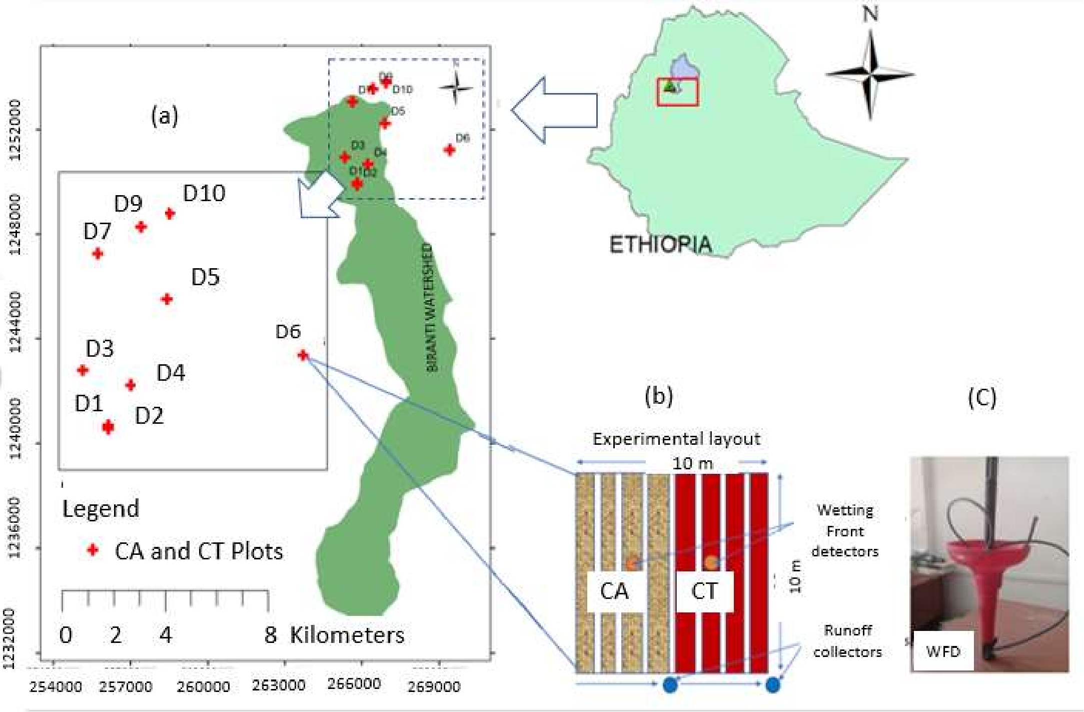


Figure 3- 1: Location map of the experimental site (a) and layout of conservation agriculture (CA) and conventional tillage (CT) treatments (a and b), and Wetting Front Detector (WFD) (c). The bottom arrows (b) indicate the direction of runoff flows relative to the runoff collector.

3.2.2. Crop management practices

Pepper was selected by farmers for second season vegetable production due to its market availability and better yields (more than one harvests). Local variety pepper (*Capsicum annuum L.*) was transplanted on 13 March, 2018, and 19 March, 2019 (Table 3-1). The spacing between rows and plants during transplanting was 40 cm. After transplanting, the initial stage lasted for 20 days; the development stage lasted for 30 days; the mid-season growth stage (flowering and fruiting) lasted for 50 days, and the late-season stage lasted for 60 days. Inorganic fertilizers (Diammonium phosphate-DAP and Urea) were not applied in the pepper growing period (the 2nd irrigation season) based on the local practice. However, urea fertilizer (46-0-0: N-P-K) was applied to the plots at the rate of 200 kg ha^{-1} using split application method (twice) during the first irrigation season from October to March. Sufficient phosphorus fertilizer was available in the soil based on soil laboratory investigation (Blanco-Canqui et al. (2007). The nutrient content of local grass and cow dung was analyzed in a known soil laboratory. Local grass (85% organic matter; 0.18% total nitrogen, and 17 ppm available phosphorus,) has been applied at the rate of 2 t ha^{-1} as mulch cover for only CA treatment twice per irrigation period. Cow dung (42% organic matter; 2.1% total nitrogen, and 82 ppm available phosphorus,) has been applied at the rate of 5 t ha^{-1} equally for both treatments at the end of the 1st season harvest. The harvesting period was from June to August for both 2018 and 2019. Farmers used 4 to 6 harvests in each season, and a fresh pepper yield was then weighed from each subplot during every harvest.

Table 3- 1: Experimental activities of 2018 and 2019 green pepper cropping seasons.

Year	Management Activities	Date	Methods and Tools
2018	Seedling	1/20/2018	Watering-can
	Cow dung application	2/5/2018	Manual
	Tillage*	2/10–20/2018	Draught animal
	Planting	3/13/2018	Manual
	Mulch application**	3/12/2018	Manual
	Irrigation	3/13/2018–5/12/2018	Drip irrigation
	Weeding/hoeing	4/20/2018, 5/5/2018, 7/10/2018	Handpick
	Harvesting	6/1/2018–8/25/2018	Handpick
2019	Seedling	1/9/2018	Watering-can
	Cow dung application	2/5/2018	Manual
	Tillage*	2/15–25/2019	Draught animal
	Planting	3/19/2019	Manual
	Mulch application**	3/12/2019	Manual
	Irrigation	3/19/2019–5/18/2019	Drip irrigation
	Weeding/hoeing	4/25/2018, 5/15/2019, 7/15/2019	Handpick
	Harvesting	6/10/2019–8/29/2019	Handpick

Note: * No tillage and mulch application for CA only.

3.2.4. Data collection

Climate data used for calculating the reference evapotranspiration (ETo) with the FAO Penman–Monteith equation Allen et al. 1998) were collected from Dangila weather station (15 km from the site) for the period of 1995–2016. In addition of the rainfall data, we excluded the years 1998–2000 from the period because of the large number of missing data. We used the average of these processed climate data which include temperature (maximum and minimum), relative humidity, actual sunshine hours, and wind speed. Crop water use (ETc) was determined by multiplying ETo by the crop coefficient (Allen et al. 1998) for initial, development, mid-season, and end stages. The same crop coefficient was used for the growth stages of pepper crop for the experimental years (i.e. 0.7 for initial, 0.95 for development, 1.05 for mid, and 0.7 for the late season). Irrigation water to be applied to pepper was determined at an allowable constant soil moisture depletion fraction ($p = 0.4$) of the total available soil water (TAW), where TAW was determined from the permanent wilting point, field capacity, root depth, and bulk density variables. The depth of water applied during each irrigation event was the net irrigation requirement estimated by Penman-Monteith method, plus that needed for inefficiencies in the irrigation system. Considering conveyance and other losses for drip system, irrigation efficiency of 90% was assumed. We used a 500 liter water storage Roto for 100 m^2 plot area, so that we can apply 5 mm of water per irrigation on average in 2018 and 2019 years with different irrigation scheduling (skipping 2 days for CA and 1 day for CT). Irrigation was ceased immediately after the onset of rainfall in mid of May.

Runoff was measured using runoff collectors of geomembrane sealed trench of size 0.5 m x 0.4 m x 1 m (200 literes in capacity), installed at the end of each treatment beds (Figure 3-1 b). One trench was used for a treatment where runoff drains from 4 beds in to the trench. It was recorded during every storm during day time and runoff collected during the night time was recorded in the morning. Each time after measurement, the trench was cleaned from incoming sediments. The amount of leachate was monitored every 10-day using Wetting Front Detector (WFD) installed 40 cm (efective root zone for pepper) below the soil surface (Figure 3-1 c), and evaporation loss for irrigated fields (wet) at this depth was neglected. Capillary rise of water from 6-10 m water table through sand filter (always wet for irrigated fields) was also assumed unrealistic. Water passing the fine sand filter was collected at the bottom of the WFD where a small hose was attached to it for draining out the leachate every 10 day using a syringe. The amount of leachate (ml) obtained in the area of WFD was converted to mm of leachate by dividing the cross-section area (20 cm diameter) of WFD. A water sample of 50 ml (20 ml for NO_3-N, 10 ml for PO_4-P) was collected from runoff and leachate for determining the concentration of nutrients (i.e. NO_3-N and PO_4-P). Available phosphorus and NO_3-N concentrations were determined using the Palintest photometer 7500 tests. The nitrate-nitrogen and available phosphorus loads were calculated by multiplying drainage volumes for each period with the corresponding measured NO_3–N and PO_4-P concentrations.

Total water used by the crop plus evaporation was calculated using Penman-Monteith method as stated by Belay et al. (2019). Actual crop water used by pepper for the growing season was computed using the soil water balance equation, Kresović et al. (2016), as shown below :

$$ETa = I + Rf + Cr - R_o - P_{40} \pm \Delta S \qquad (1)$$

where ETa is evapotranspiration (mm) during the growing season, I is the amount of irrigation water applied (mm), Rf is actual rainfall recorded at site (mm), Cr is the capillary rise(mm), considered to be zero because the groundwater table was >4 m below the surface in the growing months, P_{40} is percolation (mm) at 40 cm soil depth, considered because the soil water content below 40 cm reached field capacity during rainy season months on the sampling dates, Ro is runoff (mm), measured using runoff collectors because the field was saturated in rainy months (June to August) and ΔS is the change in soil moisture content (mm) measured using the gravimetric method at the time of transplanting and after harvest.

2.5. Data Analysis

All data are presented with arithmetic means and was statistically analyzed using a pair-t analysis for means after checking the normality using Jarque–Berra method (Jarque et al. 1984). Phosphorus concentration data were transformed to natural logarithm to observe the normality. Phosphorus concentration data showed normality after logarithmic transformation. All the results shown in tables and figures are means of treatment plots or replicates. Mean values were compared for any significant differences using the least significant difference (LSD $_{\alpha = 0.05}$) method.

3.3. Results

3.3.1. Irrigation and rainfall contributions in the pepper growing period

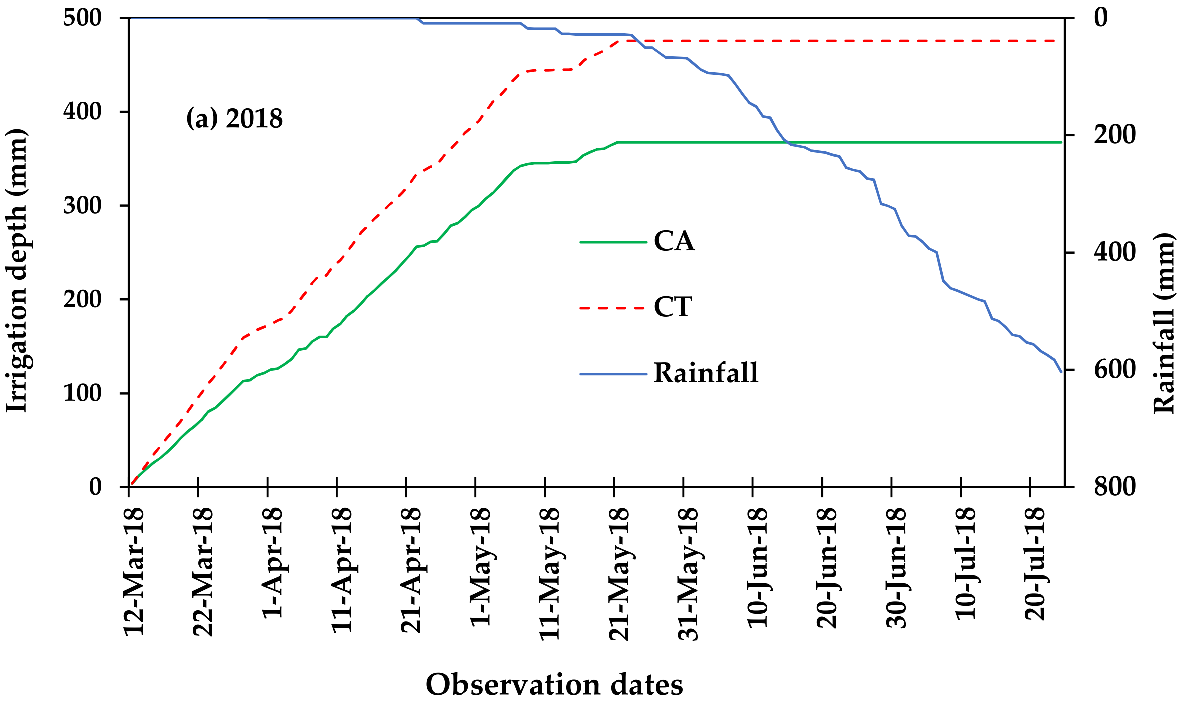
The amount of rainfall during the growing period of pepper was 594 mm in 2018 and 618 mm in 2019. The contribution of irrigation in 2018 was 46% in the CA (370 mm) and 56% in the CT (476 mm) while in 2019; its contribution was 37% in the CA (255 mm) and 42% in the CT (289 mm) (Table 3-2). The remaining pepper growth was supported by rain in the wet period (Figure 3-2). Irrigation water use was significantly reduced ($p<0.05$) under CA compared to CT management. The grass mulch and no-tillage practices under CA treatment decreased the interval of irrigation application and hence reduced irrigation water use. The cumulative depth of irrigation application throughout the dry periods of pepper growing period is plotted in Figure 3-2.

Table 3- 2: Mean ± standard deviation (StDev) for applied irrigation, runoff, percolation, crop water use (ETc) and fresh yield under conservation agriculture (CA) and conventional tillage (CT) treatment in 2018 and 2019 supplementary irrigated pepper production period.

Variables	2018		2019	
	CA	CT	CA	CT
Applied irrigation (mm)	367.3 ± 55.4 ^{b*}	475.4 ± 68 ^{a}	254.8 ± 42.9 ^{b}	287.8 ± 57.7 ^{a}
Rainfall (mm)**	594.0	594.0	618.0	618.0
Runoff (mm)	53.2 ± 8.0 ^{b}	80.1 ± 22.3 ^{a}	95.5 ± 18.4 ^{b}	123.6 ± 19.2 ^{a}
Percolation / leaching (mm)	7.5 ± 2.4 ^{a}	5.9 ± 1.9 ^{b}	6.9 ± 1.6 ^{a}	4.6 ± 2.4 ^{b}
Crop water used (ET_c) (mm)	796.7 ± 65.3 ^{b}	855.6 ± 83.1 ^{a}	678.7 ± 55.0 ^{a}	686.6 ± 69.1 ^{a}
Fresh yield (t ha^{-1})	11.7 ± 5.9	9.1 ± 4.3	6.2 ± 1.7	5.9 ± 2.3
Contribution of irrigation	46%	56%	37%	42%

*Numbers followed by same letters under the same row heads in the same year are statistically non-significant at α = 0.05 significant level. **Rainfall is assumed the same for the village.

Year to year difference in the contribution of irrigation application was due to the difference in the time of transplanting pepper. To avoid drainage problems in the rainy period, farmers have practiced transplanting of pepper at the beginning of March where the initial and development stages occurred in the drier months and fruit stage occurred in the wet months (Table 3-1).



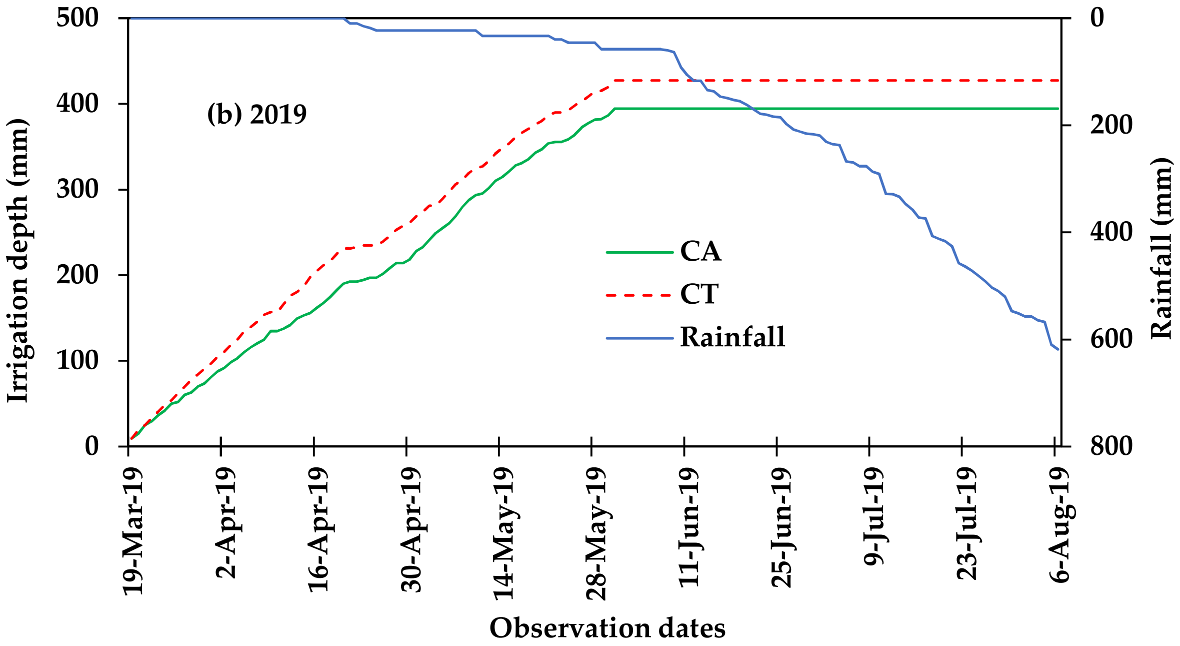
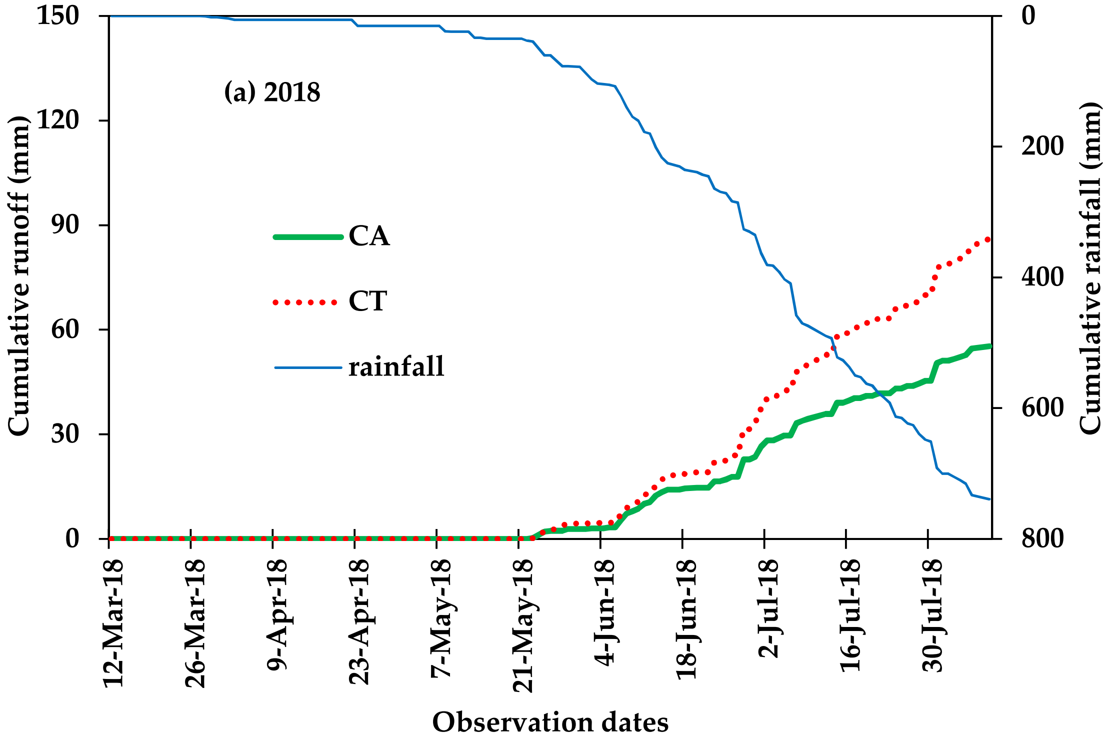


Figure 3- 2: Commutative rainfall versus irrigation water applied for conservation agriculture (CA) and conventional tillage (CT) for the experimental years of 2018 (a) and 2019 (b).

3.3.2. Effect of conservation agriculture on water dynamics (runoff and percolation)

The average runoff depth for the 2018 and 2019 years were, respectively, 53 and 96 mm under CA and 80 and 124 mm under CT (Table 3-2). In 2018, a significant ($p< 0.05$) decrease in runoff depth (about 51 %) was observed in CA (53 mm) as compared to the CT (80 mm) (Table 3-2). Similarly, in 2019, a significant ($p< 0.05$) decrease in runoff depth (about 29 %) was observed in CA (96 mm) as compared to the CT (124 mm) (Table 3-2). The commutative of daily runoff and rainfall (mm) records are plotted for both years in Figure 3-3. It showed that the runoff under CT were significantly greater compared to the CA.

Overall, runoff in year 2018 was greater than that of 2019 (Table 3-2), because of the difference in the planting date (Table 3-1) and the delays in the onset of wet period which can be related with lower contribution of irrigation in 2019.



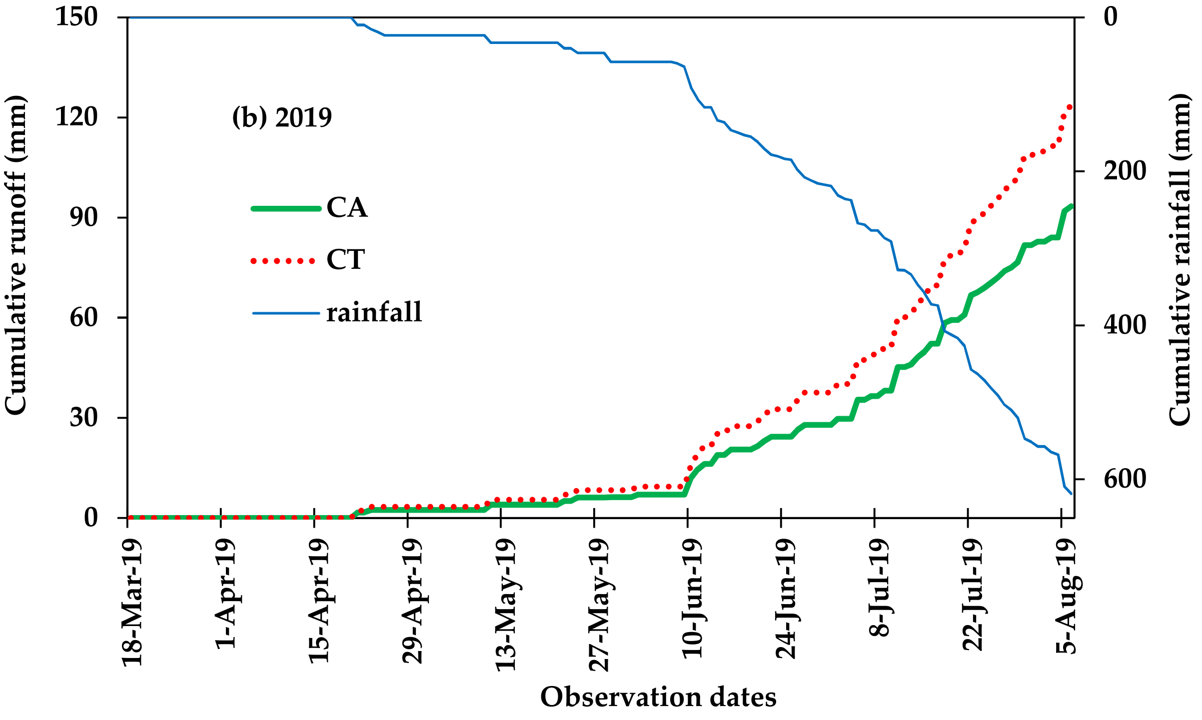
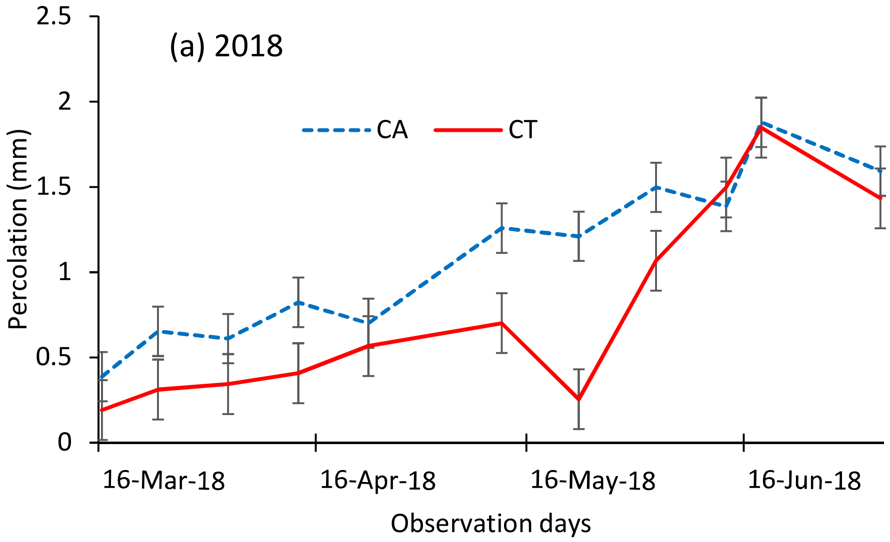


Figure 3- 3: Comparison of cumulative daily runoff depth between CA and CT treatments for 2018 (a) and 2019 (b) during the growth period of pepper.

On the other hand, the quantity of leachate was significantly (21%) increased in the CA (8 mm) when compared to the CT (6 mm) for 2018 experimental seasons (Figure 4). Similarly, in 2019, a significant ($p < 0.05$) increase in leachate (about 33%) was observed in CA (7 mm) as compared to the CT (5 mm) (Figure 3-4). The amount of leachate increased slowly during the dry season while it increased rapidly after the onset of the rainfall around the beginning of May (Figure 3-4). This supports the nature of complementary processes of runoff and percolation, where a decrease in the former corresponds to an increase in the later. The temporal variation, showed that the maximum leachate depth occurred after the 20th of July over the growing periods and then start decreasing onwards (Figure 3-4).



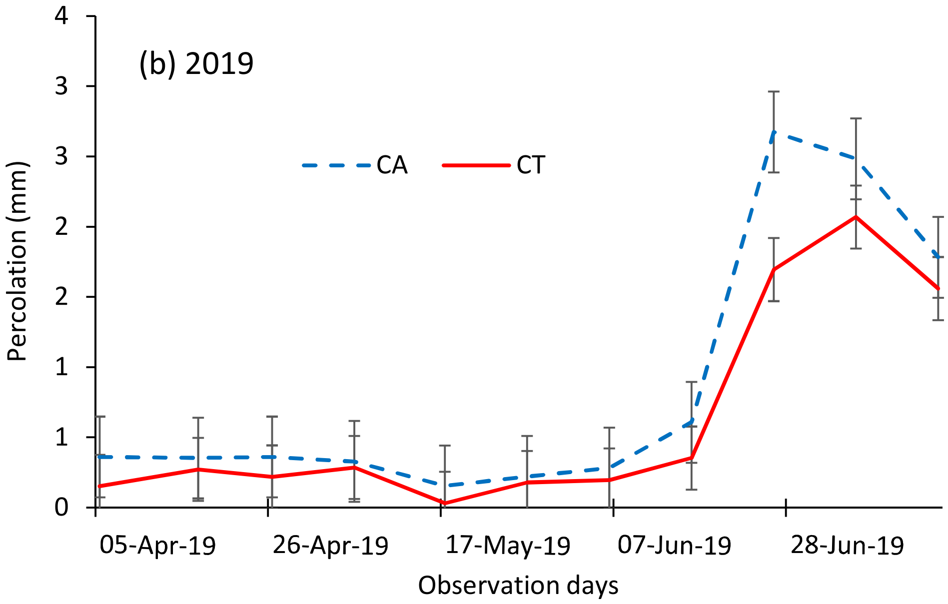


Figure 3- 4: Percolated water (leachates) measured every 10 days of the experimental periods of 2018 (a) and 2019 (b) for CA and CT management.

3.3.3. Consumptive use of pepper (ETc) under supplementary irrigation

Water used by pepper from irrigation and rainfall, actual evapotranspiration (ETa) was in the range of 750 to 950 mm and 600 to 850 mm, respectively in the years 2018 and 2019 (Figure 3-5). The maximum ETa in the CA management was 770 mm and 700 mm while it was 798 mm and 715 mm in the CT, respectively, for the years 2018 and 2019. However, the difference between treatments in Eta was significant ($p<0.05$) only for 2018 (Table 3-2). However, the yield of pepper was greater in CA compared with CT management (Figure 3-6). The average yield of pepper under CA was 11.8 t ha^{-1} in 2018 and 6.1 t ha^{-1} in 2019 while the yield was 9.1 t ha^{-1} in 2018 and 5.7 t ha^{-1} in 2019 under CT management. It showed that the yield return achieved in 2018 under CA treatment was 30% higher compared to the CT. In 2019, the yield of pepper was 10% higher under CA compared to the CT. The yield difference was statistically different ($p<0.05$) only for the 2018. The peak pepper yield in CA occurred ahead of CT management in response to lower optimum water use for the site conditions. However, the yield under CT management has continued even after the end of the last harvest of pepper (Figure 3-5). The yield results in Figure 3-4 and the runoff results in Table 3-2 agree in that runoff in 2018 was less than 2019, however, the yield in 2018 was higher when compared with the yield in 2019. It means that plots in 2019 were subjected to water logging problems. Based on farmers intrinsic knowledge which is in line with (Aliyu et al. 2000), well-drained soil is suitable to pepper production.

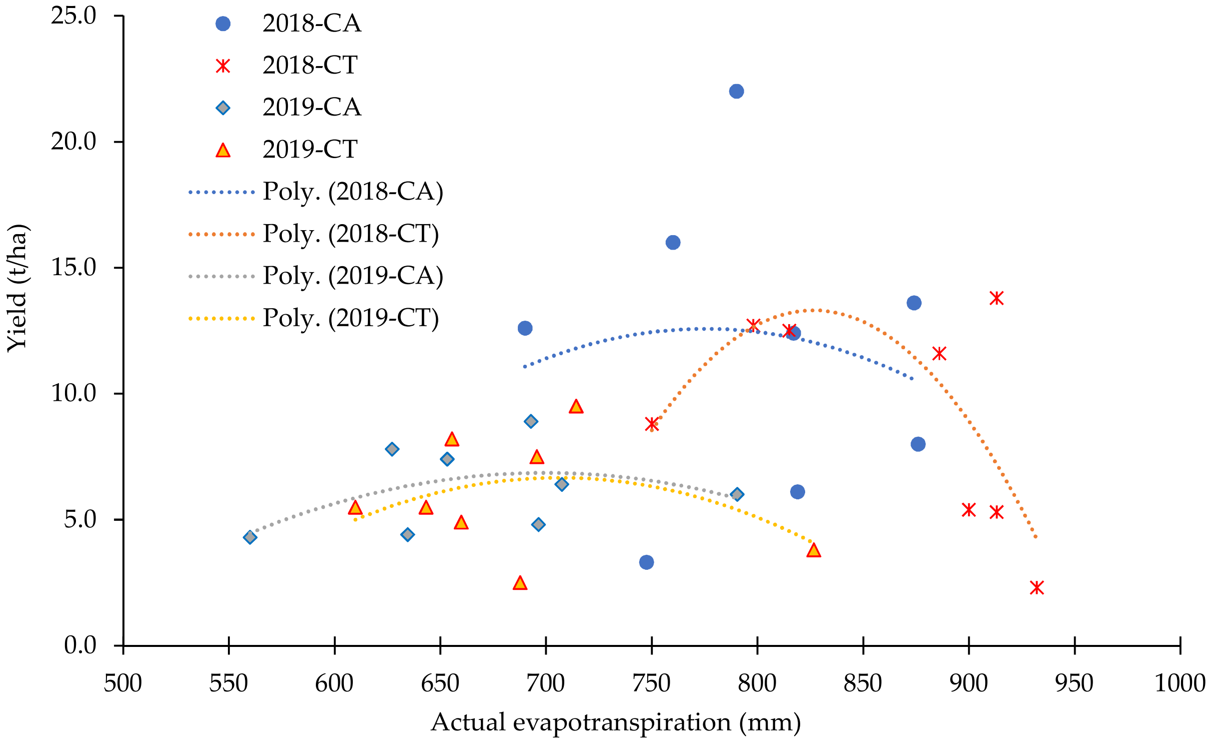


Figure 3- 5: The relationship between water use and pepper yield (t/ha) based on the data from replicated subplots of conservation agriculture (CA) and conventional tillage (CT) treatments conducted in 2018 and 2019 experimental years.

3.3.4. Nitrogen (NO_3-N) dynamics

NO_3−N concentrations in percolated water during the whole pepper growing period under CA and CT practices are shown in Figure 6. The concentration of NO_3-N in the leachate was greater in the CT management compared to the CA. At higher crop growth stages, with increased canopy cover, the difference in the concentration of NO_3-N between the treatments was minimum (Figure 3-7). The mean concentration of NO_3-N in the leachate was 2.8 and 1.8 mg/L in the CA treatment and 3.2 and 2.6 mg/L in the CT, respectively for 2018 and 2019 pepper growing seasons (Table *3*-3). The mean NO_3-N loss in the leachate was significantly ($p<0.05$) reduced under CA (29 %) when compared with CT treatment (Table 3-3). Correspondingly, the load (g ha^{-1}) of NO_3-

N in the leachate was 20.1 and 15.1 in the CA treatment and 21.6 and 16.6 in the CT for the cropping season. When the amount of leachate decreased, the associated NO_3-N concentration increased at early crop stages over the drier months; from the start of cultivation to harvest of pepper (Figure 3-6). Nitrate concentrations in leachate for both treatments were the highest at the beginning of the growing period and decreased at the end of the growing period as rainfall amount increases (Figure 3-6).

Table 3- 3: The mean concentration of nitrogen (NO_3-N) in the leachate (mg/L), and the corresponding load (g/ha); the concentration of NO_3-N removed by surface runoff (mg/L), and the corresponding load (g/ha) for the two years in conservation agriculture (CA) and conventional tillage (CT) treatments.

Variables	**2018**		**2019**	
	CA	**CT**	**CA**	**CT**
NO_3-N (leachate), mg l^{-1}	2.8 ± 0.9 ^{b}	3.2 ± 1.3 ^{a}	1.8 ± 0.7 ^{b}	2.6 ± 1.2 ^{a}
NO_3-N (leachate), g ha^{-1}	20.1 ± 7.8 ^{a}	21.6 ± 9.1 ^{a}	15.1 ± 12.8 ^{a}	16.6 ± 16.2 ^{a}
NO_3-N (runoff), mg l^{-1}	0.3 ± 0.1 ^{b}	0.6 ± 0.15 ^{a}	0.4 ± 0.1 ^{b}	0.8 ± 0.3 ^{a}
NO_3-N (runoff), g ha^{-1}	148.8 ± 66.2 ^{b}	384.0 ± 75 ^{a}	333.7 ± 122 ^{b}	866 ± 359 ^{a}

* Numbers followed by same letters under the same row heads in the same year are statistically non-significant at $\alpha = 0.05$ significant level.

On the other hand, the concentration of NO_3-N in the runoff was 0.3 and 0.4 mg/L in the CA and 0.6 and 0.8 mg/L in the CT, respectively for 2018 and 2019 cropping seasons (Table 3-3). Consequently, the load (g ha^{-1}) of NO_3-N in surface runoff was found 39% lower in CA when compared with CT (Table 3-3). The result indicated that NO_3-N concentration was significantly ($P<0.5$) lower in runoff when compared with its concentration in the leachate.

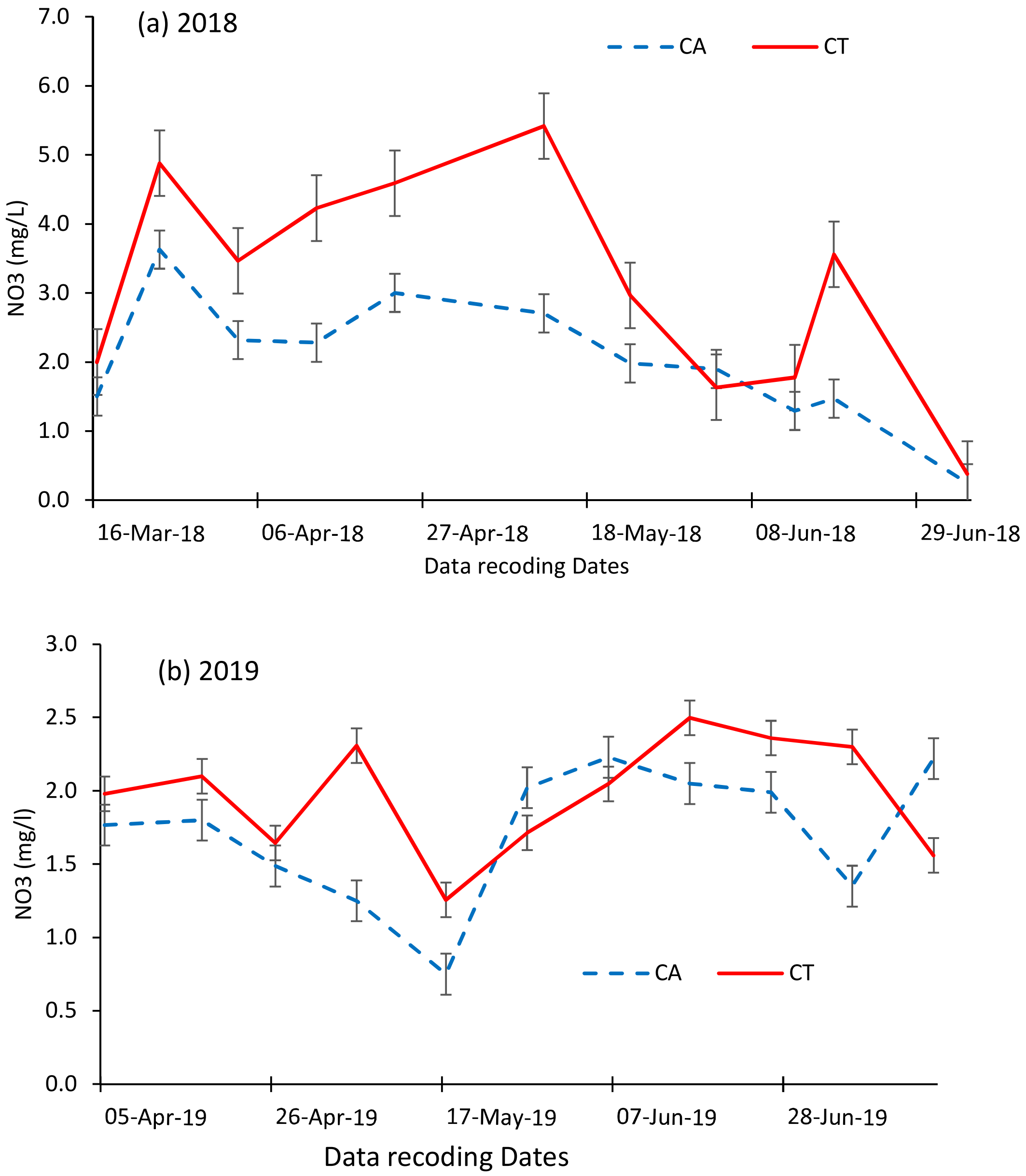
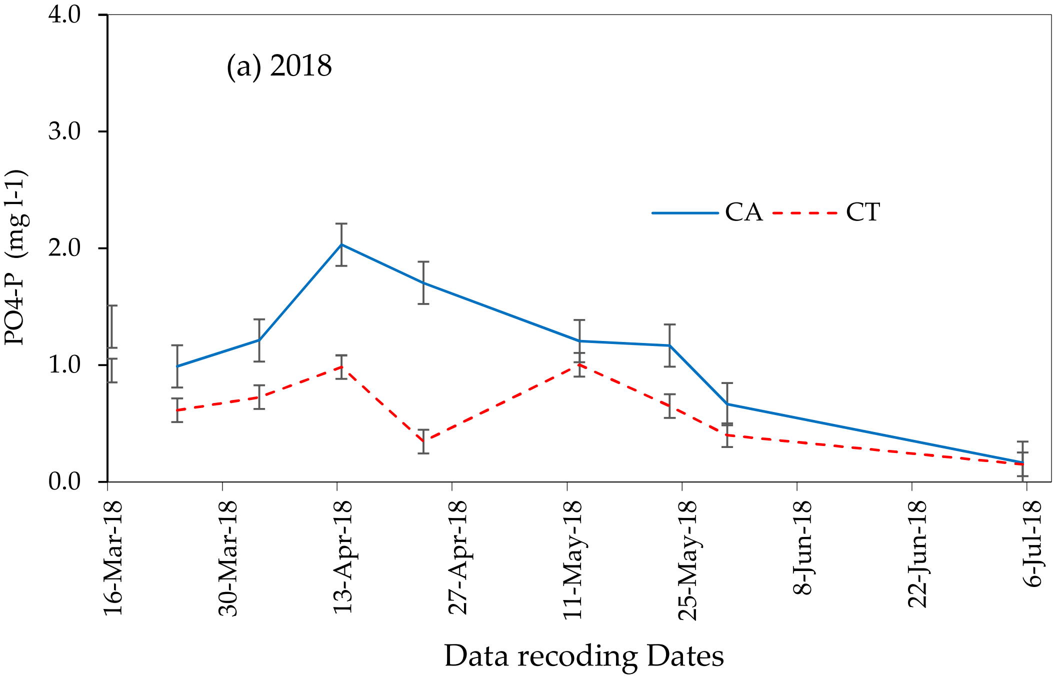


Figure 3- 6: NO_3-N concentration (mg/L) in the leachate; data collected every 10 days during pepper production period under conservation agriculture (CA) and conventional tillage (CT) treatments in 2018 (a) and 2019 (b) experimental years.

3.5. Phosphorus (PO_4-P) dynamics

Available phosphorus below 40 cm soil layer showed a decreasing trend from dry to wet months of 2018 and 2019 cropping seasons (Figure 3-8). The concentration of PO_4-P decreased with an increase in the leachate in 2018 and 2019 (Figures 3-4 and 3-7). Figure 3-7 shows that PO_4-P concentration is increased from May to August and decreased from March to May. The mean concentration of PO_4-P was 1.1 and 1.6 mg/L in the CA and 0.8 and 0.6 mg/L in the CT, respectively for 2018 and 2019 cropping seasons (Table *3*-4). The mean PO_4-P concentration in the leachate was significantly (29%) higher in CA as compared with CT (Table 3-4). Correspondingly, the load (g ha^{-1}) of PO_4-P in the leachate was 8.4 and 15.1 g ha^{-1} in the CA treatment and 5.6 and 16.6 g ha^{-1} in the CT, respectively for 2018 and 2019 cropping seasons (Table *3*-4). The PO_4-P concentration increased at early crop stages while the quantity of leachate decreased in the dry months (March to May).



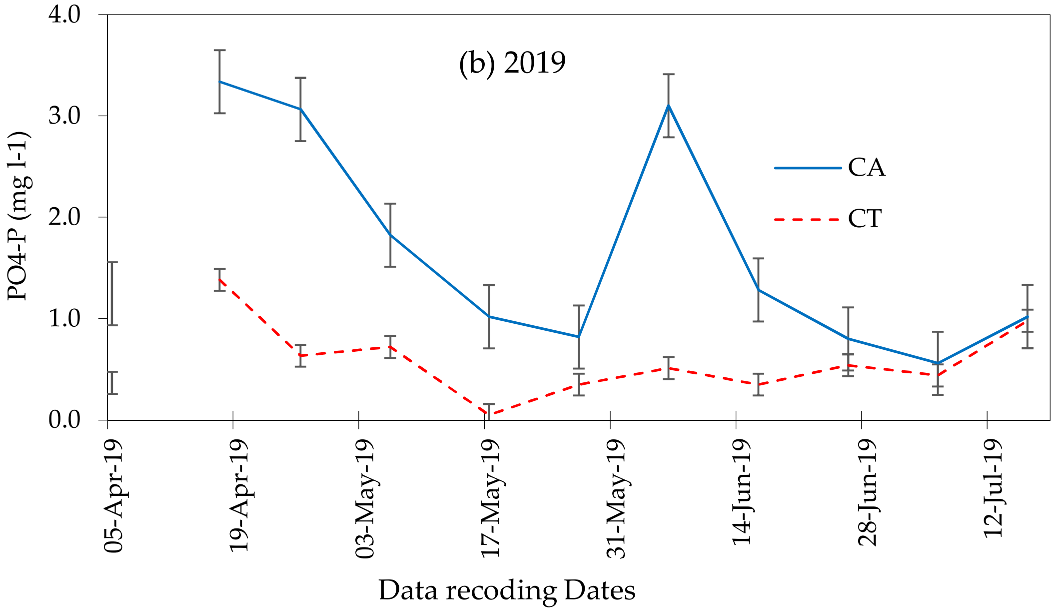


Figure 3- 7: The concentration of PO_4-P (mg/l) in the leachate under CA and CT for 2018 (a) and 2019 (b).

On the other hand, the mean concentration of PO_4-P in runoff was 0.55 and 0.6 mg/L in the CA and 0.64 and 0.7 mg/L in the CT for 2018 and 2019 cropping seasons, respectively (Table *3*-4). However, the difference between CA and CT was statistically insignificant ($p>0.05$) (Table 3-4). The corresponding load (g ha^{-1}) of PO_4-P in the leachate was 243 and 501 g ha^{-1} in the CA whereas 389 and 702 g ha^{-1} in the CT for 2018 and 2019 cropping seasons, respectively (Table *3*-4).

Table 3- 4: The concentration of phosphorus (PO_4-P) in the leachate (mg/L) and its load (g ha^{-1}); the concentration of phosphorus (PO_4-P) removed by surface runoff in (mg/L), and the associated load (g ha^{-1}) for the two treatments and under experimental years.

Variables	**2018**		**2019**	
	CA	**CT**	**CA**	**CT**
PO_4-P (leachate), mg l^{-1}	1.2 ± 0.7 ^{a}	0.80 ± 0.4 ^{b}	0.80 ± 0.5 ^{a}	0.6 ± 0.3 ^{b}
PO_4-P (leachate), g ha^{-1}	8.4 ± 4.0 ^{a}	5.6 ± 2.6 ^{b}	15.1 ± 4.2 ^{a}	16.6 ± 2.6 ^{b}
PO_4-P (runoff), mg l^{-1}	0.55 ± 0.1 ^{a}	0.64 ± 0.15 ^{b}	0.6 ± 0.2 ^{a}	0.7 ± 0.3 ^{b}
PO_4-P (runoff), g ha^{-1}	243 ± 66.2 ^{a}	389 ± 75 ^{b}	500.8 ± 215 ^{a}	702.6 ± 312 ^{b}

[*] Numbers followed by same letters under the same row heads in the same year are statistically nonsignificant at $\alpha = 0.05$ significant level.

3.4. Discussion

3.4.1. Effects of CA on agricultural water management

Conservation agriculture (CA) showed reductions in irrigation water use and runoff while it has increased soil water/percolation in the root zone compared with conventional tillage (CT) (Table 3-2). This was potentially due to the protection provided by the mulch cover and due to the minimum disturbance of soil by no-tillage practices. The use of mulch reduces evaporation of water from the soil (Diaz et al. 2005); reduce runoff by absorbing the energy of raindrops, and increase percolation of water by delaying runoff (Mohammed et al. 2010). No-tillage encourages less disturbances of soil pore networks that increase porosity which increases percolated water within the soil reducing runoff (Kabir et al. 2005). This water flow within the root media again encourages an improvement in soil water that reduces water stress of shallow-rooted vegetable crops (Tesfaye et al. 2011, Stroosnijder et al. 2009). Irrigation water reduction of about 15 % was also reported under CA practice compared with the CT in the dry phase of garlic production in similar location (Belay et al. 2019). In agreement with this study, Babalola et al. (2007) reported that vetiver grass mulch (2 tones ha^{-1}) has decreased runoff by 62% compared to the control (CT) while other study indicated the reduction of runoff by the use of crop residue mulches (Erenstein et al. 2002).

As discussed earlier, our objective with CA study is not only to investigate the pathways of surface water (runoff) but also to observe the water movement within the soil profile under vegetable fields. In this study, we observed increased percolated water under CA management compared with the CT, because of the use of mulch cover and no-tillage practices (Table 3-2). A continuous application of grass mulch cover prevented the formation of soil crust which contributes to the reduction in surface runoff and the increased effectiveness of the macro-porosity of the soil that enhances percolation water. Edwards. et.al. (1988) observed that large numbers of continuous macropores formed by burrowing earthworms were observed in the no-till watershed compared with tilled one, and the authors speculated that no-till contributed to high infiltration rates. Moreover, the increased grass mulch cover of no-till soil may produce a cooler and wetter environment near the soil surface which is more favorable for faunal activity (Drees et al. 1994, Pagliai et al. 1994). Less soil compaction as a result of no-tillage combined with grass mulch directly encourages faunal activities and can improve the vertical water movement within the soil structure (Blanco-Canqui et al. 2007). Besides, primary concern with CA practices is not only to investigate the pathways of surface and subsurface water over or within the soil but also to observe the quality of the dynamic water in the soils of irrigated vegetable fields. Understanding how CA and CT practices affect the movement of water, however, allows us to concentrate on the factors most likely to influence nutrient movement under supplementary irrigated farms.

3.4.2. Effects of CA on the nitrogen movement

Conservation agriculture practices reduced the concentration of NO_3-N in the leachate under vegetable production (Table 3-3), possibly due to grass mulch and no-tillage practices that allows minimum nutrient movement. More water applied in the CT during dry irrigation months has probably increased the removal of NO_3-N by leaching due to fertilizer turnover by tillage (Table 3-2). At higher crop growth stages, with increased canopy cover, the difference in the concentration of NO_3-N between the treatments was minimum (Figure 3-6). The NO_3-N flux in the root environment was greater for some weeks after transplanting while it decreased subsequently as the vegetative cover of pepper has increased. In line with this study, a study in China showed that the NO_3−N concentrations in percolated water were in a regular decreasing pattern from drier to wetter phases of irrigated straw mulched rice production (Zheng et al. 2019). Consistent result of NO_3-N load in the leachate was also reported by Govaerts et. al. (2009) in the CA experiment conducted in Mexico. Our study results are also in line with the study in Croatia (Romic et al. 2003). In both years, the concentration of NO_3-N in runoff was lower in the CA than the CT due to various possible reasons. In the context of CA, the method of fertilizer application and soil disturbance during crop cultivation were important since Urea (46-0-0; N-P-K) fertilizer were locally applied to vegetables near the seedlings during the 1st irrigation phase. In this regard, more nutrient movement would be expected by leaching, not by runoff. This is in agreement with the result of Yadav et al (1997) which showed that 20% of NO_3-N that joins the groundwater came from the root zone for most of the crops. Another study indicated that grass mulch incorporated greater soil organic matter and NO_3-N over surface soil layers and protected it from runoff in the case of CA (Larson et al. 2019).

3.4.3 Effects of CA on phosphorus movement

In CA treatment, PO_4-P concentration (mg l^{-1}) and load (g ha^{-1}) were increased in the leachate and decreased in runoff compared with the CT treatment (Table 3-4). The higher PO_4-P concentrations in the leachate may be attributed to its subsequent accumulation in the lower layers due to the higher water movement in the soil layer under CA practices. No-tillage combined with mulch, in general, is characterized by a higher phosphorus content in surface soil profile which contributed to phosphorus dynamics within the soil layers compared to CT. Similar results have been also reported by Ben-Gal and Dudley (2003). Higher total phosphorus content was also reported in the soil surface layers under no-tillage compared to CT (Bollinger et al. 2006). The higher result in no-tillage is mainly due to minimum soil disturbance, allowing the accumulation of phosphorus fertilizer applied, and the phosphorus of mulch or crop residues added through time Tiecher et al. 2012, Redel et al. 2007). No-tillage combined with grass mulch practices are also suitable for the transformation of inorganic phosphorus (P) added through fertilizer into organic forms, increasing biological P reactions in the soil surface layer (dos santos Rheinheimer et al. 2003). PO_4-P concentration showed decreasing from initial crop stage to harvest in which case the concentration at each observation date was higher for CA compared with the CT (Figure 3-7). PO_4-P concentration decreased from dry irrigation phase to wet rainy period where rainfall was in excess. The reason for this may be the increase in nutrient uptake by the crop and the cumulative removal of PO_4-P by runoff and leachate. Phosphorus is organic mulch dependent to be available to plants and moisture dependent to be leached down forming iron and aluminum compounds (Ravinderkumar et al. 1998).

3.4.4. Effects of CA on pepper yield

Conservation agriculture, apart from numerous other advantages, improved yield and the early maturity of pepper compared with conventional tillage treatment (Figure 3-5), which is consistent with the result of Ravinderkumar et. al. (1998) which showed the application of organic mulches resulted in the flowering of tomatoes in fewer days after transplanting compared with the control management. In both years of this study, most of the initial and development stages of pepper were sufficiently supported by irrigation and fruit filing stages supported by rainfall in both treatments. However, the yield return achieved in CA treatment for 2018 and 2019 years was higher compared with CT. The yield variation between the treatments was caused by the conducive soil moisture availability under CA management due to the use of grass mulch and minimum soil disturbance, particularly at the initial and development stages during the dry phase. This is attributed to the fact that conservation agriculture increases the availability of nutrients to the soil and this enhances nutrient uptake in plant tissues (Sharma, 2002).

In 2019, the yield of pepper was lower than the yield in 2018 which may be attributed to the period of transplanting of pepper relative to the rainfall onset. In 2019, transplanting was conducted one week later than in 2018, and received more rainfall and was exposed to over-watering during the fruit filing stage. As the results in section 3.1 indicate, the contribution of irrigation was higher in 2018 (46% for CA and 56% for CT) compared with 2019 (35% for CA and 37% for CT) for both treatments. In agreement with this study, Jaimez et al. (2000) revealed that a water deficit and overwatering during the period of flowering, and fruit development stages reduced pepper fruit production. The authors, in addition, concluded that transplanting of pepper about 2 months before the rainy season can improve the yield since the rain season coincides with flowering and fruit development stages (Wale et al. 2019). Conversely, these stages are also critical and water availability in the root zone in the dry phase is essential to avoid a significant decrease in fruit production, which was maintained by CA practices in this study. It has been observed that under CA practice, 20–40 mm additional water has been stored in the root zone, especially in the lower root-soil layers. Wale et. al. (2019) also noted that the optimum crop water requirement of green pepper lies between 300 mm and 700 mm depending on the climatic condition.

3.5. Conclusions

In this study, we found that conservation agriculture (CA) practices reduced irrigation water, reduced runoff and the associated nitrogen concentration while it increased the leachate and associated phosphorus dynamics in the root zone. The average of the two years indicated that 40% lower runoff, 27% higher percolation, 29% lower N-concentration in the leach, and 101% lower N-concentration in runoff were attained under conservation agriculture management compared with conventional tillage. Correspondingly, 29% higher phosphorus concentration in the leachate and 17% lower phosphorus concentration in runoff were found under conservation agriculture. While nitrogen dynamics out of the root zone indicated a decreasing rate with time, phosphorus concentration showed increasing for both treatments. The response of runoff, leachate, yield and nutrient dynamics to conservation agriculture as provided in this paper gives a first indication of what can be done to increase water productivity and the potential gains that can be achieved through certain combinations of practices. Eventually, inorganic N-fertilizers applied in-situ is highly open to the leach losses compared to the losses under runoff. This suggests that when CA practices are in place, fertilizer application should be based on the soil balance considering the available phosphorus in the soil.

References

Aliyu, L., 2000. Effect of organic and mineral fertilizers on growth, yield and composition of pepper (Capsicum annuum L.). Biol. Agric. Hortic., 18, 29–36.

Allen, R.; Pereira, L.; Raes, D.; Smith, M., 1998. Guidelines for Computing Crop Water Requirements; FAO Irrigation and Drainage Paper 56; FAO-Food and Agriculture Organisation of the United Nations: Rome, Italy,. Available online: http://www.fao.org/docrep (accessed on 3/162020).

Araya, T.; Cornelis, W.M.; Nyssen, J.; Govaerts, B.; Gebregziabher, T.; Oicha, T.; Getnet, F.; Raes, D.; Haile, M.; Sayre, K.D.,2010. Impact of Conservation Agriculture on Runoff, Soil Loss and Crop Yield on a Vertisol in the Northern Ethiopian Highlands. In Proceedings of 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia, August 2010.

Assefa, T.; Jha, M.; Reyes, M.; Srinivasan, R.; Worqlul, A.W., 2018. Assessment of suitable areas for home gardens for irrigation potential, water availability, and water-lifting technologies. Water 2018, 10, 495.

Assefa, T.; Jha, M.; Reyes, M.; Tilahun, S.; Worqlul, A.W., 2019. Experimental evaluation of conservation agriculture with drip irrigation for water productivity in Sub-Saharan Africa. Water, 11, 530.

Assefa, T.; Jha, M.; Reyes, M.; Worqlul, A., 2018. Modeling the impacts of conservation agriculture with a drip irrigation system on the hydrology and water management in Sub-Saharan Africa. Sustainability, 10, 4763.

Assefa, T.T., 2018. Experimental and Modeling Evaluation of Conservation Agriculture with Drip Irrigation for Small-Scale Agriculture in Sub-Saharan Africa. North. Ph.D. Thesis, Carolina Agricultural and Technical State University, Greensboro, NC, USA.

Babalola, O.; Oshunsanya, S.; Are, K., 2007. Effects of vetiver grass (Vetiveria nigritana) strips, vetiver grass mulch and an organomineral fertilizer on soil, water and nutrient losses and maize (Zea mays L) yields. Soil Tillage Res., 96, 6–18.

Bekele, S.; Tilahun, K., 2009. Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. Agric. Water Manag., 89, 148–152.

Belay, S.A.; Schmitter, P.; Worqlul, A.W.; Steenhuis, T.S.; Reyes, M.R.; Tilahun, S.A., 2019. Conservation agriculture saves irrigation water in the dry monsoon phase in the Ethiopian highlands. Water, 11, 2103.

Ben-Gal, A.; Dudley, L.M., 2003. Phosphorus availability under continuous point source irrigation. Soil Sci. Soc. Am. J., 67, 1449–1456.

Blanco-Canqui, H.; Lal, R., 2007. Regional assessment of soil compaction and structural properties under no-tillage farming. Soil Sci. Soc. Am. J., 71, 1770–1778.

Bolliger, A.; Magid, J.; Amado, J.C.T.; Neto, F.S.; dos Santos Ribeiro, M.D.F.; Calegari, A.; Ralisch, R.; de Neergaard, A., 2006. Taking stock of the Brazilian “zero-till revolution”: A review of landmark research and farmers’ practice. Adv. Agron., 91, 47–110.

Bosch, D.D.; Potter, T.L.; Truman, C.C.; Bednarz, C.W.; Strickland, T.C., 2005. Surface runoff and lateral subsurface flow as a response to conservation tillage and soil-water conditions. Trans. ASAE, 48, 2137–2144.

Bot, A.; Benites, J., 2005. The Importance of Soil Organic Matter: Key to Drought-Resistant Soil and Sustained Food Production; Food and Agriculture Organization of the United Nations: Rome, Italy.

Carpenter, S.R.; Caraco, N.F.; Correll, D.L.; Howarth, R.W.; Sharpley, A.N.; Smith, V.H., 1998. Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecol. Appl., 8, 559–568.

Diaz, F.; Jimenez, C.C.; Tejedor, M., 2005. Influence of the thickness and grain size of tephra mulch on soil water evaporation. Agric. Water Manag., 74, 47–55.

dos Santos Rheinheimer, D.; Anghinoni, I., 2003. Accumulation of soil organic phosphorus by soil tillage and cropping systems under subtropical conditions. Commun. Soil Sci. Plant Anal., 34, 2339–2354.

Drees, L.R.; Karathanasis, A.D.; Wilding, L.P.; Blevins, R.L., 1994. Micromorphological characteristics of long-term no-till and conventionally tilled soils. Soil Sci. Soc. Am. J., 58, 508–517.

Edwards, W.M.; Norton, L.D.; Redmond, C.E., 1988. Characterizing macropores that affect infiltration into non-tilled soil. Soil Sci. Soc. Am. J., 52, 483–487.

Erenstein, O., 2002. Crop residue mulching in tropical and semi-tropical countries: An evaluation of residue availability and other technological implications. Soil Tillage Res., 67, 115–133.

Ghosh, B.N.; Dogra, P.; Sharma, N.K.; Bhattacharyya, R.; Mishra, P.K., 2015. Conservation agriculture impact for soil conservation in maize-wheat cropping system in the Indian sub-Himalayas. Int. Soil Water Conserv. Res., 3, 112–118.

Giller, K.E.; Corbeels, M.; Nyamangara, J.; Triomphe, B.; Affholder, F.; Scopel, E.; Tittonell, P., 2011. A research agenda to explore the role of conservation agriculture in African smallholder farming systems. Field Crops Res., 124, 468–472.

Govaerts, B.; Sayre, K.D.; Goudeseune, B.; De Corte, P.; Lichter, K.; Dendooven, L.; Deckers, J., 2009. Conservation agriculture as a sustainable option for the central Mexican highlands. Soil Tillage Res., 103, 222–230.

Grandy, A.S.; Loecke, T.D.; Parr, S.; Robertson, G.P., 2006. Long-term trends in nitrous oxide emissions, soil nitrogen, and crop yields of till and no-till cropping systems. J. Environ. Qual., 35, 1487–1495.

Heathwaite, A.L.; Johnes, P.J., 1996. Contribution of nitrogen species and phosphorus fractions to stream water quality in agricultural catchments. Hydrol. Process., 10, 971–983.

Jaimez, R.; Vielma, O.; Rada, F.; García-Núñez, C., 2000. Effects of water deficit on the dynamics of flowering and fruit production in Capsicum chinense Jacq in a tropical semiarid region of Venezuela. J. Agron. Crop Sci., 185, 113–119.

Jarque, C.M.; Bera, A.K., 1980. Efficient tests for normality, homoscedasticity and serial independence of regression residuals. Econ. Lett., 6, 255–259.

Kabir, Z., 2005. Tillage or no-tillage: Impact on mycorrhizae. Can. J. Plant Sci., 85, 23–29.

Kresović, B.; Tapanarova, A.; Tomić, Z.; Životić, L.; Vujović, D.; Sredojević, Z.; Gajić, B., 2016. Grain yield and water use efficiency of maize as influenced by different irrigation regimes through sprinkler irrigation under temperate climate. Agric. Water Manag., 169, 34–43.

Lal Bhardwaj, R., 2013. Effect of mulching on crop production under rainfed condition—A review. Agric. Rev., 34, 188–197.

Lanckriet, S.; Araya, T.; Cornelis, W.; Verfaillie, E.; Poesen, J.; Govaerts, B.; Bauer, H.; Deckers, J.; Haile, M.; Nyssen, J., 2012. Impact of conservation agriculture on catchment runoff and soil loss under changing climate conditions in May Zeg-zeg (Ethiopia). J. Hydrol., 475, 336–349.

Larsson, A., 2019. The Effect of Agricultural Intensification on Nitrate Concentrations in Shallow Groundwater in Two Watersheds in Ethiopia. Thesis Report, Uppsala Universitet, Uppsala, Sweden.

Logan, T.J., 1993. Agricultural best management practices for water pollution control: Current issues. Agric. Ecosyst. Environ., 46, 223–231.

Matson, P.A.; Parton, W.J.; Power, A.G.; Swift, M.J., 1997. Agricultural intensification and ecosystem properties. Science, 277, 504–509.

Mohammad, A.G.; Adam, M.A., 2010. The impact of vegetative cover type on runoff and soil erosion under different land uses. Catena, 81, 97–103.

Pagliai, M.; Raglione, M.; Panini, T.; Maletta, M.; La Marca, M., 1994. The structure of two alluvial soils in Italy after 10 years of conventional and minimum tillage. Soil Tillage Res., 34, 209–223.

Pretty, J.; Toulmin, C.; Williams, S., 2011. Sustainable intensification in African agriculture. Int. J. Agric. Sustain., 9, 5–24.

Radford, B.J.; Thornton, C.M., 2011. Effects of 27 years of reduced tillage practices on soil properties and crop performance in the semi-arid subtropics of Australia. Int. J. Energy Environ. Econ., 19, 565.

Ravinderkumar, S., 1998. Influence of different mulches on flowering an fruit setting of winter tomato. Crop Res., 12, 174–176.

Redel, Y.D.; Rubio, R.; Rouanet, J.L.; Borie, F., 2007. Phosphorus bioavailability affected by tillage and crop rotation on a Chilean volcanic derived Ultisol. Geoderma, 139, 388–396.

Rockström, J., 1999. On-farm green water estimates as a tool for increased food production in water scarce regions. Phys. Chem. Earth Part B Hydrol. Oceans Atmos., 24, 375–383.

Rockström, J.; Kaumbutho, P.; Mwalley, J.; Nzabi, A.; Temesgen, M.; Mawenya, L.; Barron, J.; Mutua, J.; Damgaard-Larsen, S., 2009. Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research. Soil Tillage Res., 103, 23–32.

Romic, D.; Romic, M.; Borosic, J.; Poljak, M., 2003. Mulching decreases nitrate leaching in bell pepper (Capsicum annuum L.) cultivation. Agric. Water Manag., 60, 87–97.

Sharma, S.N.,2002. Nitrogen management in relation to wheat (Triticumaestivum) residue management in rice (Oryza sativa). Indian journal of agricultural science, 72(8): 449- 452

Stroosnijder, L., 2009. Modifying land management in order to improve efficiency of rainwater use in the African highlands. Soil Tillage Res., 103, 247–256.

Tesfaye, A.; Cornelis, W.M.; Nyssen, J.; Govaerts, B.; Bauer, H.; Gebregziabher, T.; Oicha, T.; Rates, D.; Sayre, K.D.; Haile, M., 2011. Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia. Soil Use Manag., 27, 404–414.

Thierfelder, C.; Wall, P.C., 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil Tillage Res., 105, 217–227.

Tiecher, T.; dos Santos, D.R.; Calegari, A., 2012. Soil organic phosphorus forms under different soil management systems and winter crops, in a long-term experiment. Soil Tillage Res., 124, 57–67.

Tomer, M.; Moorman, T.; Kovar, J.; Cole, K.; Nichols, D., 2016. Eleven years of runoff and phosphorus losses from two fields with and without manure application, Iowa, USA. Agric. Water Manag., 168, 104–111.

Wale, A.; Girmay, G., 2019. Determination of irrigation regime for hot pepper (Capsicum annum L.) in dry-land areas of Wag-Himra, North Eastern Amhara, Ethiopia. Arch. Agric. Environ. Sci., 4, 101–108.

Yadav, S.N., 1997. Formulation and estimation of nitrate-nitrogen leaching from corn cultivation. J. Environ. Qual., 26, 808–814.

Zheng, C.; Zhang, Z.; Wu, Y.; Mwiya, R., 2019. Response of vertical migration and leaching of nitrogen in percolation water of paddy fields under water-saving irrigation and straw return conditions. Water, 11, 868.

CHAPTER 4

EFFECT OF CONSERVATION AGRICULTURE ON SOIL NUTRIENT CONTENT AND ORGANIC MATTER UNDER VEGETABLE PRODUCTION IN THE ETHIOPIAN HIGHLAND[3]

Abstract: Agriculture in Africa is adversely affected by the loss of soil fertility. Conservation agriculture (CA) was introduced to curb the loss of soil fertility, water shortages, and decrease in crop productivity. However, information is scarce in the sub-Saharan Africa context on how CA practices enhance soil quality and nutrients. The objective was to investigate the effects of CA compared to conventional tillage (CT). A four-year CA experiment was carried out during the dry and wet monsoon phases in the northern Ethiopian highlands on vegetable farms under both rainfed and irrigated conditions. The average OM after 4 years in the CA was 13% greater than the CT for the 0-30 cm depth while it was 16% higher in the CA when compared with the CT in the 30-60 cm soil depth. The average TN concentration in CA was 0.25% in the top 30 cm soil depth while it was 0.22% for CT, which showed about 14% increment in the CA over the CT practice. Besides, the difference between treatments was also significant ($p<0.05$) after 4th production period. The average available P in the CA was 19 % greater than the CT for the top 30 cm soil and 35 % greater in the CA in the 30-60 cm soil depth. The increase in OM, TN and P in the CA was attributed to the incorporation of grass mulch combined with cattle manure, fertilizer, and no-tillage practices.

Keywords: Irrigated agriculture, conservation agriculture, organic matter, soil nutrients, Ethiopian highlands.

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4.1 Introduction

Agriculture in sub-Saharan Africa and particularly in the Ethiopian Highlands has been hampered by the loss of soil fertility and failure to replenish critical nutrients (Giller et al. 2009). Conventional tillage (CT) practices with the Marisha plow are common in the Ethiopian highlands under irrigated and rainfed conditions and have resulted in land degradation and declined soil quality despite fertilizer application (Assefa et al. 2020, Assefa et al. 2018). As a result, nutrients have reduced in the soil profile (Araya et al. 2011, Bationo et al. 2007), especially in high rainfall areas (Nyssen et al. 2005) and in the northern parts of Ethiopia where the population pressure is the greatest (Berakhi et al. 1998, Assefa et al. 2018a). The rise in population has led to smaller land sizes decreasing the food production per family (Gebre-Selassie et al. 2012). The removal of crop residues from the fields (for fuel, fodder, construction materials) coupled with a lack of minor macronutrient replacement decreases plant nutrients (Solomon et al. 2002a). Moreover, irrigated vegetable fields are most susceptible to nutrient depletion because the whole plant is harvested, and no residue is left on the farm.

Nitrogen and phosphorus are the most common limiting macronutrients in the soil for plant growth (Khosla et al. 2002, Gupta and Khosla, 2012, Assefa et al. 2020), which are lost by erosion, runoff, and leaching, and removal of crop residual (Solomon et al. 2002b). The addition of organic matter as compost, crop residues, or other organic mulches facilitates the release of nutrients to the soil for plant uptake (Richardson and Simpson, 2011). The use of organic mulch cover and no-tillage practice with proper crop rotations is called conservation agriculture (Belay et al. 2019, Assefa et al. 2020). Conservation Agriculture (CA) improves soil organic matter and consequently soil fertility through biological processes (Limon-Ortega et al. 2000), water and crop productivity (Assefa et al. 2020, Belay et al. 2019, Belay et al. 2020, Nyborg et al. 1995), and environmental sustainability such as reducing soil erosion, groundwater contamination, and greenhouse gases (Giller et al. 2011, Kassam et al. 2009). Consequently, CA is proposed as a practical solution and has been adopted recently in the northern Ethiopian highlands (Assefa et al. 2018b, Lanckriet et al. 2012, Assefa et al. 2018, Vanlauwe et al. 2014).

While CA practice is effective in increasing soil fertility and crop productivity (Assefa et al. 2020, Belay et al. 2019, Belay et al. 2020) and decreasing fertilizer input, labor, and energy costs (Vanlauwe et al. 2014, Pimentel, 2006, Sartori et al. 2005), successful implication requires that the practice is integrated with local indigenous practices (Erenstein, 2003). The suitability and adoption of CA technology in one place does not necessarily imply its adoption elsewhere. Besides, the potential benefits of CA practices have only been evaluated by one or two-year-long experiments and biophysical modeling (Assefa et al. 2018, Assefa et al. 2019, Belay et al. 2020, Yimam et al. 2020, and Belay et al. 2019). Therefore, the impact of CA on soil organic matter and macro-nutrients should be quantified over a relatively more extended period by farmers in their fields.

Therefore, the objective of this research was to quantify changes in soil organic matter and nutrients in on-farm irrigated and rainfed vegetable production. Hence, an experiment was carried on ten vegetable farms in Dengeshita in the northern Ethiopian Highlands to characterize the physical and chemical soil characteristics during a 4-year long study of rainfed and irrigated conservation agriculture conventional tillage

4.2 Materials and Methods

4.2.1 Site Description

The experimental plots in this study before the experiment were mainly used for growing corn in the rainy season (rainfed system). Irrigation was not practiced on the study plots before the experiment. Details about the location and study area description are described in chapter 2.

4.2.2 Experimental Method and field Layout

Ten on-farm fields with a size of 10 x 10 m^2 were established across the study site to conduct this research on irrigated CA during the dry and wet monsoon season starting from October 2016 to August 2019 (Figure 4-1). The texture of the top 30 cm soil depth was a loam soil and inter-plot variation was insignificant. The texture of the 30–60 cm soil layer was generally a clay loam (39% sand, 27% silt, and 35% clay) and, in some plots, the soil texture consisted of sandy loam. Detail initial soil properties as baseline data collected in 2016 are shown in Table 4-1.

The soil was slightly acidic with a pH level of 6. Field capacity, permanent wilting point, bulk density, total nitrogen (N), available phosphorus (P) and potassium (K) in the top 30 cm layer were 0.31 cm^3 cm^{-3}, 0.22 cm^3 cm^{-3}, 1.32 g cm^{-3}, 0.93 g kg^{-1}, 9.57 mg kg^{-1} and 191 mg kg^{-1}, respectively.

Table 4- 1: Average Soil characteristics (mean±standard deviation) at the beginning of the experiment (samples collected on 11 Nov 2016 from 10 replicates) for two soil depths at 0-30 cm and 30-60 cm.

Soil characteristics	Mean±St.Dev 0-30	Mean±St.Dev 30-60	p-values (α=0.05)*
Bulk density (g cc^{-1})	1.14±0.10	1.22±0.13	0.050^{s}
pH (H_2O,1:2.5)	6.0±0.64	5.8±0.63	0.097
Electrical conductivity-EC (dS m^{-1})**	1.13±0.12	0.09±0.05	0.097
Cation exchange capacity-CEC(meq kg^{-1})	24.0±4.0	25.3±4.5	0.252
Available potassium (mg kg^{-1})	1114±566	792±541	0.017^{s}
Available phosphorus (mg kg^{-1})	21.2±12.3	8.5±4.8	0.002^{s}
Total nitrogen (%)	0.17±0.05	0.17±0.06	0.493
Organic matter (%)	3.18±0.91	3.08±1.06	0.414
Organic carbon (%)	1.84±0.53	1.79±0.62	0.414
Field capacity (%)	31.4±3.9	28.8±2.8	0.005^{s}
Permanent wilting point (%)	22.2±3.6	21.6±1.93	0.264
Texture			
Sand (%)	38.5±16.5	21.6±10.1	0.003^{s}
Silt (%)	26.7±4.5	24.8±4.3	0.179
Clay (%)	34.8±16.9	53.6±14.2	0.003^{s}

* The superscript s indicates a significant (at a 5% probability) between the two soil layers. ** Slightly saline

Conservation agriculture (CA) versus conventional tillage (CT) treatments were compared in paired t-test using the experimental design setup (Figure 4-1). The CA as treatment consisted of no-tillage and application of grass mulch, while CT as control consisted of existing farmer practice of 4 to 6 tillage frequencies (tillage depth between 15-25 cm) and no grass mulch cover. During the dry phase (October to February), both CA and CT treatments were irrigated. From March to August, all practices were the same except that irrigation was from March to the onset of rainfall or wet period. The crop rotation (Table 4-2) was similar in both CA and CT treatments.

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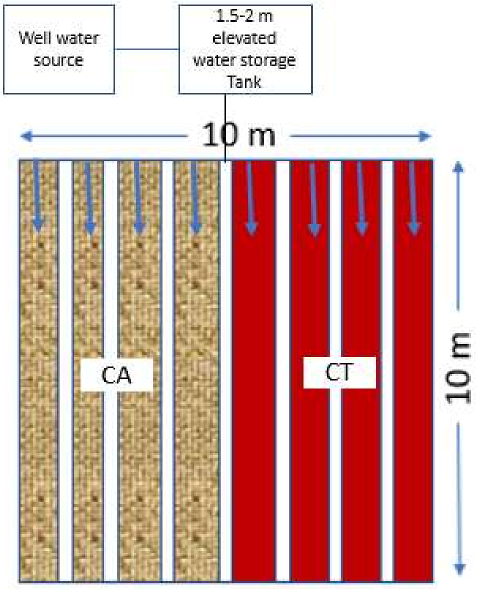


Figure 4- 1: Experimental design layout for conservation agriculture (CA) and conventional tillage (CT) and irrigation water access.

The CA and CT treatments were carried out on each of the 10 field which were randomly selected at the beginning of the experiment. Besides, half (50 m^2) of the field was randomly assigned for CA and half for CT (Figure 4-2). The crop rotation was onion-pepper-garlic-pepper-onion-pepper-onion-pepper (Table 4-2). The onion crop was grown in 2016/2017 and 2018/2019 periods; garlic in 2017/2018. Both were grown during the dry season using irrigation. Pepper was grown as a rainfed crop with supplementary irrigation. A watering can during the first one and half years, and drip irrigation was used for the remaining two and half years (pepper-onion-pepper-onion-pepper) (Table 4-2).

Fertilizer application consisted of 200 kg ha^{-1} of Urea (46-0-0) for both CA and CT and was based on the local management practices (Table 2). Local grass species called 'Tucha' (Pennisetum macrourum Trin.) harvested before seed setingwasused as mulch. The nutrient content of local grass and cattle manure was analyzed in a soil laboratory. Local grass (85% organic matter; 0.18% total N; and 17 ppm available P) was applied at the rate of 2 Mg ha^{-1} as mulch cover for only CA treatment twice per cropping period (8 t ha^{-1} yr^{-1}) throughout the four-year experimental period(Table 2). Cow manure (42% organic matter; 2.1% total N; and 82 ppm available P) was applied at the rate of 5 t ha^{-1} uniformly in both treatments at the end of the first season harvest each year. Onion and garlic were harvested in February or March and pepper in July or August (Table 4-2),. The vegetable yield was weighed for each plot.

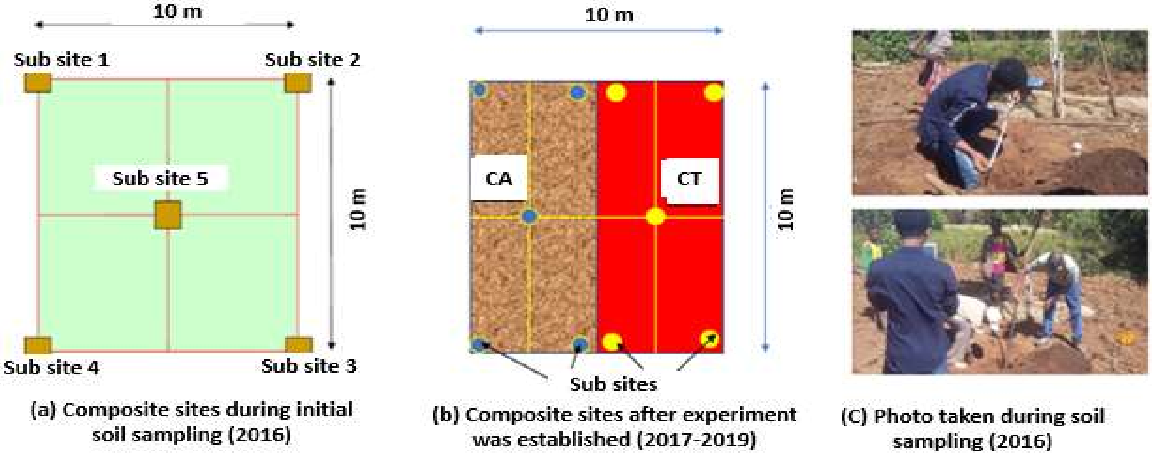
Table 4- 2: Schedule of farm operations, crops grown from soil sampling dates for continuous irrigated and rainfed from 2016 to 2020. The crop varieties grown were Adama Red Onion (*Allium cepa L.*), Local variety garlic (*Allium Sativium L.*), and local variety Mareko pepper (*Capsicum annuum L.*).

Crop Rotation		Tillage	Transplanting	Fertilizer application	Mulch application	Harvesting	Soil sampling	Manure application
Onion 2016/2017	Date	9/25/2016-3/30/2016	12/20/2016	12/25/2016	01/05/2017	3/22/2018	3/25/2017	3/25/2017
	Amount (kg/ha)	-	-	200	4000	-	-	5000
Pepper 2017	Date	2/20/2017-4/25/2017	05/01/2017	-	05/01/2017	7/10/2017-8/10/2017	08/10/2017	
	Amount (kg/ha)	-	-		4000	-	-	
Garlic 2017/2018	Date	10/18/2017	10/27/2017	10/27/2017	15/27/2017	2/26/2018	2/26/2018	2/27/2018
	Amount (kg/ha)	-	-	200	4000	-	-	5000
Pepper 2018	Date	2/10-20/2018	3/13/2018	03/12/2018	07/05/2018	6/1/2018-8/25/2018	8/25/2018	
	Amount (kg/ha)	-	-	100	4000	-	-	
Onion 2018/2019	Date	10/10-20/2018	10/27/2018	10/27/2018	11/05/2018	02/02/2019	02/02/2019	02/05/2019
	Amount (kg/ha)	-	-	200	4000	-	-	5000
Pepper 2019	Date	2/10-20/2019	3/02/2019	3/02/2019	7/15/2019	6/20/2019	-	-
	Amount (kg/ha)	-	-	200	4000	-	-	5000
Onion 2019/2020	Date	02/10-20/2019	03/11/2019	03/11/2019	07/15/2019	6/20/2019	-	-
	Amount (kg/ha)	-	-	200	4000	-	-	5000
Pepper 2020	Date	2/15-25/2020	3/25/2020	6/30/20	04/05/2020	6/15/2020-8/25/2020	8/25/2020	-
	Amount (kg/ha)	-	-	100	4000	-	-	

4.2.3 Soil Sampling and Analytic Methods

Soil samples were collected six times: at the beginning of the experiment, after the first five harvests and then at the end of the experiment in 2020 (Table 4-2). Two soil depths were sampled: the top 0-30 cm, and subsoil in 30-60 cm. These two layers were selected purposefully to investigate the impacts of CA and CT management practices on shallow rooted vegetables and the water nutrient interactions in the 0-30 cm lay, and deeper rooted cereal crops. The top 25-30 cm depth of soil is a plow layer (Tripathi et al., 1997) which was used to differentiate the tilled and no-tilled experiments in this study. The effective root zone for most of the local vegetable varieties here used, such as garlic and onion lies within top 30cm while for cereals such as maize and millet reaches up to 60 cm. Based on detailed field observation, composite samples were made by mixing 5 sub-samples from the same treatment as shown in Figure 4-2. Composite sampling was made from soil layers (0-30 and 30-60 cm) to get the average soil properties of the entire profile. About 1 kg of the composite soil sample was prepared for analysis of physical and chemical properties.

To determine bulk density, a cylinder, drop-hammer core sampler with a 5 cm height and 5 cm diameter was driven into the soil with a hammer. The core sampler was driven at 20 cm depth for the upper 0-30 cm soil layer, and at 40 cm depth for the next 30 cm layer. The cylinder containing an undisturbed soil core was then removed and trimmed. The weight of the soil core was then determined after drying in an oven at 105°C for about 24 hours (O'Kelly, 2004).



(a) Composite sites during initial soil sampling (2016)
(b) Composite sites after experiment was established (2017-2019)
(C) Photo taken during soil sampling (2016)

Figure 4- 2: Composite Soil sampling techniques before (a) and after (b) experiment at two soil layers (0-30 cm and 30-60 cm) under CA and CT subplots conducted at 10-replicated sites

Soil samples were air-dried, sieved by a 2 mm sieve, and analyzed using standard laboratory procedures. The major soil properties include pH (H_2O), cation exchange capacity (CEC) in cmol (+) kg^{-1}, available P (mg kg^{-1}), available K (g kg^{-1}), total N (g kg^{-1}), field capacity (m^3 m^{-3}), permanent wilting point (m^3 m^{-3}), clay (g kg^{-1}), silt (g kg^{-1}), and sand (g kg^{-1}). Soil pH was determined in 1:2.5 (soil: water suspension) by using a glass electrode at 25°C (at room temperature), organic carbon by wet oxidation method (Walkley and Black, 1934), and available P was extracted by Bray 2 method for acidic soils (Bray and Kurtz, 1945) and P in the extract was determined colorimetrically by spectrophotometer. Total N was determined by the Kjeldahl method as cited by Aticho et al. (2011). Available K was extracted by Morgan's solution and K in the extract measured by a flame photometer (MacDonald et al. 1978). Cation exchange capacity (CEC) was determined at pH 7 using ammonium acetate as an exchange (Rengel et al. 1989). The determination of electrical conductivity (EC) is made with a conductivity cell by measuring the electrical resistance of a 1:5 soil: water suspension by using calibration solution of 0.01 M KCl or potassium chloride (MacDonald et al. 1978).

Field capacity and permanent wilting point were determined in the laboratory using a pressure plate apparatus by applying 33 kPa pressure to a saturated soil sample for field capacity and applying 1500 kPa pressure to determine the permanent wilting point. When water was no longer leaving the soil sample at these suction pressures, the soil moisture in the sample was determined gravimetrically and equated to field capacity or permanent wilting point (Cassel et al. 1986).

2.4 Data Analysis

The treatment means were compared using a paired t-test analysis to evaluate the effects of soil management (CA and CT) on soil physical and chemical characteristics. The normality test showed that the data had a normal distribution without a logarithmic transformation. We used a trend analysis t-test to test for a significant difference between the slopes of CA and CT trend lines. The data displayed in the tables and figures are means of replicates.

4.3 Results

4.3.1 Initial Soil Characteristics

The soil was significantly more sandy for the top surface 30 cm than for the 30-60 cm soil layer (Table 4-1). Additionally, bulk density, field capacity, total N, available P, and available K were all greater initially in the surface layer than in the layer below (Table 4-1). The soil test values were within the range suitable for growing vegetables in the area (Islam et al., 1980; Alexander, 2012).

4.3.2 Effects of CA on Soil Characteristics after 3 and 4 years

Soil pH and available K concentrations were greater but not significantly under CA than the CT in both soil depths and after the third and fourth year, while the CEC increased slightly in the 0-30 cm (Figure 4-3). Compared with the CT, soil CEC in the CA was only slightly increased after the third and fourth year in the 0-30 cm soil depth and slightly decreased in the 30-60 cm soil depth after the third and fourth year (Figure 4-3b). Similarly, compared with CT, available potassium (Av. K) content in the soil under CA increased significantly ($P<0.05$) by 12% and 19% in 0-30 cm and by 67% and 62% in 30-60 cm soil depth, respectively, after 3rd and 4th-year experiment (Figure 4-3c).

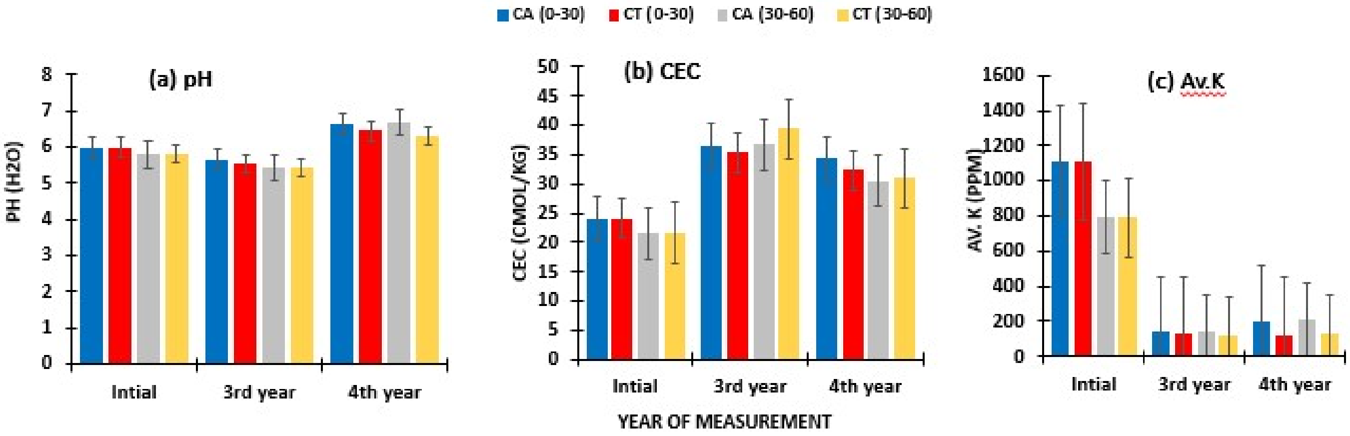


Figure 4- 3: Soil properties for the 0-30 cm and 30-60 cm depth under conservation agriculture (CA) and conservation tillage (CT) at the beginning of the experiment and in the 3rd and 4th year (a) soil pH; (b) cation exchange capacity (CEC) and (c) available K- (Av.K).

4.3.3 Organic Matter (OM)

The average OM after 4 years in the CA was 13% greater than the CT for the 0-30 cm depth while it was 16% higher in the CA when compared with the CT in the 30-60 cm soil depth (Table 4-5). Although the OM increased for both treatments with time for both soil depths, it was just not statistically significant at ($P>0.10$) (Table 4-3). In addition, the difference in slope was not significant between the two treatments (Table 4-4). The slope at the 0-30 cm depth for CA was

0.43% a^{-1}, and 0.28% a^{-1} for CT (Figure 4-4a). There was also a minor and not significant difference in slope at the 30-60 cm soil depth for CA and CT (Figure 4-4b).

Table 4- 3**:** Summary of t-test results to test the significant difference of trend slopes from zero between CA and CT treatments for the two soil depths (α=0.10)

		OM		TN		AP	
Soil depth	t-statistics	CA	CT	CA	CT	CA	CT
	Trend slope	0.62	0.42	2.72	2.27	4.4	4.1
0-30	p-value	0.21	0.25	0.072*	0.098*	0.022**	0.028**
	Trend slope	0.46	0.27	2.11	1.44	2.25	3.15
30-60 cm	p-value	0.39	0.52	0.125	0.25	0.095*	0.051*

*significant at 10% risk; **

Table 4- 4**:** Summary of t-test results to test the significant differences between slopes of trend lines of CA and CT treatments for the two soil depths (α=0.10)

Solid depth	Trend slope difference (CA-CT)	p-value	significant level	lower confidence limt	upper confidence limt
Organic matter (%)					
0-30	0.2	0.38	1.94	-0.26	-0.46
30-60	0.19	0.39	1.94	1.5	1.37
Total nitrogen (%)					
0-30	0.019	0.23	1.94	0.007	0.076
30-60	0.0152	0.218	1.94	0.0088	0.0607
Available phosphorus (mg/kg)					
0-30	1.86	0.27	1.94	3.37	0.63
30-60	0.6	0.42	1.94	10.45	9.3

The increase in organic matter content in the top 20 or 30 cm soil under conservation tillage with increased plant residues compared with CT is consistent with findings of Benbi et al. (2010). Rasmussen (1999),Johnson et al. (2007), Roldán et al. (2003), Alvear et al. (2005) and Campell et al (1999). The OM contents were less at the end of the rain season when peppers were grown than at harvest time of crops grown with irrigation during the dry season, which could be partly caused by the loss of topsoil due to erosion during the intense monsoon storms (Shi and Schulin, 2018)

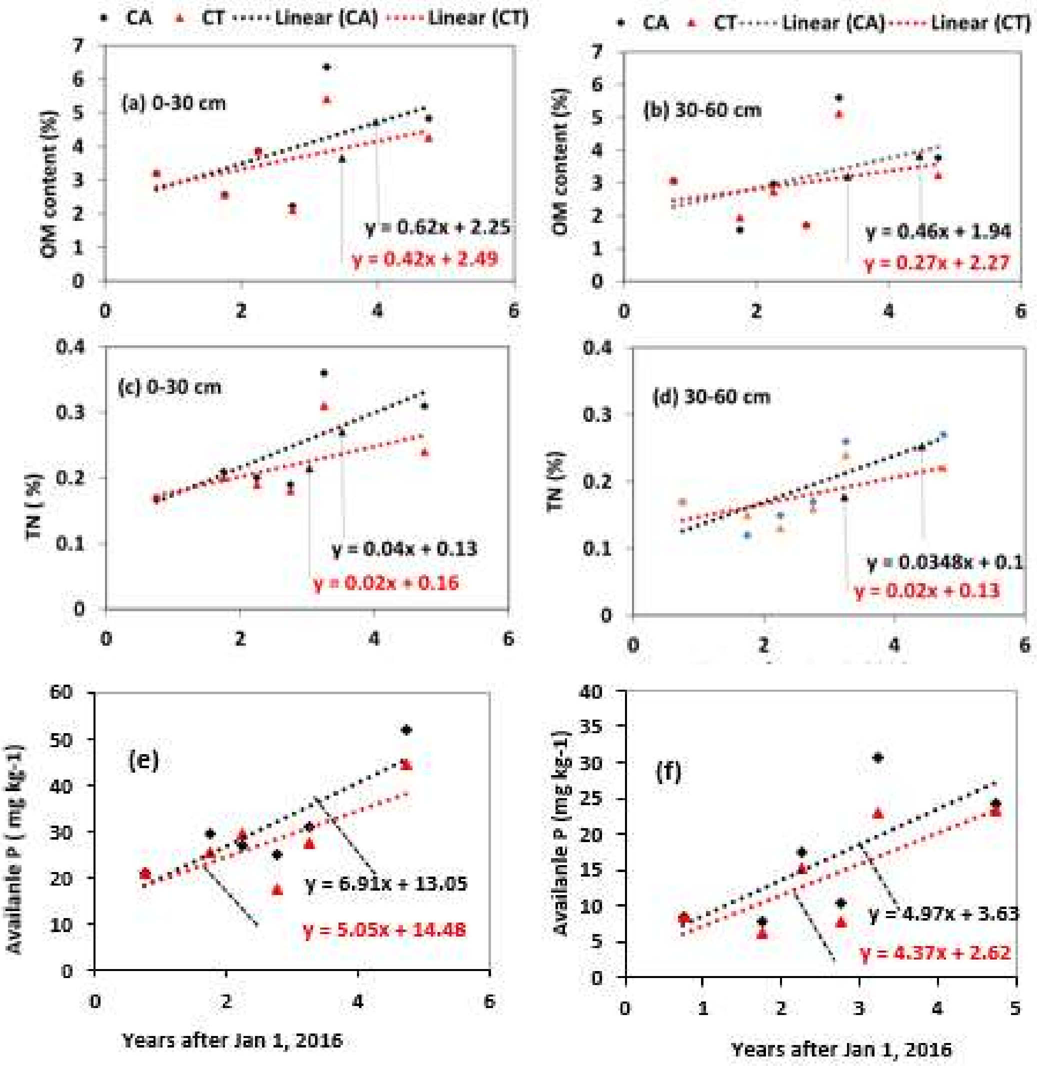


Figure 4- 4: Trends of organic matter-OM in 0-30 cm soil depth (a) and 30-60 cm soil depth (b), Trends of Total Nitrogen-TN in 0-30 cm soil depth (c) and 30-60 cm soil depth (d), Trends of available P in 0-30 cm soil depth (a) and 30-60 cm soil depth (b)under CA and CT treatments and shown in years after January 1, 2016 (beginning of the experiment).

Table 4- 5: Organic matter content(OM), total nitrogen concentration (TN), and available phosphorus (P) in the 0-30 cm and 30-60 cm soil depths under conservation agriculture (CA) and conventional tillage (CT) treatments for a four-year on-farm' experiment in the sub-humid Ethiopian highlands.

Vegetable	Year (Irrigated or	0-30 cm		30-60 cm	
		CA	CT	CA	CT
Organic matter content (%)					
	2016 (Initial)	3.18 ± 0.92	3.18 ± 0.92	3.08 ± 1.10	3.08 ± 1.10
Pepper	2017 (wet)	2.58 ± 0.81^{a}	2.56 ± 0.68^{a}	1.57 ± 0.32^{a}	1.95 ± 0.61^{a}
Garlic	2017/2018	3.89 ± 1.28^{a}	3.86 ± 0.98^{a}	2.97 ± 1.09^{a}	2.74 ± 0.50^{a}
Pepper	2018 (wet)	2.24 ± 0.84^{a}	2.11 ± 0.85^{a}	1.71 ± 0.56^{a}	1.73 ± 0.59^{a}
Onion	2018/2019	6.37 ± 2.93^{a}	5.41 ± 2.99^{b}	5.61 ± 1.79^{a}	5.13 ± 2.54^{a}
pepper	2020 (wet)	4.83 ± 0.09^{a}	4.26 ± 0.57^{b}	3.77 ± 0.76^{a}	3.24 ± 0.73^{a}
	Mean	3.98 ± 1.19^{a}	3.64 ± 1.21^{b}	3.13 ± 0.90^{a}	2.96 ± 0.99^{a}
4-Years changes (%)*		25.2^{a}	14.5^{b}	1.49^{a}	-3.96^{b}
Total nitrogen (%)					
	2016 (Initial)	0.17 ± 0.05	0.17 ± 0.05	0.17 ± 0.06	0.17 ± 0.06
Pepper	2017 (wet)	0.21 ± 0.06^{a}	0.20 ±0.05^{a}	0.12 ± 0.03^{a}	0.15 ± 0.04^{a}
Garlic	2017/2018	0.20 ± 0.06^{a}	0.19 ± 0.05^{a}	0.15 ± 0.05^{a}	0.13 ± 0.02^{a}
Pepper	2018 (wet)	0.19 ± 0.07^{a}	0.18 ± 0.08^{a}	0.17 ± 0.03^{a}	0.16 ± 0.05^{a}
Onion	2018/2019	0.36 ± 0.16^{a}	0.31 ± 0.14^{b}	0.26 ± 0.10^{a}	0.24±0.14^{a}
pepper	2020 (wet)	0.31 ± 0.03^{a}	0.24 ± 0.06^{b}	0.27 ± 0.04^{a}	0.22 ± 0.04^{b}
	Mean	0.25 ± 0.08^{a}	0.22 ± 0.08^{b}	0.19 ± 0.05^{a}	0.18 ± 0.06^{a}
4-Years changes (%)*		25.2^{a}	49^{a}	32^{b}	14^{a}
Available phosphorus (mg kg^{-1})					
	2016 (Initial)	21.2 ± 12.3	21.2± 12.3	8.5 ± 4.7	8.5 ± 4.7
Pepper	2017 (wet)	29.5 ± 37.7^{a}	25.6 ± 26.5^{a}	7.9 ± 9.7^{a}	6.2 ± 3.9^{a}
Garlic	2017/2018	27.0 ± 17.0^{a}	29.3 ± 18.5^{a}	17.4 ± 15.9^{a}	15.1 ± 11.4^{a}
Pepper	2018 (wet)	24.8 ± 17.6^{a}	17.4 ± 11.3^{b}	10.3 ± 10.1^{a}	7.7 ± 4.7^{a}
Onion	2018/2019	31.2 ± 25.5^{a}	27.3 ± 22.7^{b}	30.6 ± 30.8^{a}	22.9 ± 21.1^{b}
Pepper	2020 (wet)	51.7 ± 24.9^{a}	44.3 ± 25.9^{b}	24.1 ± 13.7^{a}	23.1 ± 14.4^{a}
	Mean	32.8 ± 24.6^{a}	28.8 ± 21.0^{b}	18.1±16.1^{a}	15.0 ± 11.1^{b}
Increase over 4 years (%) *		55^{a}	36^{b}	112	77^{b}

Note: ^{a,b} Numbers followed by the same letters under the same row heads in the same soil layer, and containing treatment fields (CA and CT) show statistically not significant at 5% significant level using pair-t test. *4-years changes are the percent change when the mean of the 4-years content is compared with the initial.

4.3.4 Total Soil Nitrogen (TN)

The average TN concentration in CA was 0.25% in the top 30 cm soil depth. It was 14% greater than the TN concentration in CT. Unlike the OM, the trend line for TN concentration for the top 0-30 cm was significantly larger than zero ($p<0.10$) for both treatments (Figure 4-4c and Table 4-3). The increase in TN concentration was larger than for CT but not statistically significant (Table 4-4). Though the trend was not strong, TN for CA and CT increased over time at the 30-60 cm soil depth (Figure 4-4d).

The concentration of TN for CA in the top 30 cm soil depth was slightly lower after the rainy season than after the dry phase while it showed a continuous increment in the 30-60 cm soil depth (Table 4-5). There was not a clear pattern in the TN concentration for the wet and dry seasons for the CT treatment (Table 4-5).

4.3.5 Available Phosphorus (P)

Available P in the soil increased under CA and CT treatments over the two soil depths after 4 years (Table 4-5). The average available P in the CA was 19 % greater than the CT for the 30 cm soil and 35 % greater in the CA in the 30-60 cm soil depth (Table 4-5). The slope of the trend line showed that the increase in available P was significantly different from zero ($p<0.05$) for CA and CT in the top 0-30 cm soil depth and at ($p<0.10$) at the 30-60 cm depth (Table 4-3). The slope of the increase of available P for the top 30 cm soil was 6.9 % a^{-1} for CA and 5.1 % for the CT (Figure 4-4e). Statistically, the slopes for the two treatments were the same (Table 4-4). The increase in available P for CA and CT at the 30-60 cm depth was less than for the topsoil (Figure 4-4f and Table 4-4).

4.4. Discussion

We performed a four-year experiment with three types of vegetable crops under conservation agriculture and conventional tillage. CA consisted of incorporating organic dried grass mulch (85% OM) and cattle manure (42% OM) without tilling the soil. In CT, the soil was plowed with the traditional Maresha plow. All other farm management practices were the same between the treatments. We found an upward trend in OM, TN, and available P in the Ethiopian highlands for CA and CT (Figures 4-4). The upward trend in CT was attributed to the addition of fertilizer and irrigation during the dry phase. The upward trend in CA was greater than in CT due to the application of organic matter in the form of grass and manure (Table 4-1, and Figure 4-4).

Our findings are in agreement with other experiments carried out in the Ethiopian highlands under irrigated conditions (Assefa et al. 2018, 2019, and 2020, Yiman et al. 2020). However, the duration of all of these and our experiments were less than four years and was too short of showing a significant difference between the upward trends of CT and CA (Figure 4-4; Tables 4-4,4-5). Therefore, to establish a trend for conservation agriculture, we reviewed published studies from China (Richardson and Simpson, 2011), Brazil (Malecka et al. 2012), Philippines (Tripathy et al. 1997), Poland (Redel et al. 2007), USA (poudel et al.2001), Nigeria (Busari et al. 2013), Chile (Redel et at.2007), and Sudan (Sanchez et al. 1997).

4.4.1. Organic Matter (OM)

Our results were consistent with the other studies in the world (Elias et al. 1998, Tripathi et al. 1997, Tiecher et al. 2012, Redel et al. 2007). Plotting organic matter versus clay percentage, CEC, and soil pH, it was evident that our results (identified as Ethiopia in the plot) fall between other studies (Figure 4-5). The OM is positively correlated for clay but not significant ($R^2=0.43$), though not significant for studies in Nigeria, Poland, and Spain (Figure 4-5a). This is consistent with Solomon et al., (202O) that the clay fraction is associated with the largest pool of most humified soil OM in the tropical soils. Organic matter had a significant solid linear relationship ($R^2=0.89$) with the CEC as expected because clay and organic matter both have a high CEC (Figure 4-5b). The high OM contents and CEC values (Figure 4-5b) originated from studies in China, Poland, and Brazil (Richardson and Simpson, 2011, Redel et al. 2007, Malecka et al. 2012). Organic matter had a weak and negative correlation with pH ($r^2=0.54$) (Figure 4-5c).

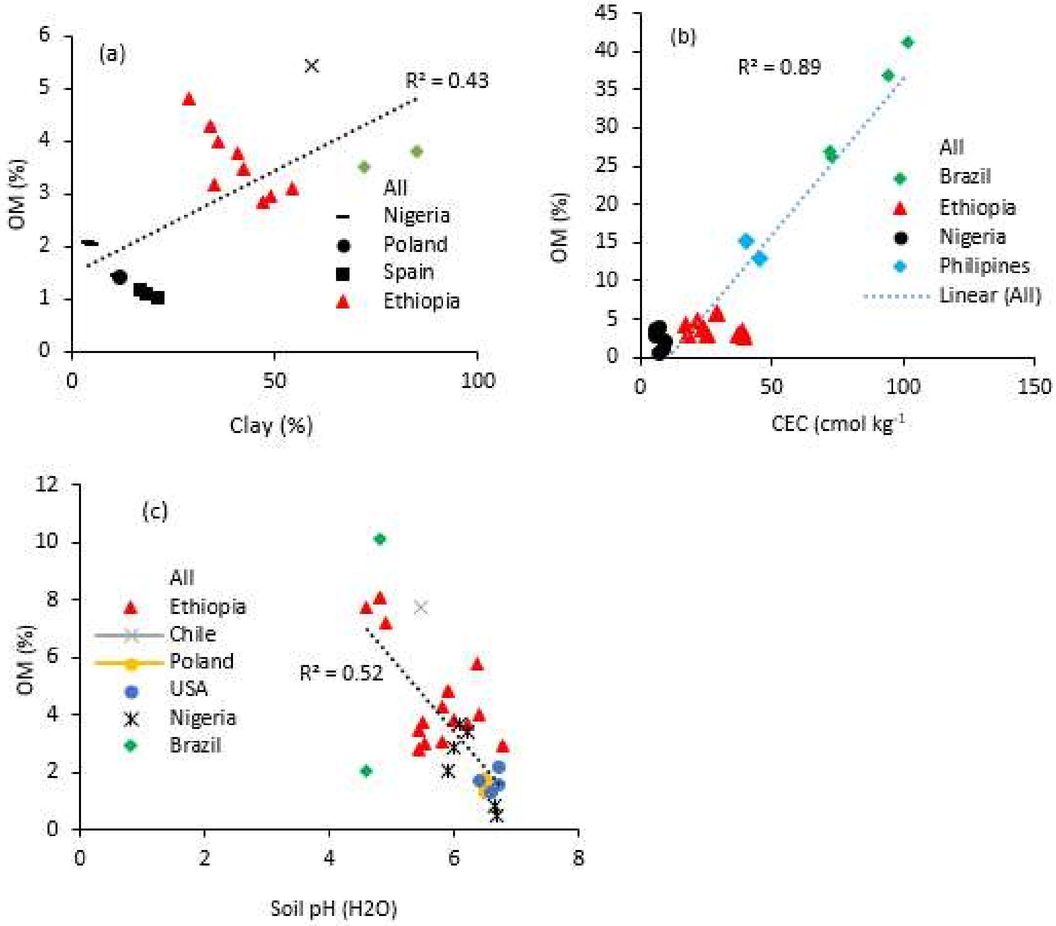


Figure 4- 5: The relationship of OM (%) for this and other recent studies with (a) clay content (%), (b) soil CEC and (c) soil pH (Elias et al.,1998, Tripathi et al. 1997, Richardson and Simpson, 2011, Tiecher et al. 2012, Redel et al. 2007, Yimam et al. 2020, Emiru et al. 2013, Sanchez et al. 1997, Metay et al. 2007, Calegari et al. 2008, Balota et al. 2004, Sisti et al. 2004, Chivenge et al. 2007, Laghrour et al. 2016, Busari et al. 2015, Busari and Salako, 2013).

4.4.2 Total Soil Nitrogen (TN)

The increase in TN over the four-year experimental period (Figure 4-4c,d) is directly related to increasing organic matter content, as confirmed by research on conservation agriculture in China (Rechardson et al. 2011), the Philippines (Tripathy et al. 1997), Poland (Malecka et al. 2011), the USA (Poudel et al. 2001), Nigeria (Busari et al. 2013), Chili (Redel et al. 2007), and Sudan (Sanchez et al. 1997) (Figure 4-6b). Since organic matter and clay content are related, there is also a moderate relationship between clay content and total N (Figure 4-6a). This relationship was not significant because TN may also depend on other soil chemical processes in conservation agriculture, such as microbial action (Williams et al. 2018, Blevins et al. 1983), weed growth (Shahzad et al. 2016), transport by erosion, and leaching (Adimassu et al. 2020, Belay et al. 2020, Dalal et al. 1995)

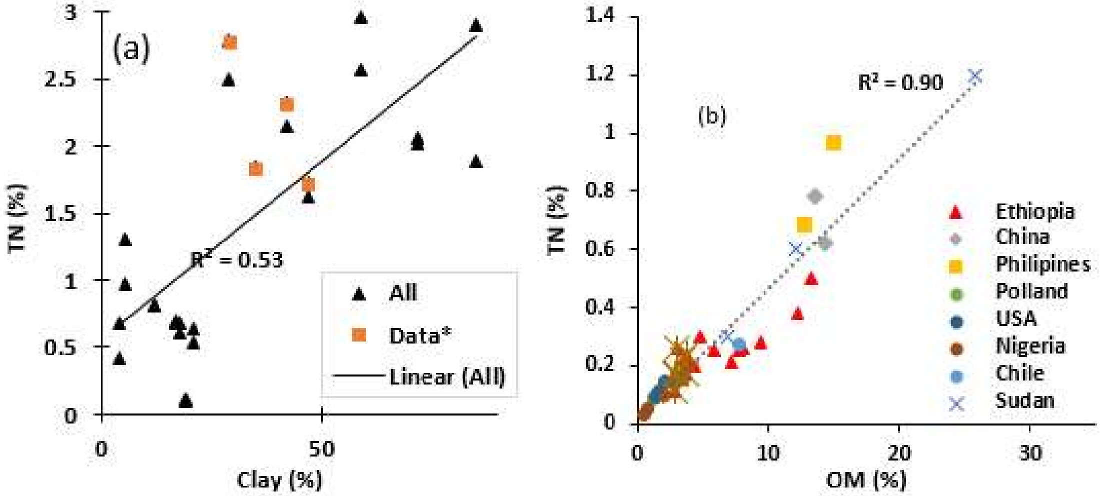


Figure 4- 6: The relationship of total N (TN) for this and other recent studies for both conservation agriculture and conservation tillage with (a) clay content and (b) organic matter (OM.). *Data (a and b) indicates Results from this study in the Ethiopian highlands

4.4.3 Available Phosphorus (P)

Similar to organic matter, soil available P in this study was low after the pepper harvest in the rainy season compared to after the harvest of the crop grown during the dry phase for both treatments (Table 4-5). Possible reasons for this included the roots and other organic material of the large pepper plants decomposed during the dry season favored the growth and development of micro-organisms (Richardson and Simpson, 2011, Barber and Gunn, 1974, Redel et al. (2007). Erosion of the topsoil could have been one of the reasons as well.

4.4.4 Long term studies

It is worthwhile since most conservation agricultural experiments are only recent to investigate the effect of no-tillage on the buildup of organic matter, total N, and available P with the number of years that the soil is not tilled. Studies in Ethiopia (Yimam et al. 2020) and in the other locations (Laghrour et al. 2016; Chivenge et al. 2007, Claudia et al. 2004, Richardson et al. 2011, Poudel et al. 2001, Busari et al. 2013) show that the increase in organic matter content is moderately correlated ($r^2=0.55$) with the number of years that no-till was implemented (Figure 4-7a). These studies also show that available phosphorus is related to the duration that the soils have not been cultivated and the crop residues left on the field ($r^2=0.58$, Figure 4-7b). In our 4-year study with double cropping, the rate of increase in organic matter OM, TN, and P were more significant than in the other studies, such as annual cereal cropping systems with only one crop.

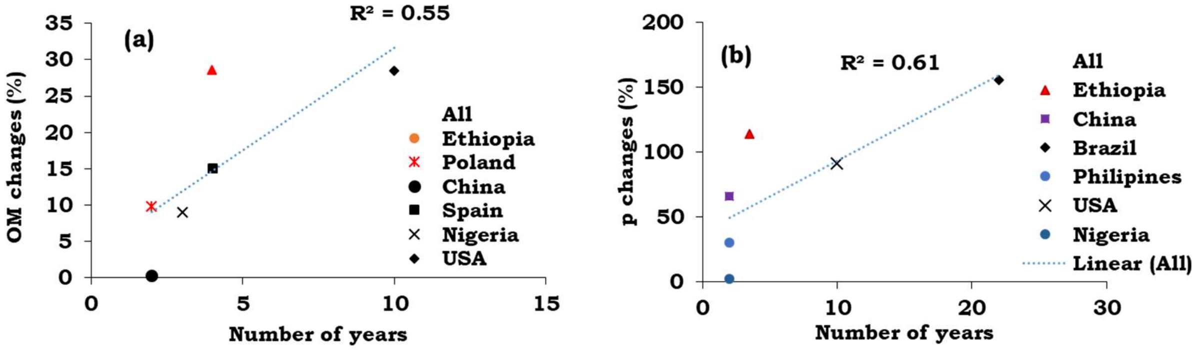


Figure 4- 7: Average organic matter and available Phosphorus (P) as a function of the number of years of continuous conservation tillage practices with the number of years CA has been continuously conducted

4.5 Conclusions

The objective of this study was to quantify the magnitude of soil physicochemical characteristic changes and soil fertility improvements under CA practice during irrigated and rainfed phases of vegetable production systems in the Ethiopian highlands. Organic matter, total nitrogen, and available phosphorus showed a trend of increment for both soil layers (0-30 and 30-60 cm) after a 4-year. The concentration of OM and TN decreased slightly with an increase in soil depth while available P increased with soil depth. Besides, CA increased the OM and TN approximately by 16% compared to CT in the 0 to 30 cm soil depth. Similarly, the available P in the CA was increased by 20% and 35% at 0 to 30 and 30 to 60 cm, respectively when compared with the CT. While OM and TN were decreased in the 30 to 60 cm soil layer compared to the 0 to 30 soil layers, available P increased threefold in both treatments. Soil organic matter and TN under the CA treatment showed a slight improvement, particularly in the upper soil layer while the organic matter was fairly similar between the two soil layers in the CT. Soil pH, available K, and CEC were increased under CA compared with the CT treatment over the 4-year experiment. Better soil properties can help improve yields, and conservation agriculture practices have become more important now than ever.

References

Adimassu, Z., Tamene, L. & Degefie, D. T., 2020. The influence of grazing and cultivation on runoff, soil erosion, and soil nutrient export in the central highlands of Ethiopia. Ecological Processes. 9**,** 1-11.

Alexander, S., 2012. A Guide to Vegetable Growing. Teagasc, Oak Park, Carlow, Ireland.

Alvear, M., Rosas, A., Rouanet, J., Borie, F., 2005. Effects of three soil tillage systems on some biological activities in an Ultisol from southern Chile. *Soil and Till. Res.* 82**,** 195-202.

Araya, T., Cornelis, W., Nyssen, J., Govaerts, B., Bauer, H., Gebreegziabher, T., Oicha, T., RAES, D., Sayre, K. D., Haile, M., 2011. Effects of conservation agriculture on runoff, soil loss and crop yield under rainfed conditions in Tigray, Northern Ethiopia. *Soil Use and Management.* 27**,** 404-414.

Assefa, T., JHA, M., Reyes, M., Tilahun, S. & Worqlul, A. W., 2019. Experimental Evaluation of Conservation Agriculture with Drip Irrigation for Water Productivity in Sub-Saharan Africa. *Water* 11**,** 530.

Assefa, T., JHA, M., Reyes, M., Worqlul, A., Doro, L., Tilahun, S., 2020. Conservation agriculture with drip irrigation: Effects on soil quality and crop yield in sub-Saharan Africa. *Jour. Soil and Water Cons.* 75**,** 209-217.

Assefa, T., JHA, M., Reyes, M. & Worqlul, A. W., 2018. Modeling the impacts of conservation agriculture with a drip irrigation system on the hydrology and water management in sub-Saharan Africa. *Sustainability.* 10**,** 4763.

Assefa, T. T., 2018. Experimental and Modeling Evaluation of Conservation Agriculture with Drip Irrigation for Small-Scale Agriculture in Sub-Saharan Africa. North Carolina Agricultural and Technical State University.

Aticho, A., Elias, E. & Diels, J., 2011. Comparative analysis of soil nutrient balance at farm level: a case study in Jimma Zone, Ethiopia. *International Journal of Soil Science,* 6**,** 259-266.

Balota, E. L., Colozzi filho, A., Andrade, D. S., Dick, R. P., 2004. Long-term tillage and crop rotation effects on microbial biomass and C and N mineralization in a Brazilian Oxisol. *Soil and Till. Res.* 77**,** 137-145.

Barber, D. & Gunn, K. J., 1974. The effect of mechanical forces on the exudation of organic substances by the roots of cereal plants grown under sterile conditions. *New Phytologist.* 39-45.

Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B. & Kimetu, J., 2007. Soil organic carbon dynamics, functions and management in West African agro-ecosystems. *Agricultural Systems.* 94**,** 13-25.

Belay, S. A., Assefa, T. T., Prasad, P., Schmitter, P., Worqlul, A. W., Steenhuis, T. S., Reyes, M. R. & Tilahun, S. A., 2020. The Response of Water and Nutrient Dynamics and of Crop Yield to Conservation Agriculture in the Ethiopian Highlands. *Sustainability.* 12**,** 5989.

Belay, S. A., Schmitter, P., Worqlul, A. W., Steenhuis, T. S., Reyes, M. R. & Tilahun, S. A., 2019. Conservation Agriculture Saves Irrigation Water in the Dry Monsoon Phase in the Ethiopian Highlands. *water.* 11**,** 2103.

Benbi, D. K. & Senapati, N. J., 2010. Soil aggregation and carbon and nitrogen stabilization in relation to residue and manure application in rice–wheat systems in northwest India. *Nutrient Cycling in Agroecosystems.* 87**,** 233-247.

Berakhi, O., Brancaccio, L., Calderoni, G., Coltorti, M., Dramis, F. & Umer, M. M., 1998. The Mai Maikden sedimentary sequence: a reference point for the environmental evolution of the Highlands of Northern Ethiopia. *Geomorphology.* 23**,** 127-138.

Blevins, R., Thomas, G., Smith, M., Frye, W. & Cornelius, P., 1983. Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. *Soil and tillage research.* 3**,** 135-146.

Bray, R. H. & Kurtz, L., 1945. Determination of total, organic, and available forms of phosphorus in soils. *Soil science.* 59**,** 39-46.

Busari, M. & Salako, F. J., 2013. Effect of tillage, poultry manure and NPK fertilizer on soil chemical properties and maize yield on an Alfisol at Abeokuta, south-western Nigeria. *Nigerian Journal of Soil Science.* 23**,** 206-218.

Busari, M. A., Kukal, S. S., Kaur, A., Bhatt, R., Dulazi, A. A., 2015. Conservation tillage impacts on soil, crop and the environment. *Int. Soil and Water Cons. Res.* 3**,** 119-129.

Calegari, A., Hargrove, W., Rheinheimer, D. D. S., Ralisch, R., Tessier, D., De Tourdonnet, S. & De Fatima Guimarães, M. J., 2008. Impact of long-term no-tillage and cropping system management on soil organic carbon in an Oxisol: A model for sustainability. *Agronomy Journal.* 100**,** 1013-1019.

Campbell, C., Biederbeck, V., Mcconkey, B., Curtin, D. & Zentner, R., 1999. Soil organic matter quality as influenced by tillage and fallow frequency in a silt loam in southwestern Saskatchewan. *Soil Biology & Biochemistry.* 31**,** 1-7.

Cassel, D., Nielsen, D. M., 1986. Field capacity and available water capacity. *Physical and Mineralogical Methods.* 5**,** 901-926.

Chivenge, P., Murwira, H., Giller, K., Mapfumo, P., 2007. Long-term impact of reduced tillage and residue management on soil carbon stabilization: Implications for conservation agriculture on contrasting soils. 94**,** 328-337.

Claudia P.J. Sisti a, Henrique P. dos Santos b, Rainoldo Kohhann b, Bruno J.R. Alves c, Segundo Urquiaga c, Robert M. B., 2004. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. Soil and Till., 79,38-58.

Dalal, R., Strong, W., Weston, E., Cooper, J., Lehane, K., King, A. & Chicken, C. J., 1995. Sustaining productivity of a Vertisol at Warra, Queensland, with fertilisers, no-tillage, or legumes. *Australian Journal of Experimental Agriculture.* 35**,** 903-913.

Davis, D., Gowda, P., Mulla, D. & Randall, G. J.,2000. Modeling nitrate nitrogen leaching in response to nitrogen fertilizer rate and tile drain depth or spacing for southern Minnesota, USA. *Journal of Environmental Quality.* 29**,** 1568-1581.

Ding, G., Novak, J., Amarasiriwardena, D., Hunt, P. & Xing, B., 2002. Soil organic matter characteristics as affected by tillage management. *Soil Sci. Soc. Am. J.* 66**,** 421-429.

Elias, E., Morse, S., Belshaw, D. J., 1998. Nitrogen and phosphorus balances of Kindo Koisha farms in southern Ethiopia. *Agriculture, ecosystems & environment.* 71**,** 93-113.

Emiru, N., Gebrekidan, H. J., 2013. Effect of land use changes and soil depth on soil organic matter, total nitrogen and available phosphorus contents of soils in Senbat Watershed, Western Ethiopia. ARPN Jour. Agr. and Bio. Sci.8**,** 206-2012.

Erenstein, O., 2003. Smallholder conservation farming in the tropics and sub-tropics: a guide to the development and dissemination of mulching with crop residues and cover crops. *Agriculture, Ecosystems & Environment.* 100**,** 17-37.

Gassen, D. & Gassen, F., 1996. Plantio Directo o Caminho do Futuro. ALDEIA SUL.

Gebre-Selassie, A., Bekele, T. J., J. Prammer , C. E., D. KYD-REbenburg, & J. Prammer , G., 2012. A review of Ethiopian agriculture: roles, policy and small-scale farming systems. *C. Bell & J. Prammer.* 36-65.

Giller, K. E., Corbeels, M., Nyamangara, J., Triomphe, B., Affholder, F., Scopel, E. & Tittonell, P., 2011. A research agenda to explore the role of conservation agriculture in African smallholder farming systems. *Field crops research.* 124**,** 468-472.

Giller, K. E., Witter, E., Corbeels, M. & Tittonell, P., 2009. Conservation agriculture and smallholder farming in Africa: the heretics' view. *Field crops research.* 114**,** 23-34.

Gupta, M. & Khosla, R., 2012 Precision nitrogen management and global nitrogen use efficiency. Proceedings of the 11th International Conference on Precision Agriculture, Indianapolis, USA.

Islam, A., Edwards, D., Asher, C., 1980. pH optima for crop growth. 54**,** 339-357.

Johnson, J. M.-F., Franzluebbers, A. J., Weyers, S. L. & Reicosky, D. C., 2007. Agricultural opportunities to mitigate greenhouse gas emissions. *Environmental pollution.* 150**,** 107-124.

Kassam, A., Friedrich, T., Shaxson, F. & Pretty, J., 2009. The spread of conservation agriculture: justification, sustainability and uptake. *International journal of agricultural sustainability.* 7**,** 292-320.

Khosla, R., Fleming, K., Delgado, J., Shaver, T. & Westfall, D., 2002. Use of site-specific management zones to improve nitrogen management for precision agriculture. *Journal of Soil and Water Conservation.* 57**,** 513-518.

Laghrour, M., Moussadek, R., Mrabet, R., Dahan, R., EL-Mourid, M., Zouahri, A., Mekkaoui, M. J., 2016. Long and midterm effect of conservation agriculture on soil properties in dry areas of Morocco. *Applied and E*nvironmental Soil Science. 2016, http://dx.doi.org/10.1155/2016/6345765.

Lanckriet, S., Araya, T., Cornelis, W., Verfaillie, E., Poesen, J., Govaerts, B., Bauer, H., Deckers, J., Haile, M. & Nyssen, J., 2012. Impact of conservation agriculture on catchment runoff and soil loss under changing climate conditions in May Zeg-zeg (Ethiopia). *Journal of Hydrology.* 475**,** 336-349.

Limon-Ortega, A., Sayre, K. D. & Francis, C. A., 2000. Wheat nitrogen use efficiency in a bed planting system in northwest Mexico. *Agronomy Journal.* 92**,** 303-308.

Macdonald, G., Peck, N., Vittum, M. J., 1978. Relationship between ammonium acetate-acetic acid and morgan's solution for determining extractable P, K, Ca, and Mg in soils derived from calcareous glacial till. *Communications in Soil Science and Plant Analysis.* 9**,** 717-728.

Malecka, I., Blecharczyk, A., Sawinska, Z., Dobrzeniecki, T., 2012. The effect of various long-term tillage systems on soil properties and spring barley yield. *Turkish Journal of Agriculture and Forestry.* 36**,** 217-226.

Metay, A., Moreira, J. A. A., Bernoux, M., Boyer, T., Douzet, J.-M., Feigl, B., Feller, C., Maraux, F., Oliver, R., Scopel, E. J., 2007. Storage and forms of organic carbon in a no-tillage under cover crops system on clayey Oxisol in dryland rice production (Cerrados, Brazil). 94**,** 122-132.

Nyborg, M., Solberg, E., Izaurralde, R., Malhi, S., Molina-Ayala, M., 1995. Influence of long-term tillage, straw and N fertilizer on barley yield, plant-N uptake and soil-N balance. *Soil and Tillage research.* 36**,** 165-174.

Nyssen, J., Vandenreyken, H., Poesen, J., Moeyersons, J., Deckers, J., Haile, M., Salles, C. & Govers, G., 2005. Rainfall erosivity and variability in the Northern Ethiopian Highlands. *Journal of Hydrology.* 311**,** 172-187.

O'Kelly, B. C., 2004. Accurate determination of moisture content of organic soils using the oven drying method. *Drying Technology.* 22**,** 1767-1776.

Pimentel, D., 2006. Impacts of organic farming on the efficiency of energy use in agriculture. *An organic center state of science review.* 1-40.

Poudel, D.D., Horwath, W.R., Mitchell, J.P. and Temple, S.R., 2001. Impacts of cropping systems on soil nitrogen storage and loss. Agricultural Systems, 68(3), pp.253-268.

Rasmussen, K., 1999. Impact of ploughless soil tillage on yield and soil quality: A Scandinavian review. *Soil and Tillage Research.* 53**,** 3-14.

Redel, Y. D., Rubio, R., Rouanet, J. L. & Borie, F., 2007. Phosphorus bioavailability affected by tillage and crop rotation on a Chilean volcanic derived Ultisol. *Geoderma.* 139**,** 388-396.

Rengel, Z., Robinson, D., 1989. Determination of cation exchange capacity of ryegrass roots by summing exchangeable cations. *Plant and Soil.* 116**,** 217-222.

Richardson, A. E. & Simpson, R., 2011. Soil microorganisms mediating phosphorus availability update on microbial phosphorus. *Plant Physiol.* 156**,** 989-96.

Roldán, A., Caravaca, F., Hernández, M., Garcıa, C., Sánchez-Brito, C., Velásquez, M., Tiscareno, M., 2003. No-tillage, crop residue additions, and legume cover cropping effects on soil quality characteristics under maize in Patzcuaro watershed (Mexico). *Soil and Tillage Research.* 72**,** 65-73.

Sanchez, P. A., Shepherd, K. D., Soule, M. J., Place, F. M., Buresh, R. J., Izac, A.-M. N., Uzo Mokwunye, A., Kwesiga, F. R., Ndiritu, C. G. & Woomer, P. L., 1997. Soil fertility replenishment in Africa: an investment in natural resource capital. *Replenishing soil fertility in Africa.* 51**,** 1-46.

Sartori, L., Basso, B., Bertocco, M. & Oliviero, G., 2005. Energy use and economic evaluation of a three-year crop rotation for conservation and organic farming in NE Italy. *Biosystems engineering.* 91**,** 245-256.

Shahzad, M., Farooq, M., Jabran, K. & Hussain, M., 2016. Impact of different crop rotations and tillage systems on weed infestation and productivity of bread wheat. *Crop protection.* 89**,** 161-169.

Shi, P. & Schulin, R., 2018. Erosion-induced losses of carbon, nitrogen, phosphorus and heavy metals from agricultural soils of contrasting organic matter management. *Science of The Total Environment.* 618**,** 210-218.

Sisti, C. P., Dos Santos, H. P., Kohhann, R., Alves, B. J., Urquiaga, S., Boddey, R. M., 2004. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. 76**,** 39-58.

Solomon, D., Fritzsche, F., Lehmann, J., Tekalign, M. & Zech, W., 2002. Soil organic matter dynamics in the subhumid agroecosystems of the Ethiopian highlands: Evidence from natural 13C abundance and particle-size fractionation. *Soil Science Society of America Journal.* 66**,** 969-978.

Solomon, D., Lehmann, J., Mamo, T., Fritzsche, F. & Zech, W., 2002. Phosphorus forms and dynamics as influenced by land use changes in the sub-humid Ethiopian highlands. *Geoderma,* 105**,** 21-48.

Tiecher, T., Dos Santos, D. R., Calegari, A., 2012. Soil organic phosphorus forms under different soil management systems and winter crops, in a long term experiment. *Soil and Tillage Research.* 124**,** 57-67.

Tripathi, B., Ladha, J., Timsina, J. & Pascua, S., 1997. Nitrogen dynamics and balance in intensified rainfed lowland rice-based cropping systems. *Soil Science Society of America Journal.* 61**,** 812-821.

Turner, B. L. & Engelbrecht, B. M., 2011. Soil organic phosphorus in lowland tropical rain forests. *Biogeochemistry.* 103**,** 297-315.

Vanlauwe, B., Wendt, J., Giller, K. E., Corbeels, M., Gerard, B. & Nolte, C., 2014. A fourth principle is required to define conservation agriculture in sub-Saharan Africa: the appropriate use of fertilizer to enhance crop productivity. *Field Crops Research.* 155**,** 10-13.

Walkley, A. & Black, I. A., 1934. An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil science.* 37**,** 29-38.

Williams, A., Wells, M. S., Dickey, D. A., Hu, S., Maul, J., Raskin, D. T., Reberg-horton, S. C., Mirsky, S. B., 2018. Establishing the relationship of soil nitrogen immobilization to cereal rye residues in a mulched system. *Plant and Soil.* 426**,** 95-107.

Yimam, A. Y., Assefa, T. T., Adane, N. F., Tilahun, S. A., Jha, M. K. & Reyes, M. R., 2020. Experimental Evaluation for the Impacts of Conservation Agriculture with Drip Irrigation on Crop Coefficient and Soil Properties in the Sub-Humid Ethiopian Highlands. *Water.* 12**,** 947.

CHAPTER 5

EVALUATING CHANGES IN HYDROLOGY AND SOIL QUALITY VARIABLES DUE TO CONSERVATION AGRICULTURE PRACTICES USING APEX MODEL

Abstract: The Agricultural Policy/Environmental eXtender (APEX) model have been developed to assess a wide variety of agricultural water resource and other environmental problems at a field or multi-subarea spatial scales. The model was established to evaluate the effect of conservation agriculture practices on water and nutrient loads of runoff and sediment under small on-farm experimental plots. Transferred flow model parameters from a watershed to experimental plots were used to simulate runoff with runoff and nutrient parameter adjustments under conservation agriculture and conventional tillage practices. The APEX model performed well in simulating the CA and the CT scenarios for different response variables under irrigated and supplementary irrigated vegetable production systems. It showed a decreased simulated ET by 15%, simulated average runoff by about 70%, simulated nitrogen in the runoff by 23%, and simulated phosphorus loads in the runoff by 54% under CA compared with the CT treatment while it showed increased average root zone soil water (20%), and increased average percolation (59%). The reason for the different responses of the simulated variables between CA and CT practices was obviously due to the combined use of grass mulch cover and no-tillage practices under CA treatment. APEX simulations indicated the contribution of such practices leading to the reductions in ET and runoff, which was the main reason for higher (14–27%) water-saving observed during the dry irrigation phases of various vegetable production under CA treatment. In this regard, APEX can be used as a tool to assess the impact of CA on hydrology and nutrient loads.

Keywords. APEX, root zone soil water, conservation agriculture, nutrients, runoff

5.1 Introduction

Water and nutrients are the critical inputs for rain-fed and irrigated crop production systems, although the degree of contribution varies both spatially and temporally. The dynamics of water and nutrients should always be monitored in response to different farming and management practices to manage these resources for better economic and environmental returns. However, field research used to conduct measurements across all possible locations, topography, farming, and cropping practices are often costly and even time-consuming (Chung et al. 1999). In filling such gaps, modeling techniques have been increasingly used in agriculture to evaluate the response of unmeasured variables to different farming and irrigation practices. However, the choice of an appropriate model for a specific purpose continued as a critical challenge for researchers. Recent advances in process-based models have been used to evaluate the effects of different agricultural practices at various spatial and temporal scales (Antle et al. 2017, Marin et al. 2014, Rauff and Bello 2015). However, verifying a model with adequate observed datasets for a particular region is necessary since models developed considering specific site conditions may not perform well in the other regions (Müller et al. 2017, Rivington and Koo 2010). Despite detailed field data required for verification (Iizumi et al. 2014, Ray et al. 2012), generally, process-based models such as the crop growth model (Di Paola et al. 2016), and carbon cycling model (Stockmann et al. 2013) are potentially accepted and commonly used to assess the response of water, nutrient and crop variables (growth and yield) to different irrigation, farming, and management practices at watershed, farm, or plot scale levels (Gassman et al. 2009).

Agricultural Policy Environmental eXtender (APEX) model is among few efficient process-based models used to evaluate the effect of agricultural practices at various farm levels to draw the best management practices (Clarke et al. 2017, Gassman et al. 2009, Moriasi et al. 2012, Tuppad et al. 2010b, Zhang et al. 2016). The model functions on long-term continuous time scales (daily, monthly, and annual). Unlike other models, APEX is a biophysical model that integrates different components including EPIC - Environmental Policy Integrated Climate model (Williams et al. 2008), CREAMS - daily runoff hydrology sub-model of the Chemicals, Runoff, and Erosion from Agricultural Management Systems model (Knisel 1980), GLEAMS - Groundwater Loading Effects of Agricultural Management Systems model (Leonard et al. 1987), Century model - the carbon cycling model (Parton et al. 1994), and ALMANAC - the Agricultural Land Management Alternatives with Numerical Assessment Criteria model (Kiniry et al. 2005).

APEX has been recently used to simulate runoff and sediment (Francesconi et al. 2014a, Wang et al. 2008), percolation (Kumar et al. 2011b, Wang et al. 2008), crop growth and yield (Talebizadeh et al. 2018), water quality (Sharifi et al. 2019), carbon cycling (Wang et al. 2008), and pesticides fates (Plotkin et al. 2013). It is also an important model to evaluate the effectiveness of a new practice when compared with the existing practices (control), which is then used to develop best management scenarios on the use and management of soil nutrients (Cavero et al. 2012, Francesconi et al. 2014b, Tuppad et al. 2010a), tillage practices (Francesconi et al. 2014b), and irrigation practices (Cavero et al. 2012).

Most of the above studies (Kumar et al. 2011a, Wang et al. 2008) indicate the power of the APEX model at a watershed scale and in most cases used for rain-fed practices under cereal production conditions. Although recent studies have demonstrated the good performance of APEX approaches for modeling watershed-scale flow and sediment hydrological variables (Assefa et al. 2018, Golmohammadi et al. 2014, Sharifi et al. 2019), its applicability in the evaluation of pairwise differences between conservation agriculture (CA) and conventional tillage (CT) practices is limited. In this study, we used the APEX model for evaluating various responses using field-scale three years of data. Using the entry of all recorded data as an input for both practices, the model was used to perform simulations for surface runoff, root zone percolation/deep percolation, root zone soil water and storage, rate of soil nutrient removal (nitrogen and phosphorus dynamics), the extent of soil organic matter accumulation and crop yield for various vegetable crops. The simulated model results and the response of water, nutrient and crop growth dynamics to different treatments have been compared and some variables were verified with the observed data.

The main objective of this study was to evaluate the response of water and nutrient and crop yield under CA and CT practice using the APEX model. The specific objectives are to; (1) evaluate the applicability and performance of APEX for simulating runoff and nutrient and yield at plot scale of CA and CT treatments (2) evaluate the impact of CA and CT practices on water dynamics: root zone soil water, evapotranspiration, percolation), and (3) evaluate the impact of CA and CT practices on nutrient dynamics: total carbon pool, N-mineralization, organic phosphorus).

5.2. Materials and Methods

5.2.1 Site description

The study site is found in Dengeshita watershed, Upper Abay Basin, Ethiopia. Experimental plots were established near 11.32° N latitude, 36.85 ° E longitude, and at an altitude of 2042 m above mean sea level (Figure 5-1). The mean annual rainfall of 24 years (1995-2019) in the nearby town (Dangila) meteorological station is 1400 mm with more than 80% occurring from mid-June to September. The mean annual minimum and maximum temperature are in the range of 5-12 °C and 18-29°C. Before the establishment of this experiment in 2016, most of the selected on-farm plots were used as cultivated lands mainly growing maize under the rain-fed phase (May to August). There was no irrigated crop production in the area and over the selected on-farm plots. The average slope of the plots are in the range of 2% to 5%. The dominant top (60 cm) soil was loam soil texture and slightly acidic with a pH of 6.0 as described by Belay et al. (2020).

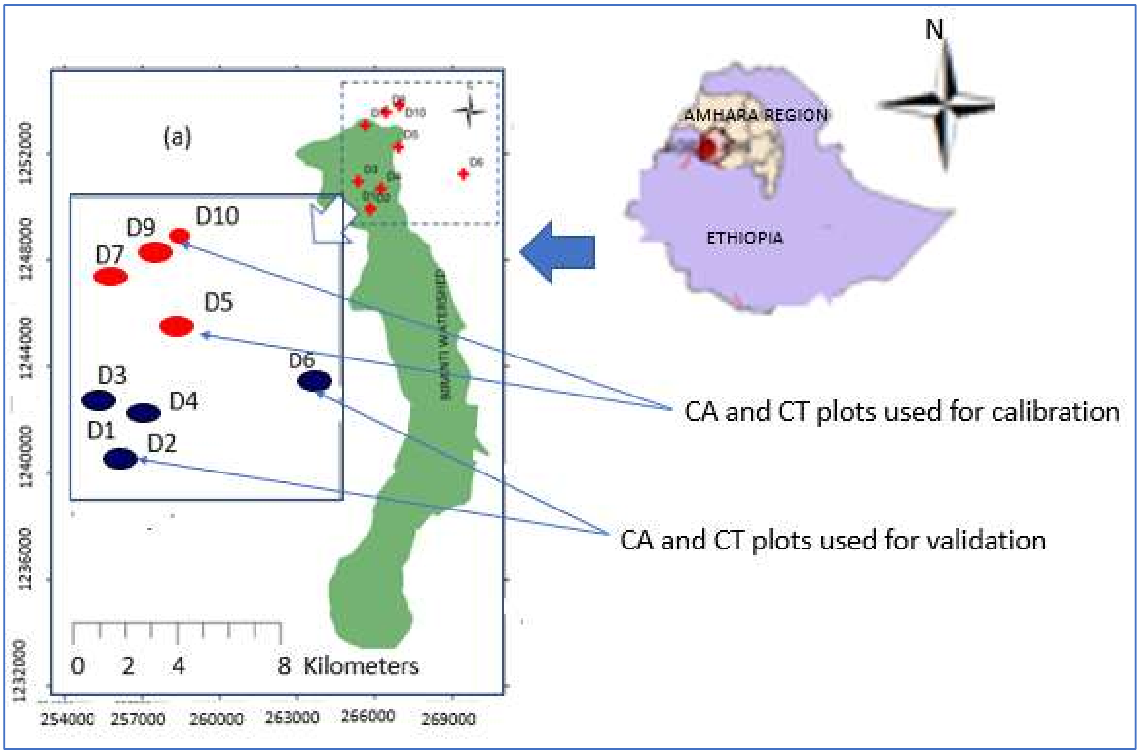
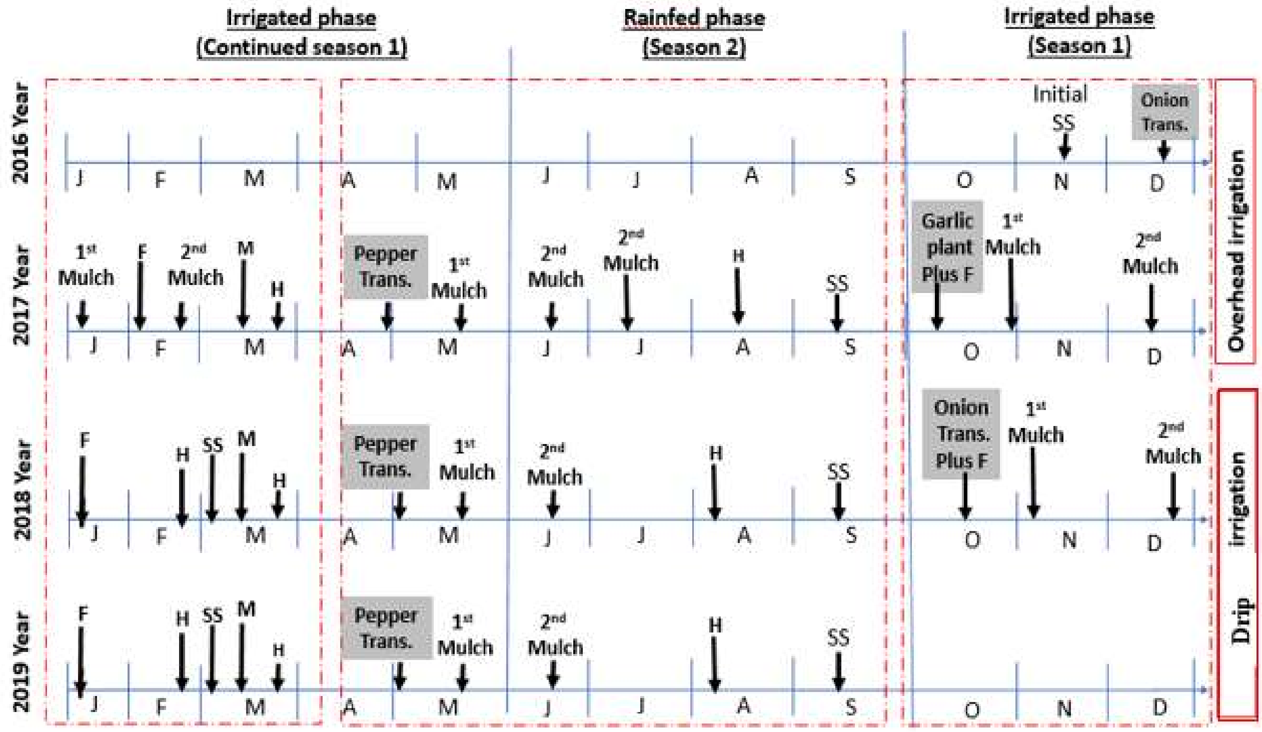


Figure 5- 1: Location map of experimental sites and plots used for modeling for calibration and validation purpose.

5.2.2 Experimental periods for modeling

This experiment was conducted continuously for three years (2016-2019) under irrigated (season 1) and rainfed (season 2) phases (Figure 5-2). Garlic and onion were grown in the 1st season (season 1) through irrigation whereas pepper was grown in the 2nd season with supplemental irrigation (start with irrigation and harvest with rain) as shown in Figure 5-2. The overhead irrigation method was used in both seasons for 2016 and 2017/2018 years and was converted to a drip system in 2018 and 2019 (Figure 5-2). Experimental activities such as transplanting, application of mulch, manure (M) and fertilizer (F), vegetable harvest (H) and soil sampling (SS), and crop rotations for both seasons are shown in Figure 5-2.

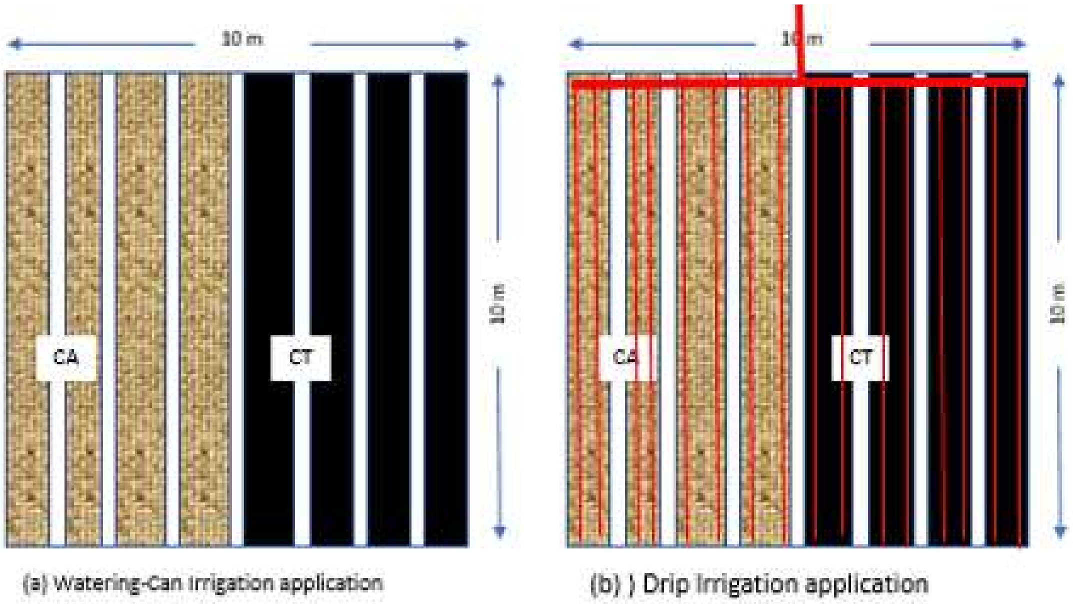


Note: SS=Soil sampling, H = harvest; M= manure application; Trans.= transplanting, letters from J to D stands for Months (January to December).

Figure 5- 2: A schematic diagram showing experimental years (2016 to 2019 years, cropping seasons (irrigation and rainfed phases), and type of irrigation method with major farming activities (transplanting, mulching, fertilizer and manure application and harvesting, crops, and operation from.

5.2.3 Experimental design and layout used for modeling

A total of 8 experimental plots were established on an area of 100 m^2 in size, where 50 m^2 was randomly assigned for CA and the rest for CT practice (Figure 5-3) under a paired ‘t’ design. All other crop management practices were equally treated. CA practice here refers to minimum soil disturbance (no-till) and application of local grass as mulch, while CT refers to the existing farmers' practice (i.e. 4 to 6 tillage frequencies with 15 to 20 cm tillage depth using animal or hand tools) without mulch. Farmers used a modified pulley system (Figure 5-4a) to lift water from shallow groundwater wells from 2016 to 2018 years and were replaced by solar Majipump technology in 2018 (Figure 5-4b).



(a) Watering-Can Irrigation application

(b)) Drip Irrigation application

Figure 5- 3: Experimental design and layout for overhead in 2016 and 2017/2018 years (a), and drip system in 2018 and 2019 (b) as indicated in Figure 5-2 for use in modeling.

(a) Pulley system (b) Solar Majipump (c) Overhead (d) Drip system

Figure 5- 4: Water lifting and irrigation technologies used during the experimental period (2016-2019), modified pulley water lifting system (a), solar-driven Majipump water lifting system (b), overhead water application system using watering-can (c), and drip irrigation system (d).

5.2.4 Agronomic practices to be used as an input for modeling

Agronomic practices such as tillage, planting, harvesting, mulching, fertilizer and chemical application were monitored during the 3 years' experiment (2017-2019) for both irrigated and rainfed production (Figure 5-2) used as an input for APEX model. UREA fertilizer (46-0-0; N-P-K) was uniformly applied to each plot at the rate of 200 kg ha^{-1}. Local seed-free (to prevent weed infestation) and dried grass (85% organic matter, 0.18% total nitrogen, and 17 ppm available phosphorus) was applied at the rate of 2 t ha^{-1} as mulch for CA plots at the beginning and mid of each cropping season (i.e. about 8 t ha^{-1}yr^{-1}). Cattle manure (compost: 42% organic matter, 2.1% total nitrogen, and 82 ppm available phosphorus) has been applied at the rate of 5 t ha^{-1} uniformly for both CA and CT management after the harvest of the 1st crop. Onion and garlic harvests were made from February to March in the dry phase while pepper was harvested from July to August (i.e. 4 to 6 harvests were made for pepper). The vegetable yield was then weighed from each plot during every harvest separately for CA and CT management.

5.2.5. Climate data

Climate data used for the model was collected from Dangila weather station (15 km from the site) for 2013 –2019 years. Data from 2013 to 2015 was used for the APEX model warm-up period of the simulation while data from 2016-2019 was used for purpose of calibration and validation processes (simulation) of water and nutrient dynamics. The climate data used include rainfall, temperature (maximum and minimum), relative humidity, actual sunshine hours, and wind speed. The monthly rainfall of Dangila metrological station is shown in Figure 5-5.

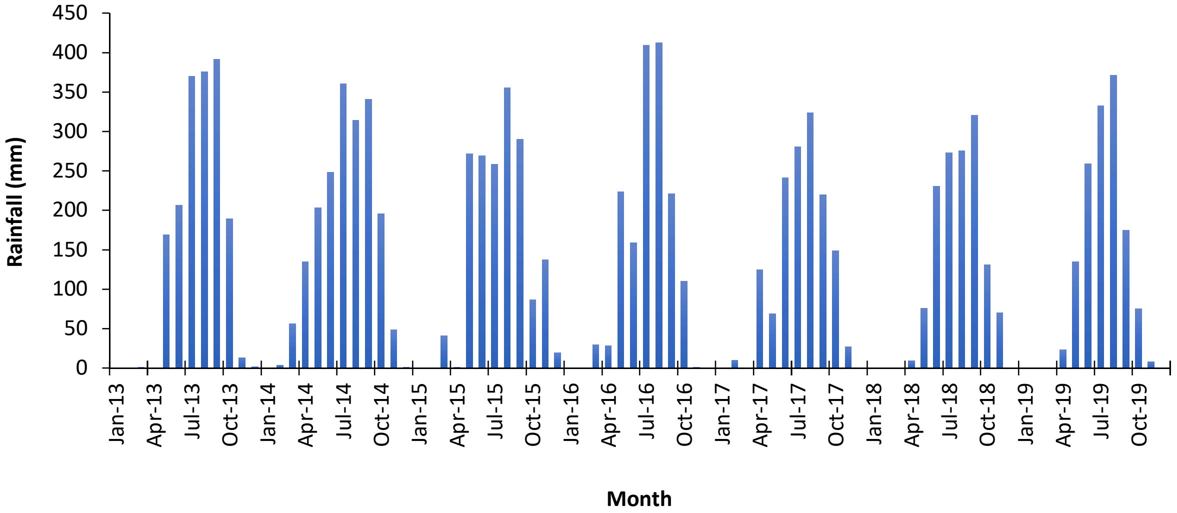


Figure 5- 5: Monthly rainfall (2013-2019) of the nearby meteorological station used for modeling

5.2.6 Runoff, soil moisture, and nutrient measurement for use in modeling

Runoff

Runoff was measured using runoff collectors of a geomembrane sealed trench of size 0.5 m by 0.4 m by 1 m (200 L in capacity), installed at the lower end of treatment beds. The data was used here for calibration and validation purpose at the crop growth period. One trench was used for a treatment where the runoff drains from 4 beds into the trench. It was recorded during every storm at daytime, and runoff collected during the nighttime was recorded in the morning. Each time after measurement, the trench was cleaned from incoming sediments (Belay et al. 2020). For dry drip and overhead irrigation periods, the return flow or excess water (runoff) was zero. The amount of percolated water (leachate) was monitored every 10 days using a wetting front detector (WFD) installed 40 cm below the soil surface (Belay et al., (2020). The runoff data was used to calibrate the APEX model for hydrology.

Sampling runoff and leachate

During the wet period, from collected runoff, a water sample of 50 mL (20 mL for NO_3-N, 10 mL for PO_4-P) was collected for determining the concentration of nutrients (i.e., NO_3-N and PO_4-P) where about 10 sampling dates are randomly selected throughout the pepper growing period. Available phosphorus and NO_3-N concentrations were determined using the Palintest photometer 7500 tests. The nitrate-nitrogen and available phosphorus loads were calculated by multiplying the drainage volumes for each period with the corresponding measured NO_3-N and PO_4-P concentrations.

Soil moisture

Soil moisture at the top 20 cm depth was monitored using time domain reflectometry (TDR) probes (TDR 200 Spectrum Technology Inc.). The TDR was not installed type. Rather, two agricultural extension agents were trained to measure the soil moisture each time by inserting a pair of 20 cm length TDR rods into the soil. TDR measurement was conducted before an irrigation event for each treatment. A detail of the process was explained by Belay et al (2020). The soil moisture data was used to compare with the model root zone soil moisture.

5.2.7 Soil Characteristics

Soil samples were collected at the beginning of the experiment (2016), and after 3 years (2019) for testing bulk density, pH (H2O, 1:2.5), electrical conductivity, cation exchange capacity, available potassium, available phosphorus, total nitrogen, organic matter, organic carbon, field capacity, permanent wilting point, and soil texture. Sampling was made at two soil depths: the top 0-30 cm, and 30-60 cm. About 1 kg of the composite soil sample was prepared for further soil laboratory analysis. A cylinder, drop-hammer core sampler with a 5 cm height (h) and 5 cm diameter (d) was driven into the soil with blows from a drop hammer to determine bulk density. The cylinder containing an undisturbed soil core was then removed and trimmed to the end, and volume was calculated. The weight of the soil core was then determined after drying in an oven at 105°C for about 24 hours (O'Kelly 2004). Average soil characteristics data of experimental plots are shown in Table 5-1.

Table 5- 1: Average soil characteristics of experimental plots determined in a soil laboratory. "√" Mark indicates that soil variable was used as an input in the APEX model for each treatment.

Soil characteristics	Initial (2016) Test results		CA (2019) Test results		CT (2019) Test results		Remark
	0-30	30-60	0-30	30-60	0-30	30-	
Organic carbon - OC, g Kg^{-1}	2.3	2.2	4.5	4.0	4.0	3.7	√
Total nitrogen-TN, g Kg^{-1}	0.17	0.17	0.36	0.26	0.31	0.24	
Electric conductivity-EC, dS/m	0.13	0.09	0.39	0.37	0.36	0.31	
Cation exchange capacity-CEC,	24.0	25.0	38.0	41.0	37.0	39.0	√
pH (H2O, 1:2.5)	6.0	5.9	5.5	5.4	5.5	5.4	√
Available-phosphorus, mg Kg^{-1}	21.0	8.5	30.2	30.7	26.7	22.9	√
Available, potassium, mg Kg^{-1}	1111.0	792.0	143.0	25.0	33.0	29.0	√
Field capacity, cm^{3} cm^{-3}	34.0	30.0	31.0	28.0	31.0	28.0	√
Permanent wilting point, cm^{3} cm^{-3}	22.0	21.0	22.0	21.0	22.0	21.0	√
Bulk density, g/cm^{-3}	1.22	1.32	1.22	1.32	1.22	1.32	√
Sand, g Kg^{-1}	39.0	22.0	28.0	27.0	25.0	24.0	√
silt, g Kg^{-1}	27.0	25.0	31.0	25.0	33.0	29.0	√

5.2.8 The APEX Model

We used Soil Conservation Service Curve Number method (SCS-CN) method in the APEX model as clearly described by Assefa et al. (2018). APEX simulates watershed or plot level processes primarily based on weather data, soil types and their characteristics, topography, vegetation, and management practices (Wang et al., 2014). The most common practices for use in APEX which were properly monitored each season in this study include tillage, planting, fertilizer, irrigation, and mulch application details (date, frequency, amount, type, and harvest). APEX input data were properly organized in the "APEX editor" macro environment to run the model using a calibrated executive application file in a similar way as Assefa et al. (2020) described. A fixed irrigation application rate of overhead and drip irrigation was provided in the APEX model. The most important management factors for the CA other than the control treatment were the use of grass mulch and no-tillage practices and were provided in the management files.

APEX model used atmospheric N inputs, fertilizer and manure N applications, crop N uptake, organic N transport on sediment; and nitrate-nitrogen (NO_3-N) losses in leaching, surface runoff, and other processes. Nitrate-nitrogen (NO_3-N) losses in runoff were used for calibrating the nutrient balance based on the observed data. Amounts of NO_3-N contained in the runoff were estimated as products of the volume of water and the average losses. The loading function considers sediment yield, organic N loss in the soil surface, and an enrichment ratio (Williams, 1995). ADDMULCH operation was in APEX version 1501 (in 2017 release) which was explained in detail by Assefa et al. (2018).

5.2.9 APEX model calibration and validation at the seasonal time scale

APEX model was calibrated for runoff and nutrients using the observed data of experimental plots under CA and CT systems with continuous vegetable production (2017 through 2019). Some hydrological parameters have been calibrated by Assefa et al. (2018) for the tilled system based on streamflow data at a watershed scale which was not calibrated according to plot level, and they transferred model parameters to the APEX plot level simulation at the experimental site by considering scale effect of parameters. Experimental plots were divided into four data sets for calibration, and four data sets for validation as we could not get the same crop every year for modeling crop yield as stated by Assefa et al. (2020). In a 3-year vegetable experiment, onion and garlic crops have been used in the first dry irrigation phase while green pepper was used in the second supplementary irrigation phase. For the dry irrigation phase, onion and garlic crops have been validated using APEX by Assefa et al. (2020). In this study, we focused on modeling pepper yield using the three seasons observed yield data of the on-farm plots, which were not calibrated for the site.

In this study, some of the parameters (Table 5-2) were modified using observed runoff and soil moisture data for both tilled (CT) and conservation agriculture (CA) at the plot level. We then used the fitted values of the most sensitive calibrated parameters for the site. The most sensitive parameters (parameter: fitted value), according to Assefa et al. (2018), used in this study include Hargreaves potential evapotranspiration (PET) equation exponent (PARM-34: 0.6), runoff CN residue adjustment parameter (PARM-15:0.25), runoff volume adjustment factor (PARM-92:0.6), runoff CN initial abstraction (PARM-20:0.191), soil water lower limit (PARM-5:0.4), and soil evaporation coefficient (PARM-12:1.512), in the order of decreasing influence (Assefa et al. 2018). Besides, we also used PARM-23, PARM-49 and PARM-61 for calibration purposes. For nutrient dynamics studies, only Param 14 (Nitrate leaching ratio) was more sensitive and was adjusted using the observed data of nitrogen and phosphorus in runoff. In all cases, we used the manual calibration technique. All other values were managed in the same way as used by Assefa et al. (2018). After calibration and validation, the unmeasured water and nutrient balance components were compared between CA and CT practices.

5.2.10 Model performance statistical measures

We used commonly used statistical measures to evaluate APEX model performance in the adjustment of some parameters in runoff and nutrient components. These include Nash – Sutcliffe efficiency (NSE), and Coefficient of determination (r^2) according to Moriasi et al. (2007) and Wang et al. (2012).

5.3. RESULTS

5.3.1 Calibration of APEX for hydrology and nutrients

Runoff

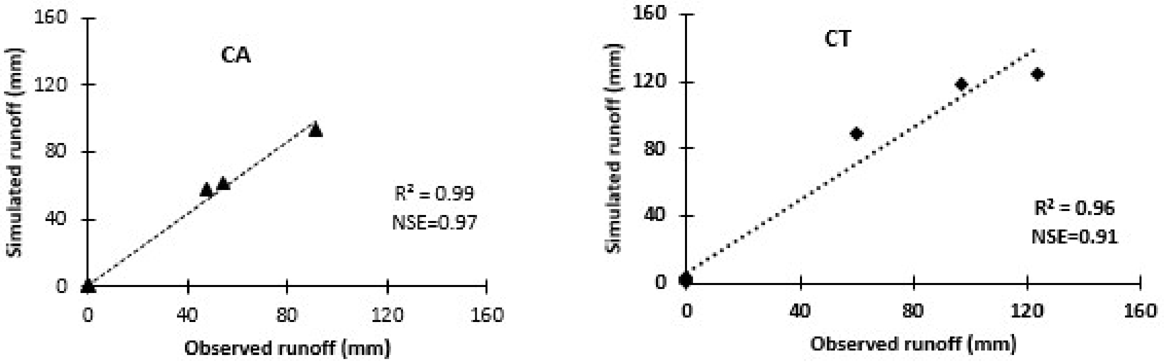
APEX calibrations of runoff during the crop growth period were improved through the adjustment of runoff parameters (Table 5-2) until the simulated runoff agreed with the observed runoff. The most sensitive parameters, in the order of importance, are shown in Table 5-2 with great modification for some as compared with the parameters set by Assefa et al. (2018).

Table 5-2: Water balance sensitive parameters, parameter value range, default value, and adjusted/calibrated values for water balance.

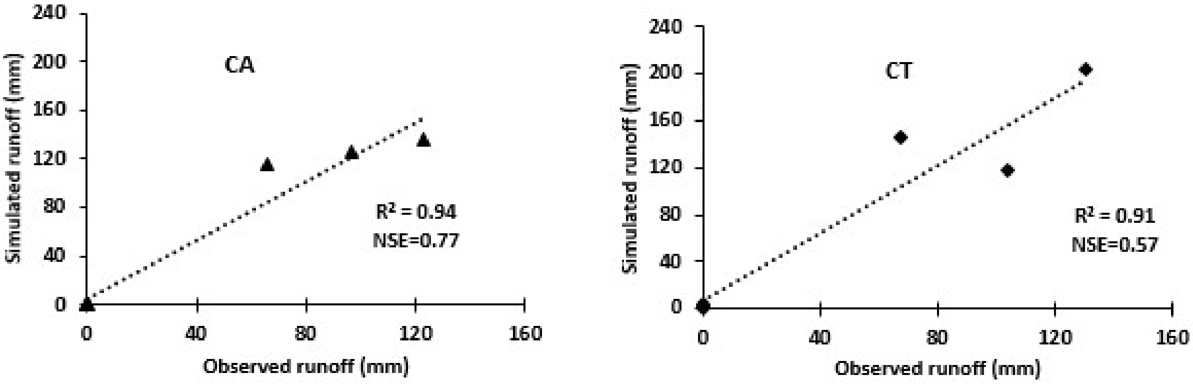
parameters	Parameter range	Assefa et al. (2018)	Calibrated values for CA	Calibrated values for CT
Param 12	1.5-2.5	1.5	1.5	2
Param 17	0-0.5	0.5	0.45	0.4
Param 20	0.05-0.4	0.191	0.191	0.2
Param 23	0.0023-0.0032	0.0032	0.0032	0.0032
Param 49	0.1-15	0.3	6*	10*
Param 61	0.05-0.95	0.2	0.95	0.95

** Parameter value valid for pepper crop.*

The APEX model simulation results of all the above (Table 5-3) parameter values across the crop growth period exhibited a very good performance with r^2=0.99 for CA and r^2 = 0.96 for CT, and with NSE =0.97 for CA and with NSE=0.91 for CT during calibration (Figure 5-6). The model results during validation across crop growth period also exhibited reasonble performance with r^2=0.94 for CA and r^2 = 0.91 for CT and with NSE =0.77 for CA and with NSE=0.57 for CT (Figure 5-6). The simulated runoff was greater than the observed runoff for both calibration and validation. An average simulated runoff reduction of 70% was achieved under CA compared with the CT during calibration while it showed a runoff reduction under CA of about 65% during validation compared with the CT. The average observed runoff showed about 35-45% lower under CA compared with the CT. Observed and simulated runoff during the three dry seasons was approximately zero as shown in Figure 5-6.



(a) Calibration case

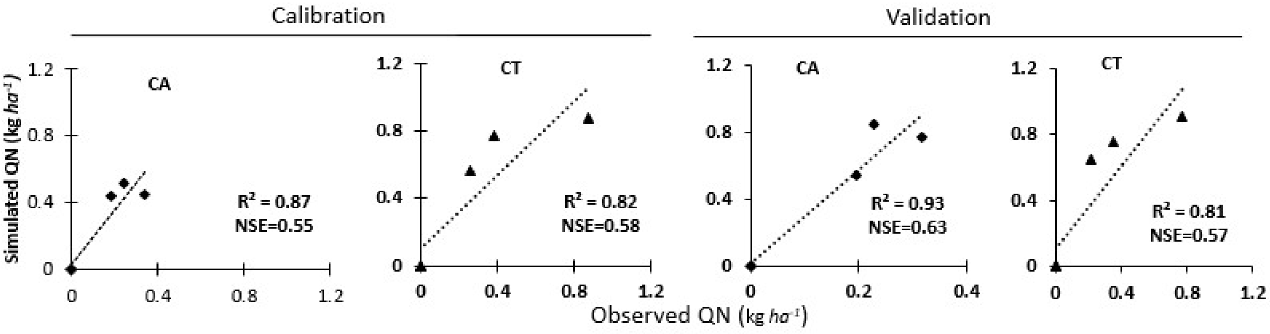


(b) Validation case

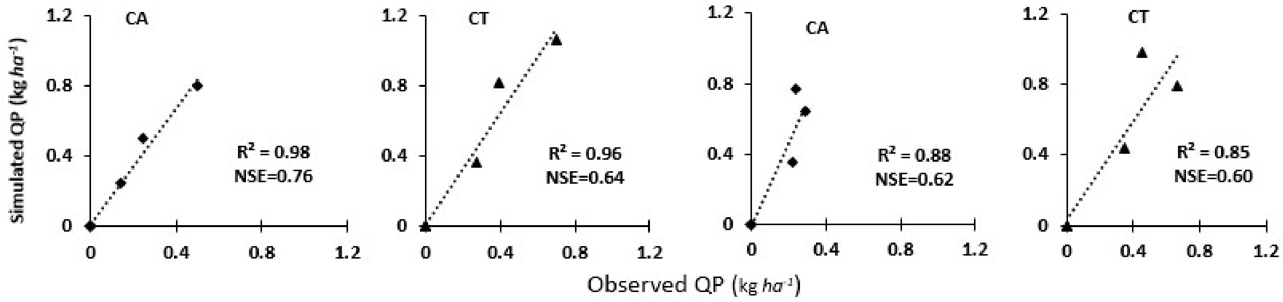
Figure 5- 6: Average observed versus simulated runoff for treatments in the crop periods (1st cycle-October to February (dry), and 2nd cycle –March to August-(rain)) and the results of model performance measures; coefficient of determination (r2) and Nash-Sutcliffe efficiency (NSE). The dry period runoff results (three seasons) were approximately zero for both simulated and observed cases.

Nutrient

APEX model simulation of nitrogen load in runoff (QN) for CA treatment was in close agreement with observed values with r^2=0.87, NSE= 0.35 and under calibration case and with r^2=0.82, NSE=0.58 under validation case (Figure 5-7). Similarly, APEX simulation of QN for CT gave a good performance with r^2=0.93, NSE= 0.63 under calibration case and with r^2=0.81, NSE=0.57 under validation case (Figure 5-7). APEX model performance using NSE measure showed poor performance under CA treatment compared with CT treatment. APEX performance was satisfactory based on the two (r^2 and NSE) model performance measures for both CA and CT treatments except for calibration case in CA (NSE=0.55). QN in this phase was nil since there was no or little runoff in dry phases of the drip irrigation system. However, CA practices showed reduced QN values for both the observed and simulated cases when compared with the CT.



(a) Simulated versus observed nitrogen in runoff (QN)



(b) Simulated versus observed phosphorus in runoff (QP)

Figure 5- 7: Average observed and simulated nitrogen in runoff (a) and phosphorus in runoff (b) under calibration and validation cases for CA and CT treatments for the crop periods and the model performance measure values; coefficient of determination (r2), and Nash-Sutcliffe efficiency (NSE).

Similarly, APEX model simulation of phosphorus load in runoff (QP) for CA treatment was in close agreement with observed values with r^2=0.98, NSE= 0.76 under calibration case and with r^2=0.88, NSE=0.62 under validation case (Figure 5-7). Similarly, APEX simulation of QP for CT showed good performance with r^2=0.96, NSE= 0.64 under calibration case and with r^2=0.85, NSE=0.60 under validation case (Figure 5-7). APEX model performance using NSE measure showed poor performance under CT treatment compared with CA treatment. APEX performance was a very good result in terms of r^2 and NSE for both CA and CT under calibration and validation cases. Similarly, since there was no or little runoff in dry phases of the drip irrigation system, QP in this phase was nil. However, CA practices showed reduced QP values for both the observed and simulated cases when compared with the CT.

Crop Yield

Onion and garlic crops have been simulated and validated by Assefa et al. (2020), however, in a 3-year vegetable experiment, green pepper was used in the second supplementary irrigation phase which was not validated by Assefa et al. (2020). After runoff and nutrient calibration, the crop parameters such as biomass-energy ratio (WA=33), harvest index (HI=0.6), optimal plant growth (TOP=25), optimum base temperature (TBS=11.5) and maximum potential leaf area index (DMLA=6) have been modified for pepper to simulate the yield at the plot level. Accordingly, the simulated and observed pepper yield of the three years were compared between treatments (Figure 5-8). It shows that the simulated yield followed similar patterns of variation with the observed pepper yield (Figure 5-8). Pepper yield from overhead irrigation (2017) was the lowest than the yield obtained from drip irrigation systems (2018 and 2019). Moreover, the APEX model showed significantly increased simulated yield under CA as compared to the CT management (Figure 5-8).

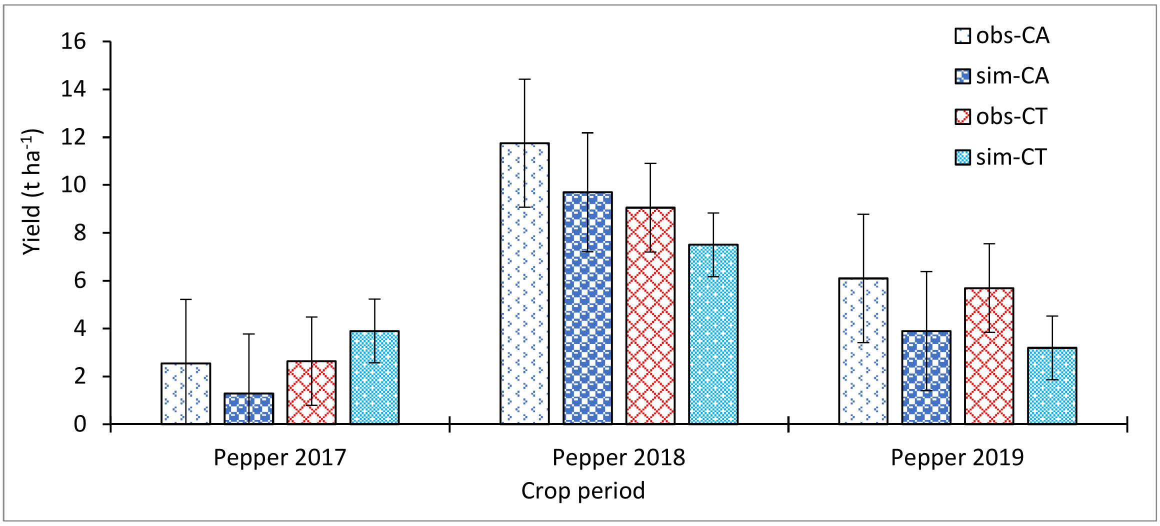


Figure 5- 8: Average observed (Obs.) versus simulated (Sim.) pepper yield (a), pepper yield (observed and simulated) in three experiential years (2017-2019) (b) under conservation agriculture and conventional tillage treatments.

5.3.2 Impacts of CA practices on unmeasured water and nutrient dynamics

(a) Evapotranspiration, percolation, and soil water results of the APEX model

After calibration and validation of the APEX model using observed runoff (Figure 5-6), the water balance components such as evapotranspiration (ET) (Figure 5-9a), root zone soil water

(RZSW), and percolation (PRK) (Figure 5-9b) were investigated to observe the impact of CA practices when compared with CT practice. It showed that the CA treatment would allow a reduction of ET by about 10-33 % during the dry and rainy periods compared with the CT, except for the rainy period of 2019 which showed an increased ET (by 15 %) in the CA (Table 5-3).

Table 5- 3: Simulated evapotranspiration (ET), percolation (PRK), and root zone soil water (RZSW) for the CA and CT treatments in the cropping periods (full and supplementary irrigation or dry and rain periods).

Variables	Treatments	Crop periods*					
		2016/2017 (Season 1)	2017 (Season 2)	2017/2018 (Season 1)	2018 (Season 2)	2018/2019 (Season 1)	2019 (Season 2)
ET	CA	373.00	388.00	229.00	693.00	265.00	632.00
	CT	411.00	500.10	304.30	696.00	353.50	537.00
	% difference	10.19	28.89	32.88	0.43	33.40	**-15.03**
PRK	CA	16.00	256.00	63.40	268.00	162.58	128.00
	CT	11.60	167.40	59.00	148.00	72.00	85.00
	% difference	37.93	53.10	7.46	81.08	125.81	50.59
RZSW	CA	97.00	85.00	79.50	85.00	82.00	52.00
	CT	78.60	72.50	75.40	83.40	64.00	35.00
	% difference	23.41	17.24	5.44	1.92	28.13	48.57

*Note: Season 1 implies crop periods from October to February (onion or garlic cropping periods) while season 2 implies crop periods from March to August (Pepper cropping period).

Similarly, the APEX model showed an increased root zone soil water **(**RZSW) in the range of 2-49% (average 21%) in the CA when compared with CT treatment over dry and rain periods under various cropping periods (Table 5-3). The variation in RZSW between treatments shown by the APEX model was the highest (>75%) during the no-soil water stress period (after irrigation and during wet periods) and was the lowest (<10 %) during the soil water-stressed period after the 1st irrigation cycle stopped (Figure 5-8b). In Figure 8b, the portion of the figure within the dashed box shows the simulated RZSW during dry and supplementary irrigated phases (variation was highest between CA and CT) while the dashed circle portion of the figure show RZSW when irrigation was stopped, and until the second planting period where the variation was lowest (Figure 5-8).

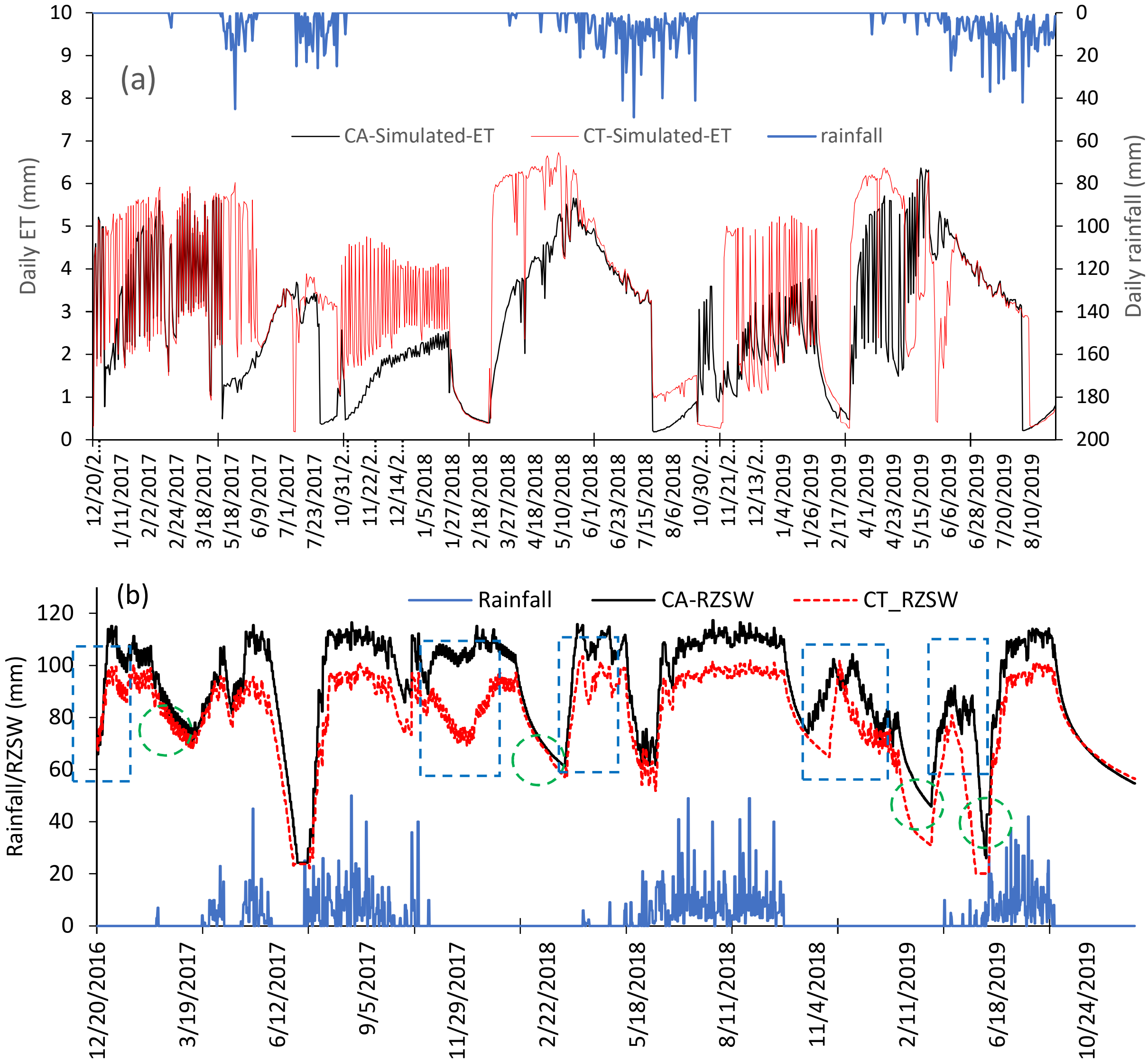
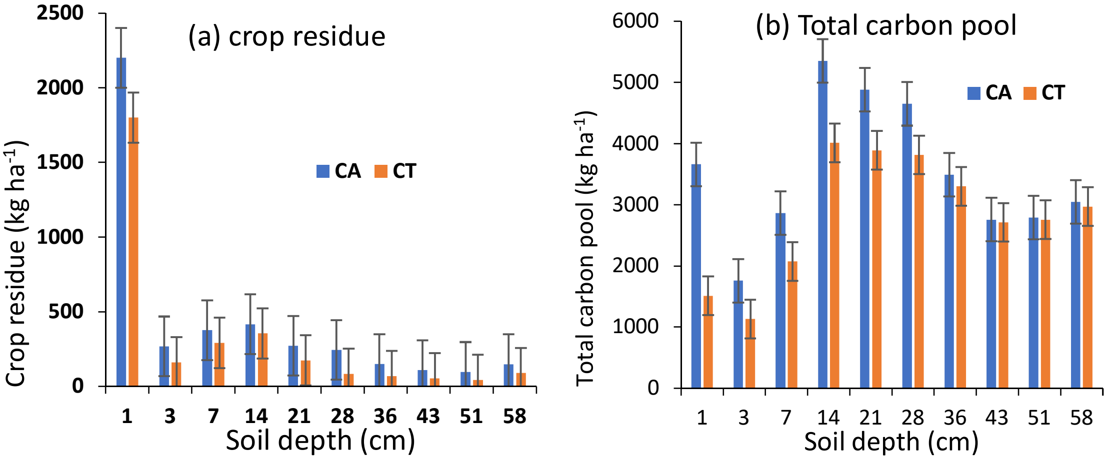


Figure 5- 9: Simulated ET (a) and root zone soil water (RZSW) (b) values for conservation agriculture (CA) and conventional tillage (CT) practices for the three years (6 irrigation cycles).

On the other hand, the response of percolation (PRK) past the root zone (20 cm) to grass mulch and no-tillage (CA) practices under both dry and supplementary irrigation phases was also well simulated by APEX showing about 8-126% higher percolation in the CA compared with CT (Table 5-3). The variation in PRK between treatments was maximum during the dry period irrigation phase and minimum during rainy periods of the experiment in the site. PRK depends on the soil water available in the upper soil layer (20 cm), greater soil water under CA may induce further percolation process to occur within the soil when compared to the CT treatment.

(b) Impacts of CA on soil quality.

Among many output options of the APEX model, crop residue, total carbon pool, net total N mineralization, and fresh organic phosphorus have been simulated across soil depths of interval approximately 1 cm (Figure 5-10). All soil organic components showed significantly higher loads (in kg ha^{-1}) under CA treatment compared with the CT for all soil depths (Figure 5-10). Simulated crop residue was significantly ($p<0.05$) higher for both treatments at 1 cm depth and lower after 35 cm soil depth which was higher under CA compared with the CT treatment (Figure 5-10a). The total carbon pool was highest near the plow depth between 14 -30 cm and lowest at 3 cm depth below the soil surface, however, it was higher under CA compared with the CT for all depths (Figure 5-10b). Similarly, Net N-mineralized was highest at the plow depth (14-21 cm) in the case of CA and was increasing with depth for CT treatment, however, greater values were simulated under CA for all depth (Figure 5-10c). Unlike the above components, simulated fresh organic phosphorus (FOP) showed higher values for the top 7 cm soil depths for both treatments however, greater simulated values were observed under CA compared with the CT (almost zero under the lower depths) (Figure 5-10d).



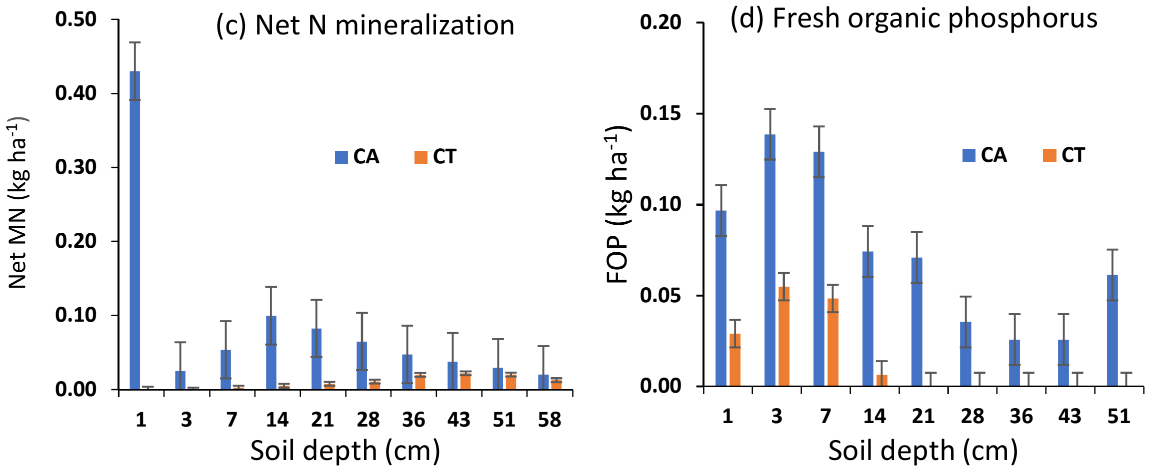


Figure 5- 10: Simulated changes in soil crop residue left on the ground (a), total carbon pool (b), total Net N mineralized (c), and fresh organic phosphorus (d) against CA and CT treatments simulated after the end of the experiment (2019).

5.4 DISCUSSION

5.4.1 Water dynamics

Runoff and Evapotranspiration

The agreement between measured and modeled runoff obtained in this work was similar in performance at watershed scale reported by Assefa et al (2018). In this study, APEX reasonably performed to simulate surface runoff in the crop growth period under CA and CT practices at the plot scale, though its performance was lower for CT (Figure 5-6). Surface mulch under CA encouraged infiltration and decreased runoff due to curve number reduction compared with CT(Williams et al. 2008). The reduction in observed runoff (4 -56%) and an increase of percolated water (20-50%) in the CA reported by Belay et al. (2020) showed an impact to increased water saving particularly during the dry irrigation phases by improving soil water storage. Besides, the use of mulch reduces runoff by absorbing the energy of raindrops and then by delaying the runoff and enhances percolated water (PRK) as reported by Mohammad and Adam (2010).

On the other hand, the APEX model has performed well in simulating ET particularly during dry phases (Table 5-3 and Figure 5-11) which is in agreement with the reduction of the evaporation of water from the soil reported by Diaz et al. (2005). Simulated ET was slightly ($p>0.05$) higher (10%) than the observed ET for CA while it showed significantly ($p<0.05$) higher

(20%) observed ET than the simulated ET under CT of the two years (Figure 5-11). However, variations in simulated ET under pepper were insignificant between CA and CT during rainfed, though it showed lower values of simulated ET for CT in 2019 as compared with 2018 (Figure 5-11). Greater reductions in ET under CA were probably due to the cooling effect (reduction in soil temperature) during dry periods as a result of surface mulch cover (Schonbeck and Evanylo 1998). The greater (14-33%) reduction in ET under CA during the dry irrigation phases of various vegetable production (Table 3) could also imply an improved water-saving (14–27%) as reported in different studies (Assefa et al. 2020, Assefa et al. 2018, Belay et al. 2020, Belay et al. 2019). Overhead irrigation system in season 2 which was conducted only in 2017 was nil as compared with the contribution of rain (95%) and therefore, had little impact to affect runoff.

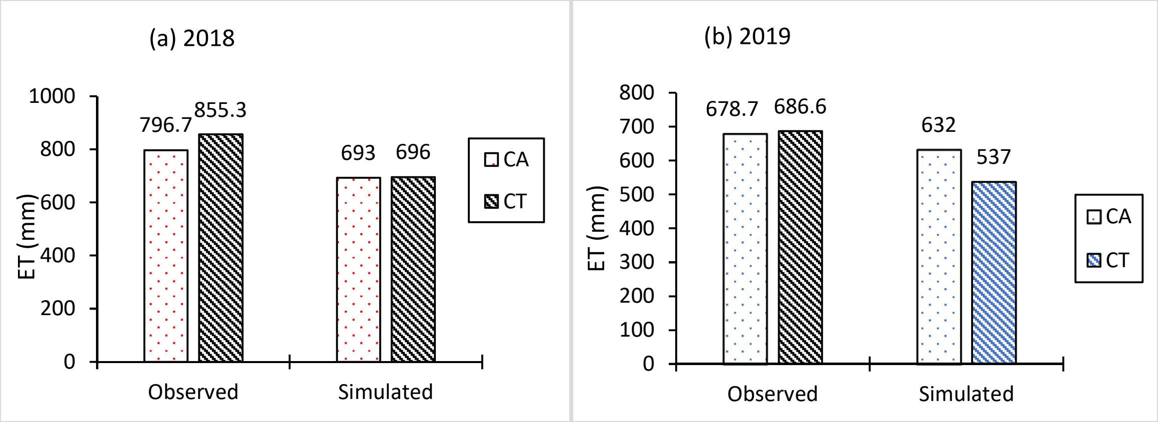


Figure 5- 11: Comparison of ET pepper crop under CA and CT treatments using measured data and simulated values for 3 supplementary irrigated seasons (season 2) as described by Belay et al. (2020).

Percolation (PRK) and root zone soil water (RZSW)

On the other hand, the observed percolated water for both treatments which was captured from only the vertical component of subsurface water was clearly explained by Belay et al. (2020). However, the result could not be compared with the simulated PRK that included all subsurface internal flows (vertical, horizontal and groundwater storage components) in the soil. The percolated water amount reported by Belay et al. (2020) was about 8-10 % of simulated PRK under CA and CT practices indicated in this study. However, the variation in simulated PRK between treatments was attributed to the use of no-tillage used to encourage less disturbance of soil pore networks and increases porosity (Kabir 2005).

In addition to this, the response of simulated RZSW to grass mulch and no-tillage practices under both dry and supplementary irrigation phases was also efficiently modeled by APEX showing a significant ($p<0.05$) difference between treatments under various cropping seasons (Table 5-3). In practice, when the water available in the soil is decreased, the potential effect of mulch becomes minimum compared to the un-mulched condition. Simulated RZSW was lower when irrigation was stopped and continued until the second planting period (Figure 5-8). This showed that APEX depicted changes in RZSW and could be used to build different farming scenarios. Similar simulated results have been reported by Assefa et al. (2018) and Golmohammadi et al. (2014). Soil moisture and temperature are the most influential factors (Carbonell-Bojollo et al. 2019, Lal 2004) to affect crop growth and microorganism activity (organic matter decomposition). Indeed, soil moisture is a key factor in the activity of soil biota that breaks down OM to plant-available form (Carbonell-Bojollo et al. 2019). In such cases, CA could have more importance in regions with limited rainfall and high evaporation rates (Hobbs et al. 2008).

In this study, observed root zone soil water in the upper soil layer (20 cm) in selected 4 crop periods was plotted with the simulated value of RZSW (20 cm soil depth) to observe the impact of CA practice compared with the CT (Figure 5-12). Though the simulated soil water was much higher compared with the observed, both the observed and simulated RZSW in CA was significantly ($p<0.05$) higher compared with the CT, particularly during dry phases (Figure 5-12a and c).

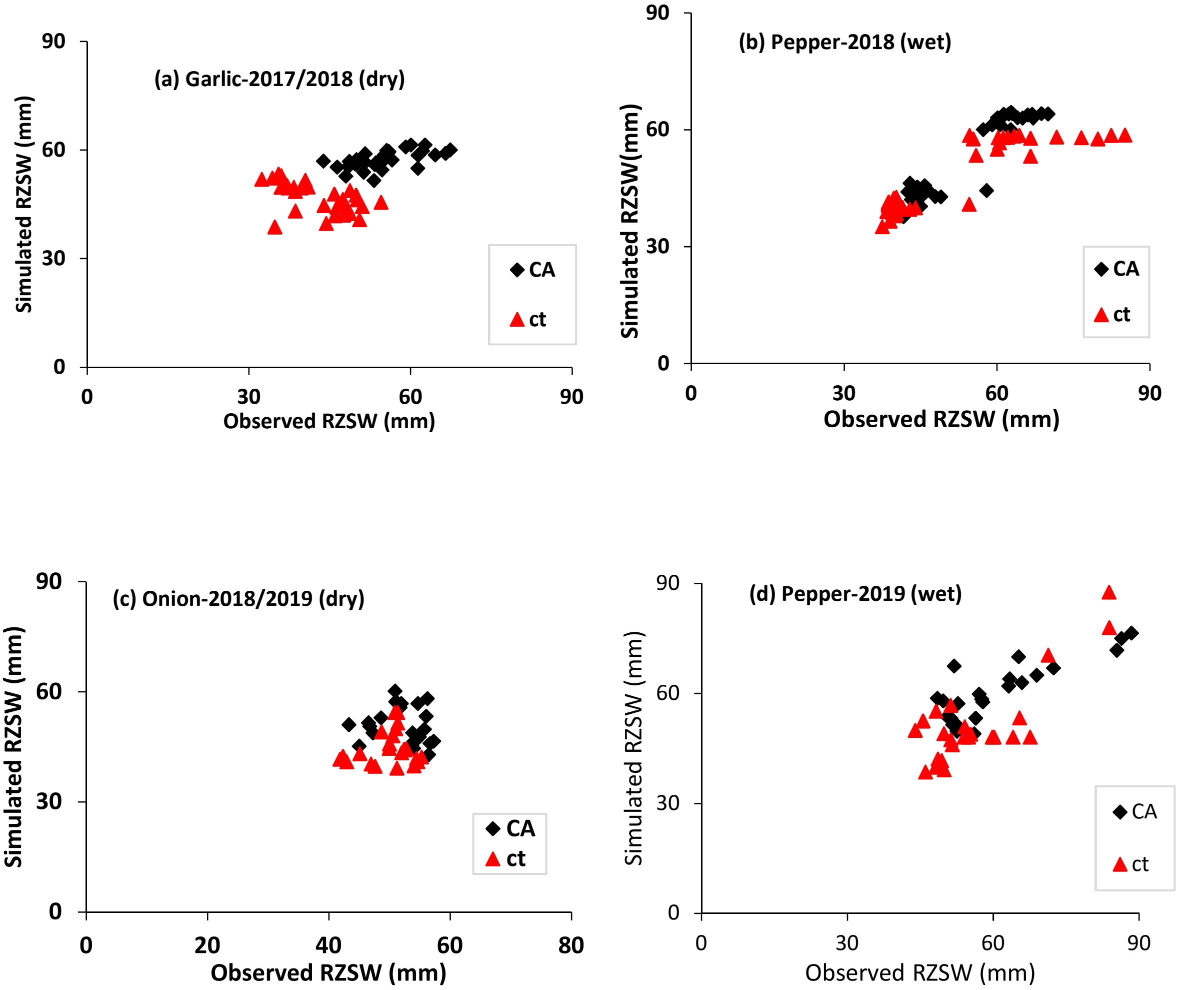


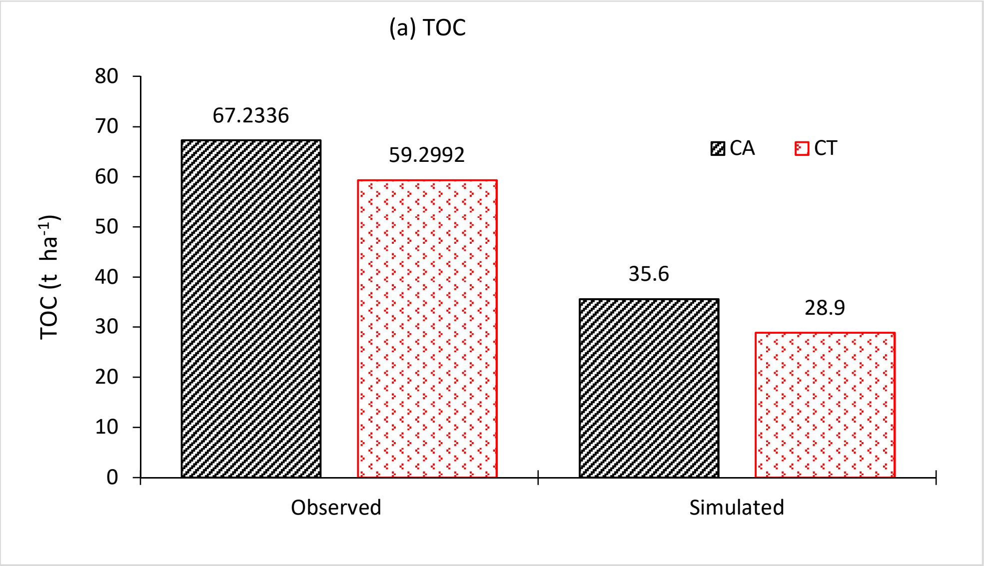
Figure 5- 12: Comparison of the RZSW under CA and CT treatments using measured data (20 cm soil depth) and simulated values (20 cm depth) for selected 4 irrigation periods. Observed RZSW was the average of calibrated TDR readings for the upper 20 cm soil layer measured before irrigation. Garlic and Onion (a and c) were selected for the dry phase while pepper (b and d) were selected for the supplementary phase.

5.4.2 Nutrient Dynamics

We found APEX model has performed well to simulate QN for both treatments with lower NSE value under CA treatment compared with CT which indicated simulated QN was greater than the observed QN since APEX has also predicted increased simulated crop residue (Figure 5-10a)., total carbon pool (Figure 5-10b) and Net N-mineralized (Figure 5-10c) due to the added mulch under CA treatment which was not practical for the observed case. However, CA practices showed reduced QN values for both the observed and simulated cases when compared with the CT. The N-loss is also similar to those found by Cavero et al. (2012) in the Mediterranean region at the watershed level.

Similarly, the APEX model simulation of phosphorus load in runoff (QP) in both treatments was in close agreement with observed values under calibration and validation conditions (Figure 5-7). However, APEX model performance using NSE measure showed lower performance under CT treatment compared with CA treatment. However, CA practices showed reduced QP values for both the observed and simulated cases when compared with the CT while APEX simulated increased fresh organic phosphorus (Figure 5-11d) under CA treatment compared with CT treatment at different soil depths. The result was also in line with Borah et al. (2006) and Chaplot et al. (2004). Moreover, APEX was proved to be an effective tool to assess CA practice as the best practice for reducing N and P loads in the runoff because of its barrier effects to reduce sediment-laden nutrients from surface runoff. The average simulated QP reduction under CA could be associated with reductions in a runoff, as QP calculation in APEX considers the volume of runoff (Wang et al. 2008). In this regard, the relevance of the CA system and its management for off-site N and P pollution control has been pointed out in several works where lower N losses were found in efficient drip irrigation systems with typical low return flow (no-runoff), and higher losses in inefficient surface irrigation systems with typical high excess unused irrigation water (Assefa et al. 2020, Belay et al. 2020, Klocke et al. 1999, Spalding et al. 2001).

In connection with simulated crop residue, an increase in net N mineralization (Figure 5-10c) with the microbial decomposition of organic N from manure, organic matter, and mulches/crop residues (Cambardella et al. 2003) has also released soluble inorganic nutrients in plant-available form. Temperature and soil moisture could play a greater role in this process (Diacono and Montemurro 2011). In this regard, mineralized N under CA was highest near the optimum root depth (14-21 cm) where most of the microorganisms exist and then decreased with depth. It means that nutrients in the organic matter must undergo mineralization before they can be used by plants. The total carbon pool was highest near the plow depth between 14 -30 cm and lowest at 3 cm depth below the soil surface, however, it was higher under CA compared with the CT for all depths due to similar reasons (Figure 5-10b). We also tried to compare the observed total soil organic carbon (TOC) and total nitrogen (TN) at the end of the experiment (2019) with the simulated one for both treatments (Figure 5-13).



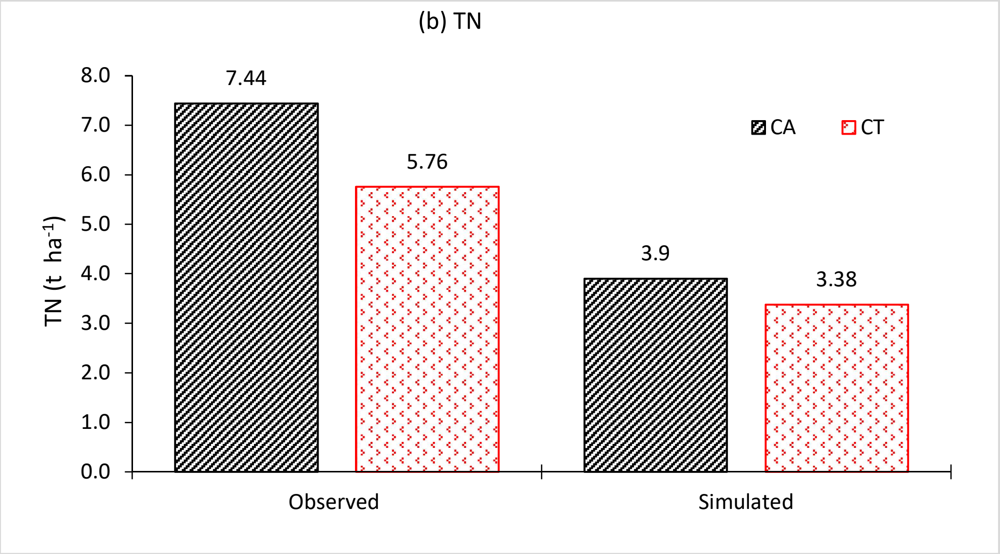


Figure 5- 13: Comparison of observed and simulated total organic carbon (TOC) and total nitrogen (TN) under CA and CT treatment.

The simulated TOC was about 1.9 and 1.7 times lower than the observed respectively for CT and CT treatments (Figure 5-12a) while simulated TN was about 1.9 and 2.05 times lower than the observed respectively for CA and CT (Figure 5-12b). Both observed and simulated TOC and TN were slightly greater under CA treatment compared with the CT due to an increased crop residue and mulch and the associated increase of TOC and TN from such input (Figure 5-10c) by microbial decomposition of organic N from manure, organic matter, and mulches/crop residues (Cambardella et al. 2003). The lower simulated values may be attributed to the higher simulated nitrogen in runoff compared with the observed as depicted in Figure 5-7a.

5.4.3 Yield and crop biomass

Simulated pepper yield followed similar patterns with the observed yield, and the variation between treatments followed the same pattern (Figure 5-8). Pepper yield from overhead irrigation (2017) was the lowest than the yield obtained from drip irrigation systems (2018 and 2019) which were probably attributed to leaf blight associated with the application of impure well water over the whole aboveground plant parts (Xie et al. 1999). In addition to this, the contribution of irrigation in 2017 (5%) was less than the contribution of irrigation in 2018 (46%) as compared to the rain which again indicated that the reduction in yield might be due to waterlogging effect (Belay et al. 2020). Besides, transplanting of pepper about 2 months before a rainy season can improve the yield since the rain season coincides with flowering and fruit development stages Jameiz et al., (2000). Moreover, the APEX model showed significantly increased yield under CA as compared to the CT management (Figure 5-8) which also showed significantly higher simulated crop biomass under CA treatment compared with the CT (Figure 5-10a).

5. 5 Conclusion

In conclusion, APEX simulations show decreased evapotranspiration, runoff, nitrogen, and phosphorus loads in runoff while it also showed an increment in root zone soil water and percolation under CA compared with the CT treatment. The reason for the different responses of simulated variables under CA and CT practices was obviously due to the combined use of grass mulch cover and no-tillage practices under CA treatment. Observed data for runoff and soil water content indicated similar trends in variation among treatments. Thus, APEX simulations can be used to effectively select the best management vegetable production scenarios compared to the existing practices. The model can therefore be used for assessing the effectiveness of various vegetable production scenarios and water uses to inform the farmer. The improvement of irrigation water saving and the decrease in the runoff for the vegetable crops allow us to conclude that mulch cover with no-tillage practices can be used as an effective farming practice in alleviating water shortage issues experienced in water shortage areas.

Reference

Antle, J.M., Basso, B., Conant, R.T., Godfray, H.C.J., Jones, J.W., Herrero, M., Howitt, R.E., Keating, B.A., Munoz-Carpena, R. and Rosenzweig, C. , 2017. Towards a new generation of agricultural system data, models and knowledge products: Design and improvement. 155, 255-268.

Assefa, T., Jha, M., Reyes, M., Worqlul, A., Doro, L., Tilahun, S., W., 2020. Conservation agriculture with drip irrigation: Effects on soil quality and crop yield in sub-Saharan Africa. *J.Soil and Water Cons.* 75(2), 209-217.

Assefa, T., Jha, M., Reyes, M. and Worqlul, A.W., 2018. Modeling the impacts of conservation agriculture with a drip irrigation system on the hydrology and water management in sub-Saharan Africa.*Sustainability* 10(12), 4763.

Belay, S.A., Assefa, T.T., Prasad, P., Schmitter, P., Worqlul, A.W., Steenhuis, T.S., Reyes, M.R. and Tilahun, S.A., 2020. The Response of Water and Nutrient Dynamics and of Crop Yield to Conservation Agriculture in the Ethiopian Highlands. *Sustainability* 12(15), 5989.

Belay, S.A., Schmitter, P., Worqlul, A.W., Steenhuis, T.S., Reyes, M.R. and Tilahun, S.A., 2019. Conservation Agriculture Saves Irrigation Water in the Dry Monsoon Phase in the Ethiopian Highlands. *Water* 11(10), 2103.

Borah, D., Yagow, G., Saleh, A., Barnes, P., Rosenthal, W., Krug, E. and Hauck, L., 2006. Sediment and nutrient modeling for TMDL development and implementation. *Transaction of ASABE* 49(4), 967-986.

Carbonell-Bojollo, R., Veroz-Gonzalez, O., Ordoñez-Fernandez, R., Moreno-Garcia, M., Basch, G., Kassam, A., Repullo-Ruiberriz de Torres, M.A. and Gonzalez-Sanchez, E., 2019. The Effect of Conservation Agriculture and Environmental Factors on CO2 Emissions in a Rainfed Crop Rotation. *Sustainability* 11(14), 3955.

Cavero, J., Barros, R., Sellam, F., Topcu, S., Isidoro, D., Hartani, T., Lounis, A., Ibrikci, H., Cetin, M. and Williams, J., 2012. APEX simulation of best irrigation and N management strategies for off-site N pollution control in three Mediterranean irrigated watersheds. *Agri. Water Mant.* 103, 88-99.

Chaplot, V., Saleh, A., Jaynes, D., Arnold, J., 2004. Predicting water, sediment and NO 3-N loads under scenarios of land-use and management practices in a flat watershed. *Water, Air, and Soil Pollution* 154(1-4), 271-293.

Chung, S., Gassman, P.W., Kramer, L., Williams, J.R. and Gu, R. , 1999. Validation of EPIC for two watersheds in southwest Iowa. *J. of Env. Quality* 28(3), 971-979.

Clarke, N., Bizimana, J.-C., Dile, Y., Worqlul, A., Osorio, J., Herbst, B., Richardson, J.W., Srinivasan, R., Gerik, T.J. and Williams, 2017. Evaluation of new farming technologies in Ethiopia using the Integrated Decision Support System (IDSS). *Agri.Water Mant.* 180, 267-279.

Davis, D., Gowda, P., Mulla, D. and Randall, 2000. Modeling nitrate nitrogen leaching in response to nitrogen fertilizer rate and tile drain depth or spacing for southern Minnesota, USA. *J. of Env. Quality* 29(5), 1568-1581.

Di Paola, A., Valentini, R., Santini, 2016. An overview of available crop growth and yield models for studies and assessments in agriculture. *J. the Sci. of Food and Agri.* 96(3), 709-714.

Diaz, F., Jimenez, C. and Tejedor, 2005. Influence of the thickness and grain size of tephra mulch on soil water evaporation. *Agri.Water Mant.* 74(1), 47-55.

Francesconi, W., Smith, D.R., Heathman, G.C., Wang, X. and Williams, 2014. Monitoring and APEX modeling of no-till and reduced-till in tile-drained agricultural landscapes for water quality. *Transaction of ASABE* 57(3), 777-789.

Gassman, P.W., Williams, J.R., Wang, X., Saleh, A., Osei, E., Hauck, L.M., Izaurralde, 2009. The Agricultural Policy Environmental Extender (APEX) model: An emerging tool for landscape and watershed environmental analyses. *R. César; and Flowers*

Golmohammadi, G., Prasher, S., Madani, A. and Rudra, 2014. Evaluating three hydrological distributed watershed models: MIKE-SHE, APEX, SWAT. *Hydrology* 1(1), 20-39.

Green, W.H. and Ampt, 1911. Studies on Soil Phyics. *Transaction of ASABE* 4(1), 1-24.

Hobbs, P.R., Sayre, K. and Gupta, 2008. The role of conservation agriculture in sustainable agriculture. T*ransaction of ASABE* 363(1491), 543-555.

Iizumi, T., Yokozawa, M., Sakurai, G., Travasso, M.I., Romanenkov, V., Oettli, P., Newby, T., Ishigooka, Y., Furuya, 2014. Historical changes in global yields: major cereal and legume crops from 1982 to 2006. J.*Global Ecol. and biogeography* 23(3), 346-357.

Jaimez, R.; Vielma, O.; Rada, F.; García-Núñez, C.,2000. Effects of water deficit on the dynamics of flowering and fruit production in Capsicum chinense Jacq in a tropical semiarid region of Venezuela. J. Agron. Crop Sci., 185, 113–119.

Kabir, Z., 2005. Tillage or no-tillage: impact on mycorrhizae. *Canadian Journal of Plant Science* 85(1), 23-29.

Kiniry, J., Cassida, K., Hussey, M., Muir, J., Ocumpaugh, W., Read, J., Reed, R., Sanderson, M., Venuto, B., Williams, 2005. Switchgrass simulation by the ALMANAC model at diverse sites in the southern US. *J.B. and Bioenergy* 29(6), 419-425.

Klocke, N., Watts, D.G., Schneekloth, J., Davison, D.R., Todd, R. and Parkhurst, 1999. Nitrate leaching in irrigated corn and soybean in a semi-arid climate. *Transaction of ASABE* 42(6), 1621.

Kumar, S., Udawatta, R.P., Anderson, S.H. and Mudgal, 2011. APEX model simulation of runoff and sediment losses for grazed pasture watersheds with agroforestry buffers. *J. Agroforestry Systems* 83(1), 51-62.

Lal, R., 2004. Soil carbon sequestration to mitigate climate change. Geodema 123(1-2), 1-22.

Leonard, R., Knisel, W. and Still, 1987. GLEAMS: Groundwater loading effects of agricultural management systems. *Transaction of ASABE* 30(5), 1403-1418.

Marin, F.R., Ribeiro, R.V., Marchiori, 2014. How can crop modeling and plant physiology help to understand the plant responses to climate change? A case study with sugarcane. *Theoretical and Experimental Plant Physiology* 26(1), 49-63.

Mohammad, A.G. and Adam, 2010. The impact of vegetative cover type on runoff and soil erosion under different land uses. *Catena* 81(2), 97-103.

Moriasi, D., Wilson, B., Douglas-Mankin, K., Arnold, J. and Gowda, 2012. Hydrologic and water quality models: Use, calibration, and validation. *Transaction of ASABE 55(4), 1241-1247.*

Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. and Veith, 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transaction of ASABE* 50(3), 885-900.

Müller, C., Elliott, J., Chryssanthacopoulos, J., Arneth, A., Balkovic, J., Ciais, P., Deryng, D., Folberth, C., Glotter, M. and Hoek, 2017. Global gridded crop model evaluation: benchmarking, skills, deficiencies and implications. 10(4), 1403-1422.

O'Kelly, 2004. Accurate determination of moisture content of organic soils using the oven drying method. *Tayler and Francis* 22(7), 1767-1776.

Parton, W.J., Ojima, D.S., Cole, C.V. and Schimel, 1994. A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. *Modeling of soil and plant* 39, 147-167.

Plotkin, S., Wang, X., Potter, T., Bosch, D., Williams, J., Hesketh, E. and Bagdon, 2013. APEX calibration and validation of water and herbicide transport under US Southern Atlantic Coastal Plain conditions. *Transaction of ASABE* 56(1), 43-60.

Rauff, K.O. and Bello, 2015. A review of crop growth simulation models as tools for agricultural meteorology. *J. of Agri. Sci.* 6(09), 1098.

Ray, D.K., Ramankutty, N., Mueller, N.D., West, P.C. and Foley, 2012. Recent patterns of crop yield growth and stagnation. *Nature* 3(1), 1-7.

Rivington, M. and Koo, 2010. Report on the meta-analysis of crop modelling for climate change and food security survey.*Cgiar Report.*

Sharifi, A., Lee, S., McCarty, G.W., Lang, M.W., Jeong, J., Sadeghi, A.M.,2019. Enhancement of Agricultural Policy/Environment eXtender (APEX) Model to Assess Effectiveness of WetlandWater Quality Functions. *Water* 11(3), 606.

Spalding, R.F., Watts, D.G., Schepers, J.S., Burbach, M.E., Exner, M.E., Poreda, R.J.,2001. Controlling nitrate leaching in irrigated agriculture. *J. of Env. Quality* 30(4), 1184-1194.

Stockmann, U., Adams, M.A., Crawford, J.W., Field, D.J., Henakaarchchi, N., Jenkins, M., Minasny, B., McBratney, A.B., 2013. The knowns, known unknowns and unknowns of sequestration of soil organic carbon. *J.Agri., Ecosystems and Environment* 164, 80-99.

Talebizadeh, M., Moriasi, D., Gowda, P., Steiner, J.L., Tadesse, H.K., Nelson, A.M.,2018. Simultaneous calibration of evapotranspiration and crop yield in agronomic system modeling using the APEX model. *Agri. Water Mant.* 208, 299-306.

Tuppad, P., Santhi, C., Wang, X., Williams, J., Srinivasan, R.,2010. Simulation of conservation practices using the APEX model. *Transaction of ASABE* 26(5), 779-794.

USDA, 2004. National engineering handbook, part 630 hydrology.

Wang, X., Gassman, P., Williams, J., Potter, S., 2008. Modeling the impacts of soil management practices on runoff, sediment yield, maize productivity, and soil organic carbon using APEX. *J.Sci. and Research* 101(1-2), 78-88.

Wang, X., Williams, J., Gassman, P., Baffaut, C., Izaurralde, R., Jeong, J. and Kiniry, 2012. EPIC and APEX: Model use, calibration, and validation. *Transaction of ASABE* 55(4), 1447-1462.

Xie, J., Cardenas, E.S., Sammis, T.W., Wall, M.M., Lindsey, D.L., 1999. Effects of irrigation method on chile pepper yield and Phytophthora root rot incidence. 42(2), 127-142.

Zhang, B., Feng, G., Read, J.J., Kong, X., Ouyang, Y., Adeli, A.,2016. Simulating soybean productivity under rainfed conditions for major soil types using APEX model in East Central Mississippi. *Agri. Water Mant.* 177, 379-391.

CHAPTER 6

CONCLUSIONS

Most of the Ethiopian population lives in rural areas and the livelihood of the majority is based on rain-fed agriculture which is subject to highly irregular rainfall pattern with detrimental impact on agricultural production. Recently, small-scale irrigation as major intervention, has impacted the livelihood of farmers through increasing agricultural production. However, most agricultural practitioners including farmers have been undermining changes and impacts that can be achieved from smallholder on-farm irrigation production systems. But, recently, scientific evidences from on-farm experimental studies discoursed that there is a huge economic return from small plots of home garden vegetable productions besides technology transfer and skill building of farmers in an experiment in the Ethiopian highlands.

A 4-year conservation agriculture-based irrigated-rainfed experiment was conducted to investigate its overall impact on irrigation water use, hydrology, yield, and soil nutrient dynamics using vegetable on-farms in the Ethiopian highlands. Experimental results from irrigated vegetables in the dry monsoon phase as discussed in chapter 2, showed that the yield and irrigation water use efficiency (IWUE) was over 40% greater under conservation agriculture, while there was still about 49 mm less irrigation water usage compared with conventional tillage. This result attained from a combination of technologies has greater implications for farmers in terms of using shallow ground wells for the smallholder irrigation system to improve food and nutrition security.

In response to the adverse effects of runoff on the availability of water, soil nutrients, and soil organic matter, supplementary irrigated CA experimental studies on pepper (*Capsicum annuum L.*) production indicated that conservation agriculture practices significantly improved such input resources. It indicated reduced irrigation water use (13-23%) and runoff (29-51%) while it increased percolated water in the root zone (32-49%) when compared with conventional tillage practice. The study also revealed that conservation agriculture practice has decreased the NO_3-N load in leachate (14-46%) and runoff (100%) while there was a significant yield increase compared with the conventional tillage. The details of experimental findings have been dealt with in chapter 3.

The current Ethiopian agricultural practices could not be able to improve productivity as a result of soil quality decline due to poor management of soil and water and nutrients as discussed in chapter 3. In response to such challenges and production constraints, experimental results organized in chapter 4 indicated that organic matter, total nitrogen, and available phosphorus in the soil increased over soil layers under conservation agriculture compared with the conventional tillage practices. The higher nutrient availability in the CA was mainly attributed to the incorporation of grass mulch (85% OM) and no-tillage practices which were not applied in the control practice.

The dynamics of water and nutrients which are critical inputs for rain-fed and irrigated crop production should always be monitored in response to different farming and management practices to understand and manage these resources for optimum economic and environmental returns. However, field research was used to conduct measurements across all possible locations due to cost and time implications. In filling such gaps, the APEX model was evaluated to investigate the response of measured and unmeasured variables to different farming and irrigation management practices which is dealt with in chapter 5. Hence, the APEX model performed well in simulating the CA and the CT practices for different response variables under irrigated and supplementary irrigated vegetable production systems. Under CA practices, the model showed decreased simulated ET, runoff, nitrogen in the runoff, and simulated phosphorus loads in the runoff while it showed increased average root zone soil water, increased average percolation under CA compared with the CT treatment.

Finally, the researcher designed and farmer-managed research covered in this study, was really useful such that both the researcher and the farmer learned not only from the result but also from the process. The practical outcome from this study provides useful information for decision making for government bodies in agriculture sector to promote participatory irrigation and farming practices including conservation agriculture practices, and to consider farmers' decisions for future enhancements in water, crop and labour productivity under rainfed and irrigation production systems.

APPENDICES

A. Publications

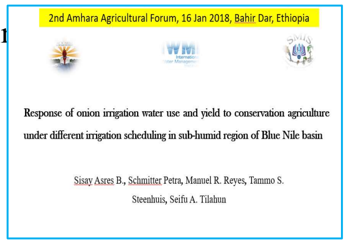
Belay, S.A., Schmitter, P., Worqlul, A.W., Steenhuis, T.S., Reyes, M.R. and Tilahun, S.A. (2019). *Conservation Agriculture Saves Irrigation Water in the Dry Monsoon Phase in the Ethiopian Highlands*. *Water* 11(10), 2103.

Belay, S.A., Assefa, T.T., Prasad, P., Schmitter, P., Worqlul, A.W., Steenhuis, T.S., Reyes, M.R. and Tilahun, S.A.J.S. (2020). *The Response of Water and Nutrient Dynamics and of Crop Yield to Conservation Agriculture in the Ethiopian Highlands*. *Sustainability* 12(15), 5989.

Belay, S.A., Assefa, T.T., Prasad, P., Schmitter, P., Worqlul, A.W., Steenhuis, T.S., Reyes, M.R. and Tilahun, S.A.J.S. (2020). Effect *Conservation Agriculture on Soil Organic Matter And Nutrient Contents Under Vegetable Production in the Ethiopian Highland*. Submitted to J. Heliyon, ELSEVIER.

B. **Conference Presentation**

1. Presented to 2nd Amhara Agricultural Forum, 16 Jan 2018, Bahi Ethiopia under the Title " *Response of Onnion irrigation water use and yield to conservation agriculture under different scheduling in subhumid regions of blue nile basin*" **Oral presentation.**



2nd Amhara Agricultural Forum, 16 Jan 2018, Bahir Dar, Ethiopia

Response of onion irrigation water use and yield to conservation agriculture under different irrigation scheduling in sub-humid region of Blue Nile basin

Sisay Asres B., Schmitter Petra, Manuel R. Reyes, Tammo S. Steenhuis, Seifu A. Tilahun

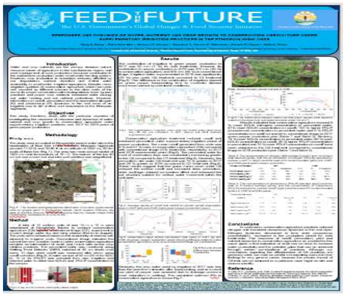
2. Presented to ASMC and SIPS IN Project Advisery committee Annual meeting , October 24, 2018, Bahir Dar, Ethiopia; Tittle: "*Irrigation water use and yield under conservation agriculture for various vegetables*". **Oral presentation**

Irrigation water use and yield under conservation agriculture for various vegetables

Sisay Asres B.[1], Abeyou Wale W[5], Schmitter Petra[2], Manuel R. Reyes[4], Tammo S. Steenhuis[3], Seifu A. Tilahun[1].

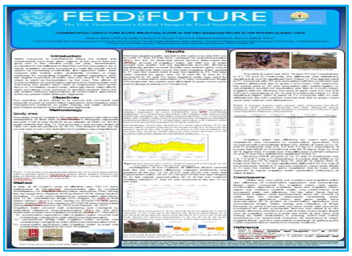
October 26,2018
Bahir Dar Ethiopia

3. 7th EAI International Conference on Advancement of Science and Technology-ICAST-2019, Bahir Dar, Ethiopia.Under the title:" *Response and dynamics of water, nutrients and crop growth to conservation agriculture under supplemntary irrigation practices in the ethiopian highlands.* **Poster presentation.**



FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

4. 7th EAI International Conference on Advancement of Science and Technology-ICAST-2019, Bahir Dar, Ethiopia.Under the title:" *Conservation Agriculture Saves Irrigation Water in the Dry Monsoon Phase in the Ethiopian Highlands.* **Poster presentation**.



FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

5. 8th EAI International Conference on Advancement of Science and Technology-ICAST-2020: October 2-4, 2020, Bahir Dar, Ethiopia. Under the title: *Conservation Agriculture impacts and its implications to the sustaiability of smallholder irrigated production systems*. **Oral presentation.**

8th EAI International Conference on Advancements of Science and Technology- ICAST 2020: October 2 - 4, 2020 Bahir Dar, Ethiopia

Conservation agriculture impacts and its implications to the sustainability of smallholder irrigated production systems

Bahir Dar Institute of Technology
Bahir Dar University

Sisay A. Seifu A. Tammo S. Manny R.
Petra S. Abeyou W.

6. 2021 SIIL Virtual Annual Meeting Poster Competetion on January 28,2021, Kansas State University, Under the title: " *<u>Conservation Agriculture Saves Irrigation Water in the Dry Monsoon Phase in the Ethiopian Highlands</u>*.
   Poster presentation. 2nd Place Award

FEED THE FUTURE
The U.S. Government's Global Hunger & Food Security Initiative

SECOND PLACE AWARD

Sustainable Intensification Innovation Lab (SIIL) at Kansas State University

hereby presents this certificate to:

Sisay A. Belay

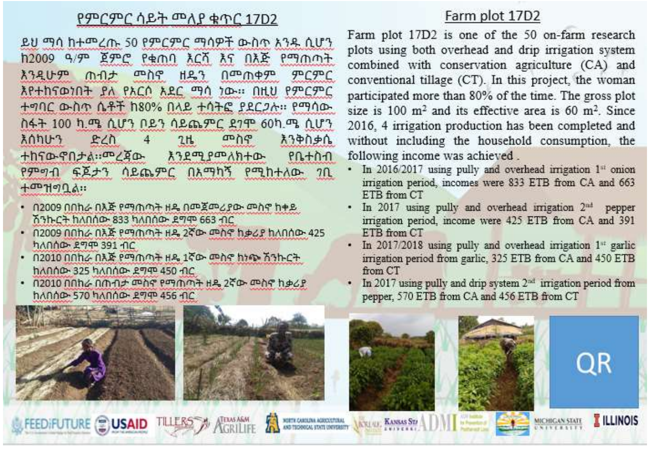
For receiving second place for their poster on
"Conservation Agriculture Saves Irrigation Water in Dry Monsoon Phase in Ethiopian Highlands"

2021 SIIL Virtual Annual Meeting Poster Competition
on **January 28, 2021**

P.V. Vara Prasad, Ph.D.
University Distinguished Professor; and
Director, SIIL
Kansas State University

B. Jan Middendorf, Ph.D.
Associate Director, SIIL
Kansas State University

7. **Posters** at Experiment Site Open for Farmers and International Visitors in Two languages.



የምርምር ሳይት መለያ ቁጥር 17D2

ይህ ማሳ ከተመረጡ 50 የምርምር ማሳዎች ውስጥ አንዱ ሲሆን ከ2009 ዓ/ም ጀምሮ የቁጠባ እርሻ እና በእጅ የማጠጣት እንዲሁም ጠብታ መስኖ ዘዴን በመጠቀም ምርምር እየተከናወነበት ያለ የአርሶ አደር ማሳ ነው። በዚህ የምርምር ተግባር ውስጥ ሴቶች ከ80% በላይ ተሳትፎ ያደርጋሉ። የማሳው ስፋት 100 ካ.ሜ ሲሆን ቦይን ሳይጨምር ደገሞ 60ካ.ሜ ሲሆን እስካሁን ድረስ 4 ጊዜ መስኖ እንቅስቃሴ ተከናውኖበታል።መረጃው እንደሚያመለክተው የቤተስብ የምግብ ፍጆታን ሳይጨምር በአማካኝ የሚከተለው ገቢ ተመዝግቧል።

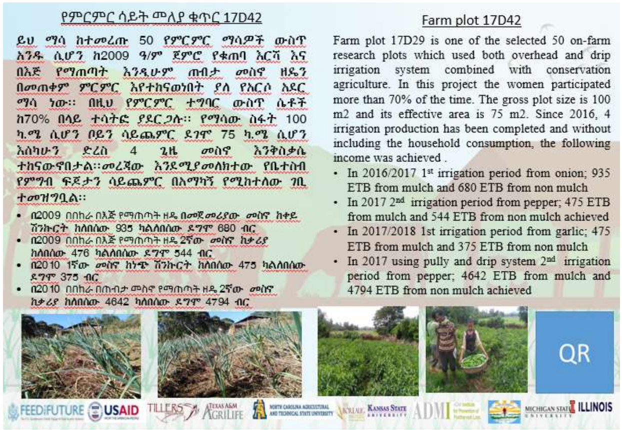
- በ2009 በበከራ በእጅ የማጠጣት ዘዴ በመጀመሪያው መስኖ ከቀይ ሽንኩርት ከለበሰው 833 ካለበሰው ደግሞ 663 ብር
- በ2009 በበከራ በእጅ የማጠጣት ዘዴ 2ኛው መስኖ ከቃሪያ ከለበሰው 425 ካለበሰው ደግሞ 391 ብር
- በ2010 በበከራ በእጅ የማጠጣት ዘዴ 1ኛው መስኖ ከነጭ ሽንኩርት ከለበሰው 325 ካለበሰው ደግሞ 450 ብር
- በ2010 በበከራ በጠብታ መስኖ የማጠጣት ዘዴ 2ኛው መስኖ ከቃሪያ ከለበሰው 570 ካለበሰው ደግሞ 456 ብር

Farm plot 17D2

Farm plot 17D2 is one of the 50 on-farm research plots using both overhead and drip irrigation system combined with conservation agriculture (CA) and conventional tillage (CT). In this project, the woman participated more than 80% of the time. The gross plot size is 100 m^2 and its effective area is 60 m^2. Since 2016, 4 irrigation production has been completed and without including the household consumption, the following income was achieved .

- In 2016/2017 using pully and overhead irrigation 1st onion irrigation period, incomes were 833 ETB from CA and 663 ETB from CT
- In 2017 using pully and overhead irrigation 2nd pepper irrigation period, income were 425 ETB from CA and 391 ETB from CT
- In 2017/2018 using pully and overhead irrigation 1st garlic irrigation period from garlic, 325 ETB from CA and 450 ETB from CT
- In 2017 using pully and drip system 2nd irrigation period from pepper, 570 ETB from CA and 456 ETB from CT

QR



የምርምር ሳይት መለያ ቁጥር 17D42

ይህ ማሳ ከተመረጡ 50 የምርምር ማሳዎች ውስጥ አንዱ ሲሆን ከ2009 ዓ/ም ጀምሮ የቁጠባ እርሻ እና በእጅ የማጠጣት እንዲሁም ጠብታ መስኖ ዘዴን በመጠቀም ምርምር እየተከናወነበት ያለ የአርሶ አደር ማሳ ነው፡፡ በዚህ የምርምር ተግባር ውስጥ ሴቶች ከ70% በላይ ተሳትፎ ያደርጋሉ፡፡ የማሳው ስፋት 100 ካ.ሜ ሲሆን ቦይን ሳይጨምር ደገሞ 75 ካ.ሜ ሲሆን እስካሁን ድረስ 4 ጊዜ መስኖ እንቅስቃሴ ተከናውኖበታል፡፡መረጃው እንደሚያመለክተው የቤተስብ የምግብ ፍጆታን ሳይጨምር በአማካኝ የሚከተለው ገቢ ተመዝግቧል፡፡

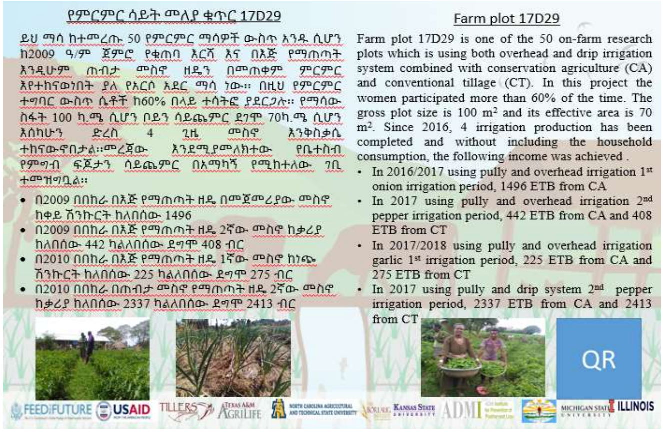
- በ2009 በበከራ በእጅ የማጠጣት ዘዴ በመጀመሪያው መስኖ ከቀይ ሽንኩርት ከለበሰው 935 ካልለበሰው ደግሞ 680 ብር
- በ2009 በበከራ በእጅ የማጠጣት ዘዴ 2ኛው መስኖ ከቃሪያ ከለበሰው 476 ካልለበሰው ደግሞ 544 ብር
- በ2010 1ኛው መስኖ ከነጭ ሽንኩርት ከለበሰው 475 ካልለበሰው ደግሞ 375 ብር
- በ2010 በበከራ በጠብታ መስኖ የማጠጣት ዘዴ 2ኛው መስኖ ከቃሪያ ከለበሰው 4642 ካለበሰው ደግሞ 4794 ብር

Farm plot 17D42

Farm plot 17D29 is one of the selected 50 on-farm research plots which used both overhead and drip irrigation system combined with conservation agriculture. In this project the women participated more than 70% of the time. The gross plot size is 100 m2 and its effective area is 75 m2. Since 2016, 4 irrigation production has been completed and without including the household consumption, the following income was achieved .

- In 2016/2017 1st irrigation period from onion; 935 ETB from mulch and 680 ETB from non mulch
- In 2017 2nd irrigation period from pepper; 475 ETB from mulch and 544 ETB from non mulch achieved
- In 2017/2018 1st irrigation period from garlic; 475 ETB from mulch and 375 ETB from non mulch
- In 2017 using pully and drip system 2nd irrigation period from pepper; 4642 ETB from mulch and 4794 ETB from non mulch achieved

QR



የምርምር ሳይት መለያ ቁጥር 17D29

ይህ ማሳ ከተመረጡ 50 የምርምር ማሳዎች ውስጥ አንዱ ሲሆን ከ2009 ዓ/ም ጀምሮ የቁጠባ እርሻ እና በእጅ የማጠጣት እንዲሁም ጠብታ መስኖ ዘዴን በመጠቀም ምርምር እየተከናወነበት ያለ የአርሶ አደር ማሳ ነው። በዚህ የምርምር ተግባር ውስጥ ሴቶች ከ60% በላይ ተሳትፎ ያደርጋሉ። የማሳው ስፋት 100 ካ.ሜ ሲሆን ቦይን ሳይጨምር ደገሞ 70ካ.ሜ ሲሆን እስካሁን ድረስ 4 ጊዜ መስኖ እንቅስቃሴ ተከናውኖበታል።መረጃው እንደሚያመለክተው የቤተስብ የምግብ ፍጆታን ሳይጨምር በአማካኝ የሚከተለው ገቢ ተመዝግቧል።

- በ2009 በበከራ በእጅ የማጠጣት ዘዴ በመጀመሪያው መስኖ ከቀይ ሽንኩርት ከለበሰው 1496
- በ2009 በበከራ በእጅ የማጠጣት ዘዴ 2ኛው መስኖ ከቃሪያ ከለበሰው 442 ካልለበሰው ደግሞ 408 ብር
- በ2010 በበከራ በእጅ የማጠጣት ዘዴ 1ኛው መስኖ ከነጭ ሽንኩርት ከለበሰው 225 ካልለበሰው ደግሞ 275 ብር
- በ2010 በበከራ በጠብታ መስኖ የማጠጣት ዘዴ 2ኛው መስኖ ከቃሪያ ከለበሰው 2337 ካልለበሰው ደግሞ 2413 ብር

Farm plot 17D29

Farm plot 17D29 is one of the 50 on-farm research plots which is using both overhead and drip irrigation system combined with conservation agriculture (CA) and conventional tillage (CT). In this project the women participated more than 60% of the time. The gross plot size is 100 m^2 and its effective area is 70 m^2. Since 2016, 4 irrigation production has been completed and without including the household consumption, the following income was achieved .

- In 2016/2017 using pully and overhead irrigation 1st onion irrigation period, 1496 ETB from CA
- In 2017 using pully and overhead irrigation 2nd pepper irrigation period, 442 ETB from CA and 408 ETB from CT
- In 2017/2018 using pully and overhead irrigation garlic 1st irrigation period, 225 ETB from CA and 275 ETB from CT
- In 2017 using pully and drip system 2nd pepper irrigation period, 2337 ETB from CA and 2413 from CT

QR

የምርምር ሳይት መለያ ቁጥር 17D33 /እርጥበት ጠቋሚ መሳሪያ ተጠቃሚ

ይህ ማሳ ከተመረጡ 50 የምርምር ማሳዎች ውስጥ አንዱ ሲሆን ከ2009 ዓ/ም ጀምሮ የቁጠባ እርሻ እና በእጅ የማጠጣት ዘዴን በመጠቀም ምርምር እየተከናወነበት ያለ የአርሶ አደር ማሳ ነው፡፡ በዚህ የምርምር ተግባር ውስጥ ሴታቶች ከ65% በላይ ተሳትፎ ያደርጋሉ፡፡ የማሳው ስፋት 100 ካ.ሜ ሲሆን ቦይን ሳይጨምር ደገሞ 56 ካ.ሜ ነው ፡፡ እስካሁን ድረስ 4 ጊዜ መስኖ እንቅስቃሴ ተከናውኖበታል፡፡ ባደረግነው ምርምር ስራ 17D33 ጉድጓድ የውሀ እጥረት ይከሰትበታል፡፡በመሆኑም የእርጥበት ጠቋሚ መሳሪያ በመጠቀም ሰብል የሚፈልገውን የውሀ መጠን ብቻ በመስጠት ከፍተኛ የሆነ የውሀ እጥረትን መቋቋም ይቻላል፡፡ በ2011 ዓም በዚህ መሳሪያ ከሚገለገሉ 20 ተጠቃሚዎች ውስጥ 17D33 አንዱ ነው፡፡ ሁለት ጥንዶች እርጥበት ጠቋሚ መሳሪያዎች የምንጠቀም ሲሆን አርሶ አደሮቹ ዉሃ ሲያጠጡ ቢጫ ከለር ምልክት እንዳሳያቸዉ ማጠጣቱን ያቆማሉ፡፡

Farm plot 17D33 /Wetting front detector(WFD) user

Farm plot 17D33 is one of the selected 50 on-farm research plots which used both overhead and drip irrigation system combined with conservation agriculture. In this project the woman participated more than 65% of the time. The gross plot size is 100 m2 and its effective area is 56 m2. Since 2016, 4 irrigation production has been completed. 17D33 was one of the plots suffering from scarcity of well water. Therefore using WFD it is possible to reduce the amount of irrigation water. In this regard in 2018, 17D33 is one of the 20 CA farmers to use WFD. Wetting Front Detectors are usually used in pairs. While the yellow detector pop-up indicates enough irrigation, the red flag pop-up shows deep percolation. After installation of the instrument irrigators can easily be understood what is happening beneath the plant root. Moreover, It can be used for checking nutrient dynamics within the root zone using water quality sampling.

C. ATV Media presentation

1. The use of different water saving technologies such as drip irrigation in the site Broadcasted in in February 2018 by Amhara Media.
2. The use of Conservation agriculture and water saving technologies such as drip irrigation in the site Broadcasted in February 201 by Amhara Media.