Subsoiling improves soil physical properties and increases productivity in a maize farmland in Southern China

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Abstract: A two-year field experiment was conducted to assess the influence of subsoiling (SS), two passes of rotary tillage (2RT), two passes of rotary tillage + subsoiling (2RTSS), and zero tillage (ZT) on soil physical properties and maize grain yield in *Latosolic red* soil of Southern China in a randomized complete block design with three repeats. Results showed that, SS recorded lowest soil bulk density (1.41 g cm^{-3}), soil penetration resistance (1.81 MPa), soil gravimetric water content (21.12%), and volumetric water content (29.19%), resulting in highest soil porosity (47.36%) at 0-40 cm soil depth. Highest plant, ear height, ear length, ear weight, number of rows per ear, and number of grains per row were observed under SS. Also, maximum grain yield 7.37 ton ha^{-1} (9.81%), dry matter, harvest index, and 1000-grain weight were recorded under SS. Overall, SS improved soil physical properties and facilitated highest maize yield and yield components, and therefore, SS could be adopted as a strategy for higher productivity leading to a sustainable agricultural system under the changing climatic conditions.

Keywords: Maize yield, soil bulk density, harvest index, 1000 grain weight

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1 Introduction

Soil physical properties change due to the continue tillage application which affect crop growth and yield (Strudley et al., 2008). Subsoiling causing loosening up of soil improves infiltration, root penetration, better fertilizer placement, and breaking up of the soil plow pan (Diaz-Zorita, 2000; Strudley et al., 2008; Bai et al., 2014; Sang et al., 2016). High soil compaction and porosity resulting from tillage methods affect soil bulk density, soil penetration resistance and infiltration (Hamza and Anderson, 2005). The loosening up of the soil in the upper layer and the compacted soil in the lower layer of the root zone are auspicious for maize growth and effectively prevent maize stalk from lodging in the late season (Yang et al., 2013). Reduced surface runoff and increasing of the water availability of the soil due to subsoiling practices, helps in improving the possibility of enhancing crop growth, yield, water use efficiency, and sustainability (Ekelöf et al., 2015; McGarry et al., 2000; Ahmed and Adeeb, 2014). Alternative strips of ploughed and untilled

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partial subsoiling fields were found to upsurge the water- and nutrient-holding capacity of the soil and lessen soil evaporation (Abu-Hamdeh, 2003; Martin-Rueda et al., 2007; Tian et al., 2014).

Work done by Alamouti and Navabzadeh (2007) recorded improved soil bulk density, infiltration, and crop yield under subsoiling compared to semi or shallow tillage methods. Their results established an increase in the tilth depth increasing the soil bulk density, infiltration rate as well as an increase in the crop yield. Decreases in cone index with increasing depth of soil softening are affected by the type of tillage tool and its intensity (Hedayatipoor and Alamooti 2020).

More work on subsoiling has been conducted with few reports on them as a result of inconsistency in crop yield (Popp et al., 2001). The enhancing of soil quality and fertility as a result of reduced soil erosion by conservation tillage methods in affecting crop growth and yield are expected to have an advantage over the no tillage as reported by Liang et al. (2007).

An inconsistent response of tillage method impacts on response to crop yield with difference in climatic situations and soil properties was reported by Rusinamhodzi et al. (2011) and Liu et al. (2013). Work done by He et al. (2011) and Cullum (2012) showed an improvement in crop yield in warm-dry climate compared to Chen et al. (2011) and Arvidsson et al. (2014), who recorded a lower crop yield in cool-humid climate under conservation. However, higher maize yield was observed under conservation tillage method (Zugec, 2003). Whereas Hussain et al. (1999) showed that four-year average maize yields were equal under no tillage, chisel plow and moldboard plow systems.

Yield and yield components are the principal single-mindedness of the espousal and development of tillage practices as crop yield which is an index for the adoption by any production practices (Rusinamhodzi et al., 2011). Therefore, the adoption of these practices can be attained only when crop yield benefits are definite. The objective of this study was to evaluate the influence of tillage methods on soil physical properties and maize yield and yield components in Latosolic red soil of Southern China.

2 Materials and Methods

2.1 Experimental setup

A field experiment was conducted on a middle term (7 years) consistence tillage practice farm of Wufengtai Agricultural Investment Co. Ltd., which was located in Heyuan City ($24^0$09′N, $114^0$23′E and 121 m above sea level) Lianping County, Guangdong Province, China. The research station is characterized by a central sub-tropical monsoon climate with an annual mean temperature and precipitation of 19.5 ^{0} C and 1779.7 mm respectively. The site also has an annual humidity of 79% which occurs in May, June and July. The site is a level terrain with red Latosolic soil which is a typical soil type in the Guangdong Province, and it is classified as a sandy-clay-loam soil developed from the Quaternary Red Earth (Gong et al., 2007). The soil physical conditions in the depth of 0-40 cm before the start of the experiment are shown in Table 1.

The field experiment was arranged in randomized complete block design with three repetitions for each treatment in 2016 and 2017. The experiment included four treatments: (i) two passes of rotary tillage (2RT at 20cm depth); (ii) subsoiling (SS at 40cm depth); (iii) two passes of rotary tillage + subsoiling (2RTSS at 20cm + 40cm depth combined); (iv) zero tillage (ZT). The size of a single plot area measured 150 m^2 (1.5 m x 100 m). The hybrid maize variety used throughout the study was *Yue Tian 26* (85 days ripening time), which was sown at a spacing of 0.3 m within rows and 0.5 m between rows of 44,400 plant ha^{-1} population density by a 2BMQE-2A seeder. All in-crop fertilizer of NPK was applied at planting (N: 220 kg ha^{-1}, P: 80 kg ha^{-1} and K: 150 kg ha^{-1}). The maize plants were grown under rain-fed conditions.

2.2 Measurement of soil physical properties

Soil bulk density was used as a significant indicator of changes in soil structure and water retention capacity (Arshad et al., 1999) and was progressively determined from 50 mm diameter sampler cores to a depth of 40 cm

(Blake, 1965). The soil was measured from undisturbed soil cores collected from four depths (0-10 cm, 10-20 cm, 20-30 cm, 30-40 cm). Soil cores were weighed wet, dried in an oven at 105 ^{0} C for 48 h, and weighed again to determine the soil water content and bulk density (Ferraro and Ghersa, 2007). Gravimetric water content was multiplied by soil bulk density to obtain the volumetric water content. Soil porosity (%) was then calculated from the bulk density as;

$$\text{Total porosity}=(1-\frac{\rho_b}{\rho_s}) \quad (1)$$

Where, ρ_b is the bulk density and ρ_s is the average particle density (2.65 g cm^{-3}).

A FIELDSCOUT, SC 900 Soil Compaction Meter (Spectrum Technologies, Inc) was used in measuring the soil penetration resistance in tens (i.e. 0-10 cm, 10-20 cm, 20-30 cm and 30-40 cm).

Table 1 Initial soil condition of the experimental site

Soil characteristics	Values
Climate	Subtropical Monsoon
Sand (%)	57.9
Clay (%)	23.4
Silt (%)	18.7
Soil Texture Class	Sandy-Clay-Loam
Bulk Density (g cm^{-3})	1.38
Porosity (%)	46.15
Penetration Resistance (MPa)	2.06
Gravimetric Water Content (%)	21.11
Volumetric Water Content (%)	30.64

2.3 Measurement of yield components

Standard procedures were adopted in recording data on yield and yield components. Ten maize plants from each plot were randomly selected to determine the maize yield and yield components. Plant height, ear height and ear length were measured with the help of measuring tape. Number of rows per cob and number of seeds per row were done by manual counting. Ear weight, 1000-grain weight, grain yield, and maize dry matter were recorded by using a digital weighing balance. Total grain weight of each plot was recorded and grain yield was calculated on the tons per hectare basis. Harvest index (%) was computed by using the formula proposed by Beadle (1987);

$$\text{HI(\%)}=\frac{GY}{BY}\times 100\% \quad (2)$$

Where HI: harvest index; GY: grain yield (t ha $^{-1}$); BY: biological yield (t ha $^{-1}$).

2.4 Statistical analysis

Analyses of variance for the measured parameters were performed using IBM SPSS 23.0 and treatments means were compared using Duncan's Multiple Range Test at $p < 0.05$ level. Pearson's correlation, principal component analysis, and hierarchical cluster analysis were carried out to reveal the relationships among plant height, ear height, ear girth, ear length, ear weight, number of rows per cob, number of seeds per row, 1000-grain weight, harvest index, grain yield, and maize dry matter.

3 Results

3.1 Soil Bulk density

The soil bulk density of different tillage practices increased significantly ($p < 0.05$) when compared to the initial data (Table 1). Before the start of the experiment, the mean bulk density in the tilth (0-40cm) was 1.38 g cm^{-3}. After the two-year experiment, the soil bulk density at the soil depth of 0-40 cm under 2RT, SS, 2RTSS and ZT increased by 5.07%, 2.17%, 4.35% and 7.79% respectively. The bulk density of 2RT, SS and 2RTSS significantly decreased at the soil depth of 0-20 cm compared to the ZT, while at 20-40 cm there was a high significant ($p < 0.05$) difference when compared to SS.

3.2 Soil porosity

The soil porosity of different tillage practices increased significantly ($p < 0.05$) under SS and 2RTSS and also decreased significantly under 2RT and ZT compared to the initial data (Table 1). Before the experiment, the mean soil porosity in the tilth (0-40 cm) was 46.15%. After the two-year experiment, soil porosity under SS and 2RTSS increased by 2.62% and 0.87% respectively, however, 2RT and ZT decreased significantly by 0.38% and 3.38% respectively at the soil depth of 0-40 cm. The soil porosity of SS, 2RTSS and 2RT significantly increased compared to ZT at the soil depth of 0-20 cm, while at 20-40 cm there was a significant reduction under ZT, 2RT and 2RTSS compared to SS.

3.3 Soil penetration resistance

2RTSS resulted in significantly higher ($p < 0.05$) increase in soil penetration resistance in the measured soil profile (0-40 cm) as shown in Table 1, compared to the initial data. There was a significant increase of 14.56% and 3.88% soil penetration resistance at 0-40 cm soil depth under 2RTSS and 2RT compared to a significant reduction of 13.81% and 3.00% under SS and ZT respectively. The soil penetration resistance under 2RTSS had lower significant reduction compared to SS, 2RT and ZT at the soil depth of 0-20 cm, while there was a higher significant increase (49.03%, 37.38%, 28.16% and 13.11%) under 2RTSS, 2RT, ZT and SS respectively at 20-40 cm soil depth respectively.

3.4 Soil gravimetric water content

ZT resulted in significantly higher ($p < 0.05$) increase in soil gravimetric water content in the measured soil profile (0-40 cm) as shown in Table 1, compared to the initial data. There was a significant increase of 2.94%, 1.18% and 0.04% soil gravimetric water content in the 0-40 cm soil depth under the ZT, 2RT and SS compared to a significant reduction of 4.40% under 2RSST respectively. The soil gravimetric water content under 2RTSS had higher significant reduction compared to SS, 2RT and ZT at the soil depth of 0-20 cm, while there was a higher significant increase (6.25%, 4.22%, 3.69% and 0.62%) under ZT, SS and 2RT compared to under 2RTSS at the 20-40 cm soil depth respectively.

3.5 Soil volumetric water content

Tillage practice under ZT resulted in significantly higher ($p < 0.05$) increase in soil volumetric water content in the measured soil profile (0-40 cm) as shown in Table 1, compared to the initial data. There was a significant increase of 5.78% and 1.14% soil volumetric water content in the 0-40 cm soil depth under the ZT and 2RT respectively compared to significant reduction of 4.97% and 2.30% under 2RTSS and SS respectively. The soil volumetric water content under 2RTSS, SS and 2RT had higher significant reduction compared to the soil depth of 0-20 cm, while there was a higher significant increase of soil volumetric water content at the 20-40 cm soil depth in the order of ZT>SS>2RT>2RTSS.

Table 2 Mean soil condition at the soil depth of 0-40 cm

Soil Depth (cm)	Soil Bulk Density (g cm^{-3})				Soil Porosity (%)				Soil Penetration Resistance (MPa)				Gravimetric Water Content (%)				Volumetric Water Content (%)			
	2RT	SS	2RTSS	ZT	2RT	SS	2RTSS	ZT	2RT	SS	2RTSS	ZT	2RT	SS	2RTSS	ZT	2RT	SS	2RTSS	ZT
0-10	1.26^{b}	1.23^{d}	1.25^{c}	1.30^{a}	52.99^{c}	54.29^{a}	53.36b	51.86^{d}	1.31^{ab}	1.14^{c}	1.45^{a}	1.24^{bc}	20.45^{a}	19.86^{ab}	19.16^{b}	20.47^{a}	25.77^{ab}	23.95^{b}	24.43^{ab}	26.61^{a}
10-20	1.39^{b}	1.34^{d}	1.37^{c}	1.50^{a}	48.14^{c}	49.88^{a}	48.88b	44.22^{d}	1.61^{b}	1.44^{d}	1.86a	1.49^{c}	21.21^{a}	20.60^{ab}	19.23^{b}	21.40^{a}	29.48^{b}	26.35^{c}	27.60^{b}	32.10^{a}
20-30	1.57^{a}	1.54^{b}	1.57^{a}	1.57^{a}	41.61^{c}	42.73^{a}	41.98b	$41..42^{c}$	2.36^{ab}	1.84^{c}	2.49^{a}	2.22^{b}	21.31^{b}	21.69^{ab}	20.26^{b}	22.39^{a}	33.46^{b}	31.81^{b}	33.40^{b}	35.15^{a}
30-40	1.57^{b}	1.54^{d}	1.56^{c}	1.58^{a}	41.61^{c}	42.54^{a}	41.98b	41.05^{d}	3.29^{b}	2.82^{d}	3.64^{a}	3.05^{c}	22.46^{a}	22.31^{a}	22.21^{a}	22.64^{a}	35.26^{ab}	34.36^{b}	34.65^{b}	35.77^{a}
Mean	**1.45**	**1.41**	**1.44**	**1.49**	**46.09**	**47.36**	**46.55**	**44.64**	**2.14**	**1.81**	**2.36**	**2.00**	**21.36**	**21.12**	**20.22**	**21.73**	**30.99**	**29.19**	**30.02**	**32.63**

2RT: two passes of rotary tillage, 2RTSS: two passes of rotary tillage + subsoil, SS: subsoiling, ZT: zero tillage. For a given soil parameter, values with different letters in rows indicates significant differences at the 5% level of Duncan Multiply Range Test (DMRT).

3.6 Relationship among variables, biplot analysis and hierarchical cluster analysis

A correlation analysis was conducted on soil physical properties as affected by tillage methods (Table 2). Results showed that there was significant correlation between the parameters, however, the highest significance level was recorded between volumetric water content and bulk density and the lowest recorded between porosity and bulk density. The biplot analysis on soil physical properties showed that, the models of accuracy; F1 (89.80%) and F2 (5.63%) together explained (95.43%) the experimental variance (Figure 1a). There was a strong correlation between bulk density, gravimetric water content and volumetric water content and F1 compared to porosity and soil penetration water content on F2. It can be seen that F1 is mainly an integrated variable representing soil physical properties.

In the hierarchical cluster analysis (Figure 1b), the soil physical properties were grouped on the bases of their roles in the transformation of their properties. Generally, two cluster were obtained from the cluster analysis that was performed. One included bulk density and soil penetration resistance and the second porosity, gravimetric water content, and volumetric water content which show a link between the soil physical properties.

Table 3 Pearson correlation coefficients between soil physical properties at the soil depth of 0-40 cm

Variables	BD	Po	SPR	GWC	VWC
BD	1				
Po	-0.999**	1			
SPR	0.804**	-0.805**	1		
GWC	0.840**	-0.844**	0.752**	1	
VWC	0.965**	-0.965**	0.807**	0.924**	1

** Correlation is significant at the 0.01 level. (BD: bulk density; Po: porosity; SPR: soil penetration resistance; GWC: gravimetric water content; VWC: volumetric water content).

3.7 Yield components

There was a significant effect of tillage methods on plant height during both growing seasons. At 10 weeks after planting, the highest plant of 217.36 cm was recorded under SS followed by 215.65 cm under 2RTSS and the lowest 212.62 cm recorded under ZT (Table 3). SS significantly (p < 0.05) improved plant height up to 2.23% than ZT.

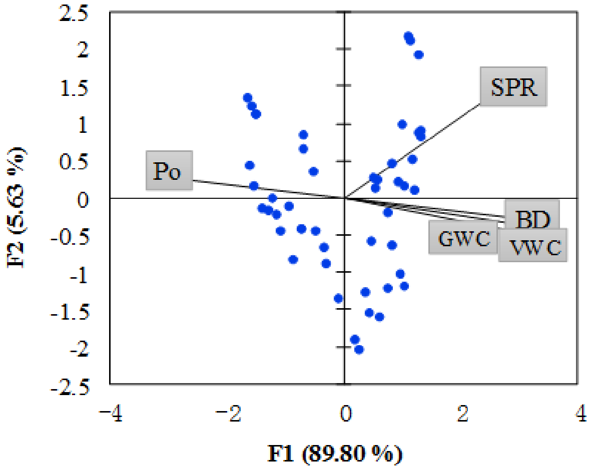
A significant effect of tillage methods was observed on ear height. SS observed the highest of 68.65 cm followed by 67.36 cm under 2RTSS and the least 65.58 cm recorded under ZT (Table 3). SS improved ear height up to 4.68% than ZT.

The two-year study showed that there was a significant effect of tillage methods on ear length of maize, the highest 194.3 mm was recorded under SS followed by 188.8 mm under 2RTSS and the lowest 175.10 mm recorded under ZT (Table 3). SS significantly improved ear length up to 10.97% than ZT.

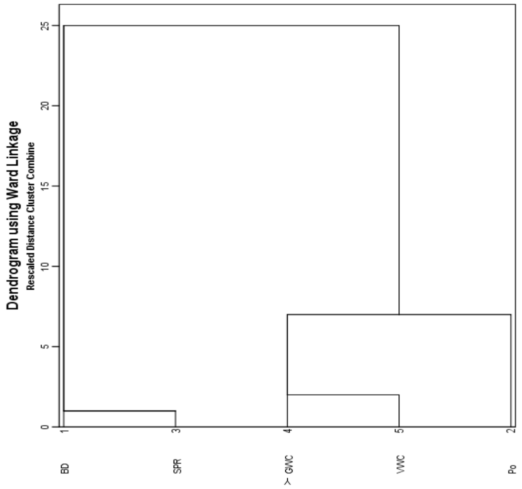
Ear weight under SS recorded 341.13 g as the highest followed by 325.04 g under 2RT and the lowest 245.59 g was observed under ZT (Table 3). However, regarding SS, ear weight was increased by 38.90% than ZT.

SS showed significantly higher values than 2RTSS and ZT. The highest 17.17 was recorded under SS followed by 16.33 under 2RT and the lowest 15.22 recorded under ZT. In regards of that, SS improved by 12.81% over ZT (Table 3).

The highest number of grains per row of 41.56 was observed under SS followed by 39.50 recorded under 2RT and the lowest 35.68 was recorded under ZT in both years of study. SS significantly improved number of grains per row up to 16.48% than ZT (Table 3).



(a) Biplot analysis



(b) Dendrogram of the ward linkage from the hierarchical cluster analysis of soil properties

Figure 1 Analysis of soil properties

Note: BD: bulk density; Po: porosity; SPR: soil penetration resistance; GWC: gravimetric water content; VWC: volumetric water content from different soil treatments.

After harvesting of maize, dry matter was the highest (19.21 t ha^{-1}) under SS followed by 18.79 t ha^{-1} under 2RT whilst the significantly lowest (17.86 t ha^{-1}) was recorded under the ZT. SS significantly improved the dry matter up to 7.56%, 4.06%, and 2.24% than the ZT, 2RTSS, and 2RT respectively (Table 3).

Highest 1000-grain (THGW) weight of 297.88 g was recorded under SS followed by 286.06 g under 2RT and the lowest 271.18 g under ZT. The SS showed greater 1000-grain weight regarding the other treatments. SS significantly improved the 1000-grain weight up to 9.85 % than the ZT (Table 3).

Table 4 Mean comparison of grain yield and yield components of maize under tillage methods

Treatment	PH (cm)	EH (cm)	EL (mm)	EW (g)	NRE	NGR	DM (t ha $^{-1}$)	THGW (g)	HI (%)	GY (t ha $^{-1}$)
2RT	214.70ab	66.64bc	185.6b	325.04a	16.33ab	39.50 a	18.79b	286.06b	38.03a	7.14b
2RTSS	215.65a	67.36ab	188.8b	308.81a	16.22b	38.52ab	18.46c	279.33c	37.73a	6.97b
SS	217.36a	68.65a	194.3a	341.13a	17.17a	41.56 a	19.21a	299.88a	38.36a	7.37a
ZT	212.62b	65.58c	175.1c	245.59b	15.22 c	35.68b	17.86d	271.18d	37.64a	6.73c

Different letters within a column represent significant differences at the 5% level of DMRT. (PH: plant height; EH: ear height; EL: ear length; EW: ear weight; NRE: number of rows per ear; NGR: number of grains per row; DM: dry matter; THGW: 1000-grain weight HI: harvest index; GY: grain yield). 2RT: two passes of rotary tillage, 2RTSS: two passes of rotary tillage + subsoiling, SS: subsoiling, ZT: zero tillage.

Harvest index of 38.36% under SS was highest followed by 38.03% under 2RT. Lowest harvest index 37.64% was recorded from the ZT t in both years. In regards, SS improved the harvest index 1.91 % than ZT (Table 3), however, there were no significant differences observed among the treatments.

Different tillage methods significantly influenced the grain yield. The highest grain yield of 7.37 t ha^{-1} was obtained in the case of SS followed by 7.14 t ha^{-1} under 2RT and the minimum of 6.73 t ha^{-1} was obtained under ZT (Table 3). However, SS was significantly higher than 2RT and 2RTSS (without differences between them) and ZT.

3.8 Correlational analysis

Correlation analyses conducted on yield and yield components as affected by tillage methods (Table 4) showed that there was a significant correlation between the parameters. However, the highest (0.957) significance level was recorded between dry matter and ear weight and the lowest (0.182) recorded between harvest index and number of grains per row.

The PCA on maize yield and yield components showed that, PCA1 (77.12%) and PCA2 (10.76%) together explained (87.88%) of experimental variance (Figure 2a). There was a strong correlation between plant height, ear height, ear length, ear weight, number of rows per ear, number of grains per row, dry matter, 1000-grain weight, harvest index, grain yield and PCA1 compared to PCA2. It can be seen that PCA1 is mainly an integrated variable representing maize yield and yield components.

In the hierarchical cluster analysis (Figure 2b), the maize yield and yield components were grouped on the bases of their roles in the transformation of their yield contents. Generally, two cluster were obtained from the cluster analysis that was performed. One included ear length, dry matter, number of rows per ear, grain yield, number of grains per row, harvest index and ear height, and the second included ear weight, 1000-grain weight and plant height which show a link between the maize yield and yield components.

4 Discussion

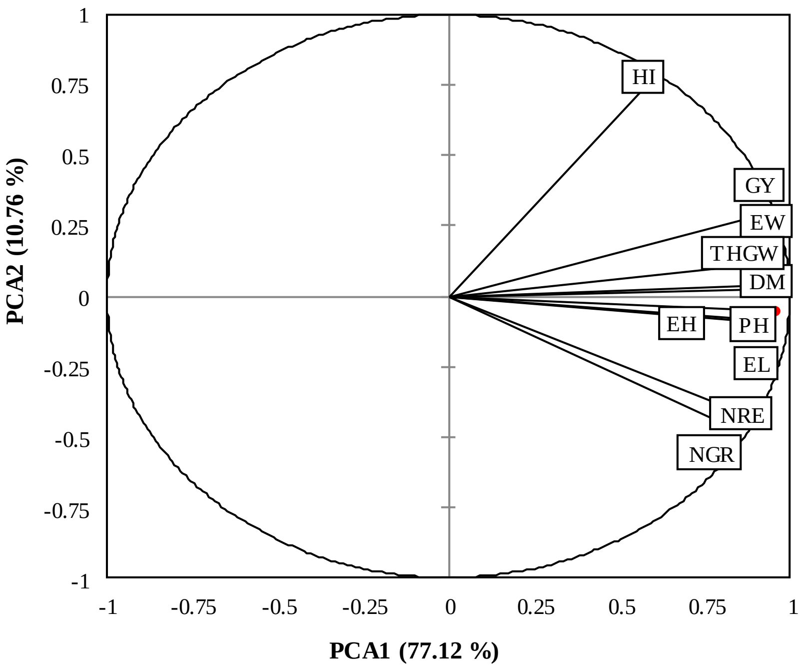
4.1 Subsoiling effects on soil physical condition

In this study, influence of tillage systems on soil physical properties were investigated. Results showed a significant response in the selected soil physical properties. The greatest increase in soil bulk density of 6.52 and 8.70% was observed under ZT treatment in the layer of 0-40 cm in both years respectively, this might be due to the undisturbed soil. Other studies also confirming the increase of soil bulk density were reported by Filipovic et al. (2006) as a result of the upward trend of compaction under different tillage systems. The rise in soil bulk density in the cultivated horizon on medium heavy soils have a negative effect on the growth and development of agricultural crops. The lowest average increase in bulk density (1.45 and 2.90% in both years, respectively) were observed under SS treatment in 0-40 cm soil depth, which might be due to the loosen of the soil as a result of the lateral cut created by the implement which increase deposition of organic matter and water permeation. Butorac et al. (1992), observed the highest corn yield on Luvisol soil with an average soil bulk density of 1.40 g cm^{-3}, while a much lower yield was obtained with the soil bulk density of 1.60 g cm^{-3}. Soils with high bulk density of the sub cultivated horizon had poor water movement and were characterized by reduced root growth, resulting in a substantial yield loss (Varsa et al., 1997).

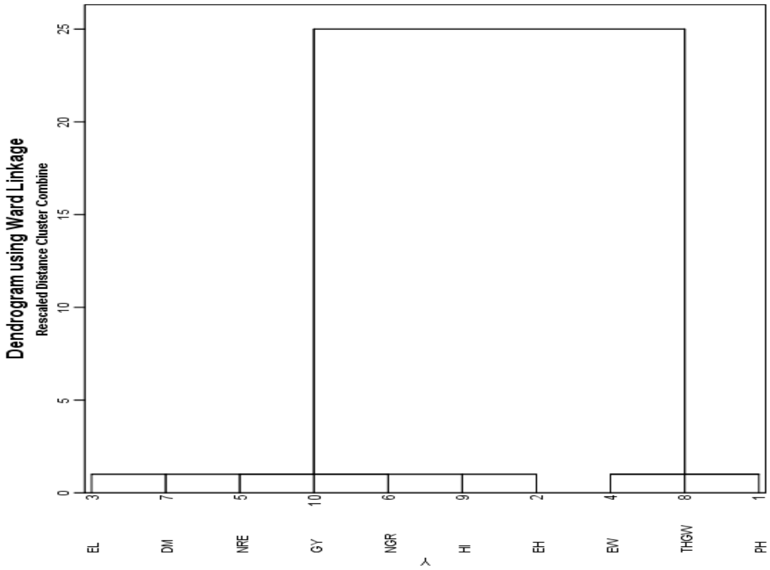
Table 5 Means of Pearson's correlation coefficients among maize yield and yield components under tillage methods

	PH	EH	EL	EW	NRE	NGR	DM	THGW	HI	GY
PH	1									
EH	0.796*	1								
EL	0.924*	0.835*	1							
EW	0.700*	0.740*	0.849*	1						
NRE	0.705*	0.751*	0.793*	0.792*	1					
NGR	0.783*	0.663*	0.798*	0.677*	0.788*	1				
DM	0.731*	0.768*	0.899*	0.957*	0.785*	0.729*	1			
THGW	0.713*	0.848*	0.834*	0.930*	0.823*	0.700*	0.931*	1		
HI	0.515*	0.465*	0.544*	0.607*	0.190*	0.182*	0.515*	0.550*	1	
GY	0.748*	0.738*	0.866*	0.944*	0.664*	0.633*	0.942*	0.917*	0.755*	1

*. Correlation is significant at the 0.01 level; PH: plant height; EH: ear height; EL: ear length; EW: ear weight; NRE: number of rows per ear; NGR: number of grains per row; DM: dry matter; THGW: 1000-grain weight HI: harvest index; GY: grain yield. 2RT: two passes of rotary tillage, 2RTSS: two passes of rotary tillage + subsoiling, SS: subsoiling, ZT: zero tillage.



(a) Principal component analysis (PCA) scores



(b) Dendrogram of the ward linkage from the hierarchical cluster analysis on tillage influence on maize yield and yield components

Figure 2 Tillage influence on maize yield and yield components

PH: plant height; EH: ear height; EL: ear length; EW: ear weight; NRE: number of rows per ear; NGR: number of grains per row; DM: dry matter; THGW: 1000-grain weight; HI: harvest index; GY: grain yield.

Tillage generally alters soil porosity, but its effects are quite transitory, which reflected in the worsening soil physical condition of the conventional tillage treatment, for example, predominance of micro porosity (Roseberg and McCoy, 1992). The consistent enhancement in the soil porosity under SS treatment was possibly related to increased aggregate stability and the residue cover. SS treatment also had a better distribution of the various pore size classes which is very important for the crop growth, since it influences plant available water, soil aeration, through increased connectivity, drainage and channeling for enhanced root development (Oliveira and Merwin, 2001).

Soil penetration resistance was greater under ZT treatment, which in average increased 9.10 and 13.38% in 0-40 cm soil depth in both years respectively. The highest reduction of 18.44 and 15.22%, in soil penetration resistance was observed under SS treatment whilst the highest increase (9.43 and 13.68%) was recorded under ZT treatment for both years in 0-40cm soil depth respectively. As perpendicular break usually occurs between ploughed soils and compacted soil below after land preparation or between tilled layer and untilled subsoil (Gliński and Lipiec, 1990), the critical values of penetration resistance that cause the stopping of root growth ranged from 3 to 4 MPa (Lipiec and Hatano, 2003).

Higher penetration resistances of 2.25 and 2.46 MPa, and 2.45 and 2.52 MPa were recorded under 2RT and ZT treatment in 20-30 cm layer in both years, respectively, whereas the penetration resistance in 30-40 cm depth under all treatments were higher than the threshold (2.0 MPa) for a good root growth and maize development. Other studies reveal that, soil penetration resistance over 2.0 MPa can significantly reduce root growth and development (Ishaq et al., 2000; Filipovic et al., 2006). Significantly, greater penetrometer resistance was found under no-tillage than under conventional tillage from surface to 20 cm depth as reported by Ferreras et al. (2000).

Both gravimetric and volumetric water content were greater under the ZT treatment, with an average increase of 30.56 % and 0.88% in 0-4 0cm soil depths respectively in both years. This may result to the presence of the crop residue on the surface of the soil which served as mulching material on the soil surface, whilst the highest decrease in average gravimetric and volumetric water content of 5.10% and 6.73% in 0-40cm respectively was observed under SS treatment. This could be probably due to the fact that the soil in the SS was exposed to evaporation by the act of turning the soil through tilling.

4.2 Subsoiling effects on yield components

Tillage practice significantly affected plant height. After 10 weeks of monitoring, the tallest plant was observed under the SS whilst the shortest plant was found under the ZT. Plant height improved under SS over ZT, which could be due to a decrease in soil bulk density and also loosening up of the soil by breaking up the soil hard pan for increased penetration of roots to aid in the uptake of plant nutrient as well as moisture. These results agree to others (Diaz-Zorita, 2000; Aikins et al., 2012), who observed the highest maize plant under ploughed soils compared to under ZT. Khurshid et al. (2006) also reported highest maize plants under conventional tillage compared to that of the minimum tillage.

Ear height, ear length, ear weight were all affected by tillage methods. The SS significantly produced a higher ear height, ear length and ear weight compared to under ZT. This might be due to the loosen up of the soil for improved root penetration for soil nutrient, infiltration, aeration, and the enhancement of decomposition of more residue crop cover.

The number of rows per ear and number of grains per row was also affected by tillage method, SS achieved significantly higher values compared to the other treatments. This decrease in soil bulk density and also loosen up of the soil by breaking up the soil hard pan for increased penetration of roots for the uptake of nutrient as well as moisture for the enhancement of the maize development resulted in an increase in the number of rows per ear and number of grains per row.

The results on number of grains per ear agree with Albuquerque et al. (2001), who concluded that the, number of grains per ear were reduced under ZT compared to SS. The work done by Keshavarzpour (2012) also recorded an improvement in number of rows per ear and number of grains per row under conventional tillage compared to conservational tillage methods.

The highest yield of maize was achieved under SS, and this might be due to lower soil bulk density aiding root penetration for the accessibility of soil nutrient by the maize crop (Cai et al., 2014). There was a lower yield under the ZT treatment hence, some greater significant differences compared to SS. Conventional tillage methods (e.g., 2RT, 2RTSS and SS) have been reported to improving more yield compared to conservational tillage methods (e.g., ZT). According to (Sartori and Peruzzi (1994), intense ploughed fields tend to produce higher yields compared to minimal ploughed fields while a higher yield reduction is more achieved when done under ZT. Also, conventional tillage methods tend to produce higher grain yields over conservational tillage methods (Borin and Sartori, 1995).

Highest dry matter was recorded under SS compared to the other treatments especially ZT. The highest dry matter may be attributed to more plant height. This results strongly relate with previous ones (Diaze-Zorita, 2000; Astier et al., 2006; Al-Kaisi and Licht, 2004; Wasaya et al., 2012), which reported that dry matter yield of maize improved due to good soil conditions provided to crop for better growth and development by loosening the soil with deep tillage or subsoiling (SS) implements.

There were no significant effects of different tillage on maize harvest index in both years. The results are closely associated with the findings of Patil and Sheelavantar (2009) and Wasaya et al. (2012), who observed the highest harvest index of maize grown in deeply tilled (subsoiling) plots respectively.

The observed results pertaining to 1000-grain weight showed significant differences in 1000-grain weight between the different tillage treatments. SS produced heavier grains compared to the other treatments especially to ZT. The results agree with those of (Ahmad et al., 2010), and according to them, significantly higher grain yields were produced under conventional tillage as compared to zero-tillage.

5 Conclusions

Results showed that:

Subsoiling at 40 cm depth (SS) recorded lower soil bulk density, soil penetration resistance, gravimetric and volumetric water content, resulting to highest porosity in 0-40 cm soil depth.

Highest plant, ear height, ear length, ear weight, number of rows per ear and number of grains per row were observed under SS.

Maximum grain yield, dry matter, harvest index, and 1000-grain weight were recorded under SS.

SS could therefore be adopted as a promising soil management practice (soil physical properties) for sustainable maize production.

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