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Full-Length Research Article

Response of maize (Zea mays) yield to traditional, conventional, and conservation agricultural practices

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ABSTRACT

Traditional agriculture has had negative effects for many years, including low crop productivity, food insecurity, and malnutrition. The main objective of this study was to compare the effects of conservation tillage with conventional and traditional tillages on maize yield and sandy soil properties at Arba Minch Zuria and Gacho Baba Woredas of Gamo Zone. This study revealed that most of the soil properties are influenced by soil management practices. The soil fertility elements such as OC, TN, and CEC were found to be low in studied soils before and after planting. "Below Optimum" (very low, low, medium) levels of nutrients such as TN, OC/OM, exchangeable bases, CEC and PBS were found to be low in studied soils; considered deficient and limit crop yield. These limiting nutrients do not allow the full expression of other nutrients that are available in optimum amounts. Multi-nutrient deficiencies in soils have led to a decline in productivity and deterioration in the quantity and quality of the produce. "Optimum" (sufficient, adequate, proportional) nutrient levels are considered adequate and will probably not limit crop growth. "Above Optimum" (high, very high, and excessive) levels of nutrients were considered more than adequate and will not limit crop yield. P_2O_5 and, K_2O are above high and not considered as a yield limiting mineral elements. CA fields increased maize yield by 39%, and 59% as compared to the CO and TR Fields in the year 2019, respectively). Similarly, CA fields increased maize yield by 54%, and 62% as compared to the CO and TR in the year 2020, respectively. Therefore, it might be advised to use management techniques that improve soil nitrogen availability. Rotation and intercropping of suitable leguminous species that contribute N to the system are also necessary, but the soils in the study area need to be Rhizobium-host-required before any specific recommendations can be made.

Keywords: conservation, conventional tillages, limiting factor, traditional tillages, soil properties

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1. INTRODUCTION

Agriculture is the mainstay of the Ethiopian economy and the main employment sector for about 80% of the country's population (Njeru *et al*., 2016). The sector is dominated by smallholder farming and 95% of the land is cultivated by smallholders to generate the key share of total production for the main crops (Alemayehu *et al*., 2012). Of the total tilled land, 90% is ploughed using backward technology and produced main crops (e.g., cereals, pulses, oilseeds, vegetables, root crops, fruits, and cash crops) (Gelaw, 2017). However, smallholder farms are facing various constraints that hamper crop productivity including unscientific cultivation, soil erosions, poor soil fertility, erratic and variable rainfall, and flooding (IFPRI, 2010; Gebregziabher *et al*., 2006; Zerssa *et al*., 2021).

Conservation agriculture's (CA) underlying three principles—minimal soil disturbance, soil cover and crop rotation—are increasingly recognized as technology (Baudron et al., 2007; Coughenour and Chamala, 2000; Hobbs, 2007; Twomlow et al., 2008). CA is a way of farming that conserves, improves, and ensures efficient use of natural resources. CA– is a farming concept that aims to gain acceptable profit through high and sustained production levels by conserving the key resources of soil and water (Coughenour and Chamala, 2000; Kassam *et al*., 2009). Those practices make soil retain nutrients better than conventional agriculture practices, that reduce soil erosion, increase water absorption and generate higher and more stable yields (Kassam et al., 2009). It boosts productivity and contributes to reduce land degradation and increase food security.

CA aims to help farmers achieve profits with sustained production levels while conserving the environment. Mulching residue management can increase soil fertility and the availability of nutrients and water to plants (Coughenour and Chamala, 2000; Hobbs, 2007). Improved water availability throughout the cropping cycle is another key mechanism of yield improvement. CA keeps the sustainability of nutrients in the soil, which leads to higher and more stable yields (Kassam *et al*., 2009). CA addresses several key constraints such as: reducing farm labor requirements; sustaining the natural resource base (by reversing land degradation, re-building of soil health through build-up of soil organic matter (SOM) though minimum soil disturbance and soil cover/cover crops); contributing to mitigating the effects of climate change; and reducing the vulnerability of farm incomes (Twomlow *et al*., 2008).

Tillage is an effective farm activity to improve soil tilth and soil physical conditions (Khan *et al*., 2010), which increased nutrient use efficiency of crops and eventually leads to good crop yield (Bahadar *et al*., 2007). Numerous factors, such as attack of pests, diseases, seasonal changes, and irrigation hampered the yield of maize but tillage is most imperative factor among them (Rosner et al., 2008). Tillage activities have also a positive effect on soil organic matter (SOM) content (Tian *et al*., 2016), as it can increase aeration of the soil, help in the decomposition of residue, organic nitrogen mineralization and availability of nitrogen to plants for use (Dinnes *et al*., 2002). CA (no till and reduced tillage with mulching practices) leads to positive changes in the physical, chemical and biological properties of soil (Bescansa *et al*., 2006). Soil physical properties that are influenced by conservation tillage include bulk density, infiltration and water retention (Osunbitan *et al*., 2004). Improved infiltration of rainwater into the soil potentially increases water availability to plants, reduces surface runoff and improves groundwater recharge (Lipic *et al*., 2005). Reduced soil cultivation decreases farm energy requirements and overall farming costs as less area has to be tilled (Monzon *et al*., 2006).

The study area is under the escarpments of Rift Valley, in which soil erosion and related problems are very serious. The escarpments of Rift Valley are among the most severely erosion-affected area in Ethiopia along with rates estimated at 10-13 mm/annum on average (IFPRI, 2010). Since erosive storms, rugged topography and mountainous geomorphic features are the most cardinal natural causes of accelerated soil erosion and decrease in soil fertility. The steep and dissected terrain with extensive areas of slopes of over 15% has accelerated soil erosion reaching up to 400 tons/ha/annum (IFPRI, 2010).There are diverse ranges of soil-related problems that limit the crop production in the study area are following: rainfall variability- in amount and distribution which cause drought/moisture stress, delayed planting date and end season drought; extreme weather phenomena – dry spells and heavy rains – causing flooding, water logging and siltation of sediments in the lower watercourse, and the competing uses for crop residues and manure as livestock feed and fuel, respectively cause severe OM depletion in soils. Even on the cool plateaus where good volcanic soils are found in abundance, crude means of cultivation have exposed the soils to heavy seasonal rain that causes extensive gully and sheet erosion. On average, there is a loss of 200 kg/ha/year of OM, 30 kg/ha/year of N and 75 kg/ha/year of P. The corresponding values of loss for OM, N and P from 780,000 km^2 of land would be 15.6, 2.16 and 5.85 million tons/year, respectively (IFPRI, 2010). In this study area, crop production systems are based mainly on intensive and continuous soil tillage which has led to a high level of soil degradation and infertility. The unscientific cultivation on the steep slopes without appropriate soil and water conservation measures is causing severe soil erosion and land degradation. The soils are losing the fertile topsoil and facing a reduction in soil depth. Deforestation, unselective grazing of the pasture and marginal lands are some other human-influenced factors of widespread land degradation in the country. The specific objectives were to assess how different tillage techniques affected maize yield and to identify any gaps or potential obstacles to boosting crop production in Arba Minch Zuria and Gacho Baba Districts of Gamo Zone, Southern Ethiopia.

2. MATERIALS AND METHODS

2.1 Agro-ecology, Climate and Description of the study area

An experiment was initiated to investigate the effect of conservation, conventional and traditional tillage practices on maize (Zea mays L) yield and sandy soil properties at target areas of Spiritan Community Out Reach in Ethiopia (SCORE) at Paraso (Demo 1), Ochollo (Demo 2), Bakole (Demo 3) Meiche (Demo 4) in Arba Minch Zuria and Gacho Baba Districts of Gamo Zone, Southern Ethiopia.

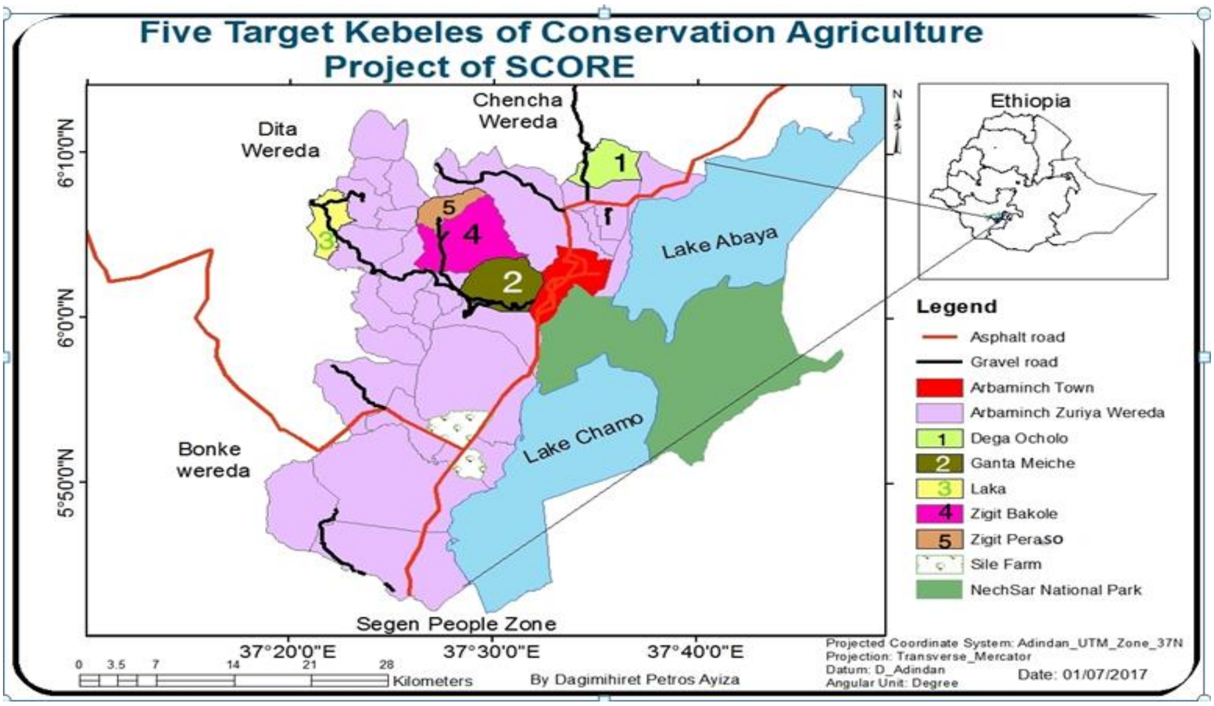

Figure 1: Map of the study area, 2020

According to the Climate classification of Ethiopia, Paraso, Ochollo, Bakole and Meiche are under temperate (Woyina Dega) whereas Laka is under cool temperate (Dega). Since Altitude 2300-3300 m.a.s.l is cool temperate (Dega) and 1500- 2300 m.a.s.l is temperate (Woyina Dega) (Table 1). The catchment has a mid-temperate and temperate climate with highly variable rainfall that is further exacerbated by unfavourable climate change. So that cool temperate is not favourable for maize crop.

Table 1: Based on altitude, climatic classification of the study area, 2020.

Data Collected	**Altitude (m.a.s.l.)**	**Description**	**Local Name**
Elevation records between 2330-2941 m.a.s.l	2300- 3300	Cool temperate	Dega
Elevation records between 1798-2270 m.a.s.l	1500- 2300	temperate	Woina-Dega

This climatic classification criterion was based on the Climatic Classification of Ethiopia, 2020

2.2 Soil sampling and Laboratory analysis

Soil samples were air dried and passed through a 2-mm sieve, processed, and analyzed for determination of physical and chemical characteristics in Arba Minch University Soil Laboratory, 2019. Particle size analysis was carried out by the modified sedimentation hydrometer procedure (Bouyoucos 1951). Bulk density was determined by using the core-sampling method (BSI, 1975). Total porosity was estimated from the bulk and particle densities. Particle size distribution was determined by the hydrometer method following Day (1965) procedure. The pH of the soils was determined in H_2O (pH-H_2O) using a 1:2.5 soil to solution ratio using a pH meter as outlined by Van Reeuwijk (Van Reeuwijk, 1993).

OC content of the soil was determined using the wet combustion method of Walkley and Black as outlined by Van Ranst et al. (1999). Soil TN was analyzed by the wet oxidation procedure of the Kjeldahl method (Bremner and Mulvaney 1982). The P_2O_5 contents of the soils were analyzed using the Olsen sodium bicarbonate extraction solution (pH 8.5) method as outlined by Van Reeuwijk (1993), and the amount of P_2O_5 was determined by spectrophotometer at 882 nm and available potassium. Exchangeable basic cations and the CEC of the soils were determined by using the 1M ammonium acetate (pH 7) method according to the percolation tube procedure (Van Reeuwijk 1993).

Surface soil samples (0–20 cm depth) were randomly collected from 40 soil samples from 4 Demo sites (=4 composites) following the standard procedures of composite soil sample collection. The location of soil sampling sites was marked on the base map on the 1:50,000 scale. The soil samples were processed and analyzed for all aforementioned parameters. Comparative evaluation of CA with CO and TR agricultures of yield comparison trial were practiced and designated as field layout of 5m by 5m plot with 3 replilicatations.

2.3 Major Field activities at Demo sites were

The Conservation tillage (CA):

- Minimum tillage (once tilled) was practiced.
- Mulching (60-80%): Soil cover (60-80%) reduces soil loss by 90-100% (Nill et al., 1996)
- Weed management was by hand dug (>3 times).
- Chemical fertilizer (NPS) was applied as recommended dose.

The Conventional tillage (CO):

- Tilling (4 times to 20–30 cm depth) by hoe, inversion tillage and residue removal were done before sowing maize seeds.
- No mulching (0 % mulch cover):
- Weed management was dug by hoe (>3 times)
- Chemical fertilizer (NPS) was applied as recommended dose.

The Traditional tillage (TR):

- Tilling (2 times to 10–20 cm depth) was done to sow seeds
- Weed management was dug by hoe (>2 times).
- Little mulching (last year residues (<20%) were found before tilling the land):
- Animal manure was applied as recommended dose (10 tone/ha).

2.4 Statistical Analysis

Randomized Complete Block Design (RCBD) was used for the selected soil physicochemical properties. A minimum of three replicates per treatment were implemented. Data analysis was carried out using SAS 9.2 Version System (SAS, 2008) to compare the effects of different treatments on tillage and maize (*Zea mays*) yield.

3. RESULTS AND DISCUSSION

3.1 Environmental Settings and Land Physiography of the Study Areas

The studied area is under the escarpments of Rift Valley, which is severely affected by erosion. Erosive storms, rugged topography and mountainous geomorphic features are the most cardinal natural phenomenon in the study area. As a result, these soils are poor and highly vulnerable to erosion. Slope of the study area are 11.36% (Paraso), 7.65% (Ochollo), 7.65% (Bakole) and 8.33% (Meiche). The slope gradients are rated as: Flat (<5%); Gentle (6- 15%); Steep/Mountains (>15%). Erosion susceptibility and past erosion damages were moderate hazard levels for placing soils (Table 2). The steep and dissected terrain over 15% of slopes with extensive areas are dominant features in the study area; which has accelerated soil erosion reaching up to 400 tons/ha/annum (IFPRI, 2010). Crude means of cultivation have exposed the soils to heavy seasonal rain that causes extensive gully and sheet erosion.

There has high runoff and good drainage, probably due to the slope of the landscape position, depth and its sandiness of the soil (Table 2). In the escarpment between lowland and highland catchments, the scattered trees were cleared and replaced by the settlement of human population because of a shortage of farmland, absence of other livelihood alternatives to rural-urban migrants, and proliferating rural poverty and unemployment. So that the poor are victims of resource degradation, and the resource depletion becomes worse when it is open access to all with high demand. The erosive storms, rugged topography and mountains geomorphic features are the most cardinal natural causes of accelerated soil erosion and that decreases soil fertility in the study area (Figure 1).

Table 2: Land Physiography, Location Data and Soil Texture of the study area, 2019

Parameters	**Land Utility**	**Altitude**	**Latitude**	**Longitude**	**Surf. Stone**	**Erosion**	**Slope**	**Sand**	**Silt**	**Clay**	**Textural Class**
		m.a.s.l.					%				
Paraso											
Value	Maize	2163	6°6`9``	37°27`16``	2 (S1)	M	11.4 (S3)	64.8	23.2	12.0	Sandy (S3)
Ocholo											
Value	Maize	2009	6°9`22``	37°35`22``	2 (S1)	M	7.7 (S2)	73.6	15.1	11.3	Sandy (S3)
Bakole											

Parameters	**Land Utility**	**Altitude**	**Latitude**	**Longitude**	**Surf. Stone**	**Erosion**	**Slope**	**Sand**	**Silt**	**Clay**	**Textural Class**
		m.a.s.l.					%				
Value	Maize	2260	6°5`14``	37°27`16``	2 (S1)	M	7.7 (S2)	77.5	11.0	11.5	Sandy (S3)
Merchie											
Value	Maize	2216	6°1`29``	37°29`10`	4 (S2)	M	8.3 (S3)	80.0	9.3	10.7	Sandy (S3)

S1= very favorable; S2= favorable; S3= Unfavorable for agriculture.
Slope gradients are rated as in eight classes are: 0-0.5%, 0.5-2%, 2-5%, 5-8%, 8-16%, 16-30%, 30-45%, and >45% slopes. Demo= Demonstration site.

3.2. Effect of Conservation, Conventional and Traditional Cultivations on Soil Characteristics

(1). Soil Physical Properties

For ease of presentation, soil texture. bulk density and porosity are treated as soil physical properties in this text. Textural classes of surface soils in all Demo sites were sandy (Table 2). Soil texture influences the ease with which water flows through soil and also the soil capacity to hold water. Sandy soils retain less water. Soil texture largely determines the water-holding capacity of a particular soil, and the amount of water is strongly related to the types and numbers of soil organisms that will inhabit and influence soil water availability, these sandy soils typically being relatively low on the SOM which influences plant productivity.

Bulk density (g/cm^3) of all demo sites was in the low range (1-1.3) (Table 3). Porosity (%) of all Demo sites was at a very high range (56.98 - 61.89) (Table 3) which is suitable for crop productivity. Lower bulk density implies greater pore space, improved aeration and increased SOM; creating a choice environment for biological activity (Werner, 1997). Porosity is itself influenced by the activity of larger soil fauna, and earthworms, ants, cicadas, and many other macro arthropods produce macrospores that are involved in water and gas movements (Dean, 1992; Jackson *et al.*, 2003; Capowiez *et al.*, 2014). Soils with a high proportion of pore spaces to solids have lower bulk densities than those that are more compact and have less pore space. Therefore, any factor that influences soil pore spaces will affect bulk density. Ratings of soil Texture, bulk density and total porosity are indicated below:

Rating	Bulk density (g cm^{-3})[a]	Porosity (%)[b]
Very low	< 1	< 2
Low	1 – 1.3	2 – 5
Moderate	1.3 – 1.6	5 – 15
Moderately high	1.6 – 1.8	15 – 40
Very high	> 1.8	> 40

Source: Landon (1991) [a], FAO (2006) [b]

(2). Soil Chemical Properties

For ease of presentation, soil pH, OC/OM, TN, P_2O_5, and K_2O are treated as soil chemical properties in this text (Table 3). The soil pH-H_2O values were varied from 5.67 - 6.43 in all Demo sites before planting (Table 3) and rated as slightly acidic to moderately acidic (Tekalign, 1991). After cropping, the surface soil pH-H_2O values were increased in the studied Demo sites. The degree of acidity based on pH is classified as follows: Ultra acidic (<3.3); extremely acidic (3.5 - 4.5); Very strong acidic (4.5 - 5.0); Strong acidic (5.1 - 5.5); moderately acidic (5.6 - 6.0); slightly acidic (6.1 - 6.5); neutral (6.6-7.3) and Slightly Alkaline (7.4-7.8). Most plants grow best at pH above 5.5. Soil pH of around 6.5 is considered optimum for nutrient availability. Soil with low pH contains relatively high exchangeable H^+ and is Al^{3+}considered as acid soil.

Table 3: Phyicochemical characteristics of the experimental site soil (0–20 cm), 2019- 2020

Soil Characteristics										
	BD	Porosity	pH(H_2O)	EC	OC	TN	OM	C:N	P_2O_5	K_2O	CEC
	g/cm^3	%	1:2.5	dS/m	%			ratio	mg/kg	g/kg	cmol(+)/kg
Paraso											
Initial	1.1	61.82	6.43	0.10	2.57	0.09	4.43	28.56	26.94	380.94	0.83
Rating	S1	S1	MA	SF	M	L	M	M	H	H	VL
CA	1.06	60.00	7.11	0.15	1.72	0.06	2.94	28.67	112.67	395.36	4.24
Rating	S1	S1	MA	SF	M	L	M	M	VH	VH	VL
CO	1.12	57.74	6.84	0.08	1.68	0.08	2.90	20.00	112.81	400.82	4.96
Rating	S1	S1	MA	SF	L	L	M	H	VH	VH	VL
TA	1.14	56.98	7.24	0.07	1,40	0.07	2.41	20.00	70.68	518.31	4.64
Rating	S1	S1	SA	SF	L	L	L	H	VH	VH	VL
Ocholo											
Initial	1.03	61.13	5.75	0.20	1.54	0.03	2.65	51.33	77.75	499.13	0.61
Rating	S1	S1	N	SF	M	L	M	M	VH	VH	VL
CA	1.02	61.51	6.13	0.27	2.52	0.12	4.34	19.38	140.15	545.63	4.28
Rating	S1	S1	SAI	SF	M	L	M	H	VH	VH	VL
CO	1.04	60.75	7.54	0.27	2.24	0.11	3.86	37.33	111.88	436.34	4.92
Rating	S1	S1	SA	SF	M	L	M	M	VH	VH	VL
TA	1.00	62.26	7.65	0.21	1.68	0.08	2.40	20.00	77.78	474.59	3.30
Rating	S1	S1	N	SF	M	L	L	H	VH	VH	VL

Soil Characteristics											
	BD	Porosity	pH(H_2O)	EC	OC	TN	OM	C:N	P_2O_5	K_2O	CEC
	g/cm^3	%	1:2.5	dS/m	%			ratio	mg/kg	g/kg	cmol(+)/kg
Bakole											
Initial	1.11	58.11	5.87	0.08	1.39	0.06	2.40	23.17	20.67	263.83	0.59
Rating	S1	S1	N	SF	M	L	M	M	H	VH	VL
CA	1.07	59.62	7.05	0.09	1.68	0.08	2.90	20.00	139.26	526.50	3.78
Rating	S1	S1	SAI	SF	M	L	M	H	VH	VH	VL
CO	1.04	60.75	6.17	0.06	1.12	0.06	1.93	18.67	127.48	318.58	2.78
Rating	S1	S1	SA	SF	L	L	L	H	VH	VH	VL
TA	1.04	60.75	6.24	0.06	1.40	0.07	2.41	20.00	136.55	395.36	4;80
Rating	S1	S1	N	SF	l	L	L	H	VH	VH	VL
Merchie											
Initial	1.03	61.13	6.26	0.10	1.48	0.05	2.55	29.60	24.24	487.69	0.58
Rating	S1	S1	N	SF	L	L	M	M	H	VH	VL
CA	1.00	62.26	7.65	0.13	1.68	0.07	2.90	24.00	97.48	545.63	3.78
Rating	S1	S1	SAI	SF	M	L	M	M	VH	VH	VL
CO	1.02	60.75	7.11	0.09	1.40	0.08	2.41	17.50	58.01	324.43	3.34
Rating	S1	S1	SA	SF	L	L	L	H	VH	VH	VL
TA	1.01	61.89	6,95	0.10	1.40	0.07	2.41	20.00	55.08	384.30	2.70
Rating	S1	S1	N	SF	L	L	L	H	VH	VH	VL

L=Low; VL= Very low; M= Moderate, and H= High; MA= moderately acidic; SA= slightly Acidic; N= Neutral SAl=Slightly Alkaline; SF= Salt Free (i.e., EC= <2dS/m). %OC x1.724 = %OM; pH = power of hydrogen; OM= organic matter; TN= total nitrogen; C:N = carbon to Nitrogen ratio; Av.P_2O_5=available phosphorous. 1 dS/m = 1000 µS/cm.

SOM contents of surface soils varied from 2.40 - 4.43% along different Demo sites (Table 3); most of the SOM contents in the studied soils were in low ranges before planting. This indicates that for both CO and TA without the application of nitrogen-containing fertilizers, no adequate yields can be achieved. According to the results of fertilizer trials carried out in Ethiopia, the critical SOM values for the common cereals grown are 2.5% for barley and wheat; 3.0% for maize; 2.0% for sorghum and teff (NFIU.1989). SOM content are categorized as very low (<1%), low (1-2%), medium (2-3%), high (3-5%) and very high (>5%) (NFIU, 1989). Also, it is similar to Tekalign's (1991) and Berhanu's (1980) ratings. SOM has the power to alter and improve the physical, chemical, and biological properties of soils and as a result increase plant productivity (Atkinson *et al*., 2010; Solaiman *et al.*, 2010; Jones *et al*., 2012).

TN content of all the Demo sites surface soils was low (0.03- 0.13%) (Table 3). It is because of the relatively fast mineralization of nitrogen from the OM that N is a limiting factor for crop production in the study area. The distribution pattern of TN across Demo sites was similar to that of SOM since SOM contents are a good indicator of available nitrogen status in the soil. TN content of soils are categorized as low (< 0.15 %), medium (0.15 - 0.25 %) and high (>0.25 %) (Havlin *et al*., 1999). Intensive and continuous cultivation aggravated SOC oxidation, resulting in a reduction of TN as compared to ploughed fields.

The C: N ratio of Demo sites were 23.17 to 51.33 before planting (Table 3), which is at a moderate level as compared to the C: N ratio (<20:1) of legume fields with the C: N ratio of wheat and oat straw (=100:1). The recorded C: N ratio status in surveyed sites suggests that the conditions for plant growth moderately favorable. This higher value of C: N ratio is due to the higher content of OC and lowers the content of TN. It is generally accepted that C: N ratios between 8:1 and 12:1 are considered to be the most favourable condition for crop production. This is a low C: N ratio which is commonly obtained from the application of manures and legumes. But high levels of C: N ratio imply relatively fast mineralization of nitrogen from the organic materials.

Available P (Olsen) contents of the Demo site soils were recorded as 20.67- 140.15 mg/kg (Table 3). The Av. P content of the surface soils was relatively higher. The available P (mg/kg) contents of the soils were rated as very low (<5), low (5- 9), medium (10- 17), high (18- 25) and very high (>25) (Havlin *et al*., 1999). Higher P values of surface soils might be attributed to a slightly preferred range of soil pH, low level of Ca in soils, greater diffusion of P in moist soil conditions (since soil and water conservation prevalent at the study site), the mineralization of OM, and difference in land use management. Based on the above results it is not compulsory to apply P_2O_5 containing fertilizers in all of the Demo sites.

Available K content of the surface soils in the Demo sites were ranged from 263.83 - 545.63 gKg^{-1} (Table 3), which is a medium to very high range. The CA mulches were increased the accumulation of soil K because the nutrient-rich branches and coarse litter fraction are all-important nutrient sources. The Available K content in (gKg^{-1}) can be rated as very low (<120), low (121- 240), medium (241-300), high (300- 360) and very high (>360) (Tandon, 2005)) and supported by Jones (2003).

The CEC of the surface soils ranged from 0.58 to 4.96 $cmol(+)kg^{-1}$ of soil (Table 3), which is a very low range. The CEC in ($cmol(+)Kg^{-1}$) can be rated as very low (<6), low (6- 12), medium (12- 25), high (25- 40) and very high (>40) (Hazelton and Murphy, 2007). The lower the CEC in surface soils, the less capable the soil can retain mineral elements. Soils with a low CEC are more likely to develop deficiencies in K^+, Mg^{2+} and other cations while high CEC soils are less susceptible to leaching of these cations (CUCE 2007). The main ions associated with CEC in soils are the exchangeable cations Ca^{2+}, Mg^{2+}, Na^+ and K^+ (Rayment and Higginson 1992), and are generally referred to as the base cations. It is accepted that OM is responsible for 25-90% of the total CEC of surface mineral soils (Oades et al., 1989). The high CEC values have been implicated with high yield in most agricultural soils and CEC values in excess of 10 cmol(+)kg^{-1} are also considered satisfactory for most crops (FAO/IIASA/ISRIC/ISS-CAS/JRC, 2012).

(3). Limiting factor(s) for crop production in the Study Areas

Based on nutrient rating and diagnostic methods (Tuma, 2013), nutrients such as TN, OC/OM and CEC (Table 3) were found to be very low, low and medium in studied soils; **i.e., "Below Optimum"** nutrient levels were considered deficient and limit crop yield. Specifically, the soil fertility factors such as OC, TN and CEC contents were found to be low in studied soils before and after planting (Table 3) theese nutrients are considered as yield-limiting factors for crop production. Nutrient levels (in Table 3) were considered adequate **i.e., "Optimum"** (sufficient, adequate, proportional) these will probably not limit crop growth and such limiting nutrients do not allow the full expression of other nutrients that are available in optimum amounts (Tuma, 2013). Based on nutrient rating and diagnostic methods, nutrients such as P_2O_5 and K_2O were found to be high, very high to excessive in studied soils; i.e., **"Above Optimum"** nutrient levels are considered more than adequate and will not limit crop yield; there is the possibility of a negative impact on the crop if additional nutrients are added. CA were improved soil fertility and organic content as compared to CO and TA. The nutrient rating and diagnostic methods (Correlation, Calibration and Interpretation)

Nutrient Index Level	Expected relative yield without fertilizer (%)	Meaning of Nutrient Index Level for crops Applying the nutrient will be beneficial
Very low	<50	Over 80% of the time
Low	50-80	65% of the time
Optimum	80-100	5% of the time
High	100	<1% of the time

Source: ISUEP, 1688 and FAO, 1980 in Zebire *et al*. (2019)

This study revealed that most of the soil properties (Table 3) were influenced by soil management practices (CA. CO and TA). Multi-nutrient deficiencies in soils have led to a decline in productivity and deterioration in the quantity and quality of the produce.

3.2 Effect of Conservation, Conventional and Traditional Agricultural Practices on Grain Yield of Maize

Grain yield is the final objective of farmers. Maximum maize (Zea mays) grain yield (7973 $Kgha^{-1}$) was noted in CA fields (Table 4), which showed statistical differ significantly ($P<0.05$) with CO and TA. The lowest grain yield (600$Kgha^{-1}$) was found in TA practice, which shows that grain yield was (7.53%) higher in CA soils over TA soil and statistical differ significantly ($P<0.05$) with CA and CO. The average maize yield of CO (kg/ha) was in moderate level as compared to TA (Table 4), and the relative advantage obtained from CO was apparent. Because maize yields of CA were highly significant as compared to maize crop yields of both CO and TA. CA tillage had substantially suppressed weed development in the experimental sites.CA fields increased maize yield by 39%, and 59% as compared to the CO and TR fields in the year 2019, respectively (Table 4), though there were no large differences among the practices of CO and TR. Similarly, CA fields increased maize yield by 54%, and 62% as compared to the CO and TR Fields in the year 2020, respectively (Table 4), though there were no large differences among the practices. A comparative analysis of CA fields in two years (2019 and 2020) was increased maize yield by 37%. The rainfall during the Belge season of 2020 was unreliable. Recent studies have reported that CA improved crop productivity by 20–120% and water productivity by 10–40% (Patil et al,. 2016). The finding of Zhang *et al*. (2015), found that grain yield was (4.4%) higher in CA soils over CO soil. Cultivations have the most direct consequences on soil erosion. No-till systems leave virtually the entire residue on the soil surface, providing up to 100% cover and nearly eliminating erosion losses (Nill *et al*., 1996).

Table 4. Harvested Grain Yield (Maize yield (kg/ha)), 2020

Maize yield (Kg/ha) in year 2019												
Site	**CA-A**	**CA-B**	**CA-C**	**Mean**	**CO-A**	**CO-B**	**CO-C**	**mean**	**TR-A**	**TR-B**	**TR-C**	**mean**
Peraso	11600	5520	6800	**7973^{a}**	4560	4200	4080	**4280^{bc}**	2640	2200	1280	**2040^{d}**
Ocholo	6520	6080	4080	**5560^{bc}**	2160	2200	1840	**2067^{d}**	3560	3600	4880	**3880^{c}**
Bakole	4160	3920	3800	**3960^{c}**	1440	2080	1840	**1787^{d}**	1800	2200	1920	**1987^{d}**
Meyche	5800	6480	5360	**5880^{b}**	2240	2600	1280	**2040^{d}**	1600	1840	1380	**1620^{d}**
Average				**5843**				**2584**				**2382**
Maize yield (Kg/ha) in year 2020												
Peraso	1800	4800	3840	**3480^{ab}**	2500	2000	1680	**2060^{c}**	1600	1680	1520	**1600^{c}**
Ocholo	4200	4000	3400	**3867^{a}**	1800	1680	1600	**1693^{c}**	2120	2000	1880	**2000^{c}**
Bakole	3400	3000	2600	**3000^{b}**	1760	1400	1200	**1453^{cd}**	1680	1260	1320	**1420^{cd}**
Meyche	4080	4560	4200	**4280^{a}**	1440	1640	1600	**1560^{c}**	600	640	560	**600d**
Average				**3657**				**1692**				**1405**

Values with different letters in a column differ significantly at $P < 0.05$; CA=Conservation Tillage; CO=Conventional Tillage; TR=Traditional Tillage; A, B, C are Replications.

A comparative analysis of the returns on investment in CO and CA in Kenya showed a potential of doubling benefits by using CA (FAO, 2009). Weeds are smothered due to soil cover with residues, leading to labor saving in weed control. A comparative analysis of the returns on investment in conventional agriculture and CA in Kenya showed a potential of doubling benefits by using CA (FAO, 2009). CA (reduced tillage with mulching practices) lead to positive changes in the physical, chemical and biological properties of soil (Bescansa *et al.*, 2006)

Maize grain yields were significantly influenced under various cultivations (Table 5). Comparison of three tillage practices in maize experimental sites; i.e., maize grain yield was positively and significantly ($P < 0.01$) affected by CA as compared to CO and TR (Table 5). Maize under CA had better grain yield and significantly higher than grain yields obtained from CO and TA, respectively (Table 4). The use of mulch and zero till in CA fields were increased maize grain yield and considered as source of fertilizer for better maize crop productivity (Coughenour and Chamala, 2000; Kassam *et al*., 2009). Maize under CA had better adaptation due to reduced runoff, increased OC/OM, improved soil physicochemical properties, increased soil fertility, increased resistance to drought, escaped from water stress, reduced weeds and reduced incidence of pests and diseases.

In CA fields erosion was reduced, the fertility of the soil was improved, and the runoff water loss was reduced, allowing the crop to have more water in dry periods. Tillage activities have also positive effect on SOM content (Tian *et al*., 2016), as it can increase aeration of soil, helps in decomposition of residue, organic nitrogen mineralization and availability of nitrogen to plants for use (Dinnes *et al*., 2002; Rosner *et al*., 2008).

Table 5. Influence of Different Cultivations on Yield of Maize, 2019- 2020

Cultivation Technologies		**Grain yield (in a year)**	
No	**Tillage Types**	2019	2020
1.	CA (Mulch (60-80%))	5843.3[a]	3656.7[a]
2.	CO (No mulch (0%))	2543.3[b]	1691.7[b]
3.	TR (Mulch (<20%))	2408.3[b]	1405.0[b]
	LSD	837.85	456.07
*	CV (%)	26.18	22.78

Values with different letters in a column differ significantly at $P < 0.05$

CA is reported in some studies to increase system diversity and stimulates biological processes in the soil and above the surface, i.e., due to reduced erosion and leaching. The adoption and development of CA tillage lead to a number of benefits in the water supply system within the agricultural ecosystems, such as greater availability of water for the crop. According to Lal (2010), CA is a good strategy not only to mitigate climate change but also to adapt agricultural ecosystems to their effects, by increasing crop resilience facing climatic variations. Mulching in contact with the soil is one of the most effective factors for reducing erosion. For example, a 90% mulch cover reduces erosion by 93% (Wischmeier, 1984). Also, Nill *et al*. (1996) reported that a 60 -80% soil cover/mulch cover reduces soil loss by 90- 100%. In CA fields, we applied mulch as a component of CA on basis of Nill *et al*. (1996). Thus CA had a negative effect on soil loss. Since mulching reduces surface runoff and reduces soil loss during and after rainfall, which increases infiltration and soil fertility. Ground cover slows down the runoff velocity, which increases the flow depth thereby providing a greater buffer for reducing the hydrodynamic impact forces of the raindrop on soil (Mutchler and Young, 1975).

3.3 Effect of environmental and tillage (Interaction) on grain yield of Maize

Grain yield of maize (in 2019) at Peraso was higher and significantly different from other Demo Sites and tillage practices, though there were no significant differences between the Demo Sites of Bakole and Meyche (Table 6). As a result, maize grain yield at Peraso was increased by 39%, and 59% as compared to other Demo Sites. Grain yield of maize (in 2020) at Ocholo was higher and significantly different from other Demo Sites and tillage practices, though there were no significant differences between the Demo Sites of Peraso and Meyche (Table 6). Interaction effects of Demo Sites (Peraso, Ocholo, Bakole and Meyche) over tillage practices (CA, CO and TR) in two years (2019 and 2020) were different because the rainfall during the Belge (winter) season of 2020 was unreliable (Table 2). Cultivations have the most direct consequences on soil erosion. No-till systems leave virtually the entire residue on the soil surface, providing up to 100% cover and nearly eliminating erosion losses (Nill *et al*., 1996). For example, recent studies have reported that CA improved crop productivity by 20–120% and water productivity by 10–40% (Patil et al., 2016). The finding of Zhang et al. (2015), found that grain yield was higher in CA soils over CO soil.

Table 6: Environmental and Cultivation (Interaction) effect on grain yield of Maize, 2019 - 2020

	Interaction Effect	Grain yield (in the year)	
No	**Demo Sites**	**2019**	**2020**
1.	Peraso	4764.4^{a}	2380^{ab}
2.	Ocholo	$3880a^{b}$	2520.0^{a}
3.	Bakole	2573.3^{c}	1957.8^{b}
4.	Meyche	3175.6^{bc}	2146.7^{ab}
	LSD	967.47	526.63
*	CV	26.18	22.78

Values with different letters in a column differ significantly at $P < 0.05$

The identified environmental factors that limit agricultural production in the study were as follow:

- Rainfall variability- in amount and distribution which cause moisture stress.
- Delayed planting date and end-season drought.
- Extreme weather phenomena – dry spells and heavy rains – causing flooding, water logging and siltation of sediments in the lower watercourses.
- The erosive storms, rugged topography and mountainous geomorphic features are the most cardinal natural causes of accelerated soil erosion.

4. CONCLUSION

Soil test categories the could be explained as: *"Below Optimum"* (very low, low and medium) levels of nutrients are considered deficient and will probably limit crop yield. There will have a moderate to a high probability of an economic crop yield response to additions of that nutrient. *"Optimum"* (sufficient, adequate, proportional) levels of nutrients are considered critical/adequate and will probably not limit crop growth. There is a low probability of an economic crop yield response to additions of these nutrients. *"Above Optimum"* (high, very high, and excessive) levels of nutrients are considered more than adequate and will not limit crop yield. There is a very low probability of an economic crop yield response to additions of these nutrients. At very high levels there is the possibility of a negative impact on the crop if nutrients are added. Specifically, the soil fertility factors such as OC/OM, TN, and CEC contents were found to be low (below optimum) in studied soils before and after planting. The limiting nutrients do not allow the full expression of other nutrients that are available in optimum amounts. Therefore, it could be recommended to include management practices that increase nitrogen availability in the study area locations. Furthermore, rotation and intercropping of appropriate leguminous that add N to the system is required, however, Rhizobium-host requirement is required to give concrete recommendation in the study area soils.

Conflict of Interest

There is no conflict of interest, according to the authors.

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