Asian Journal of Research in Crop Science

Volume 8, Issue 3, Page 79-91, 2023; Article no.AJRCS.97610
ISSN: 2581-7167

Effects of Reduced Tillage on Dynamic Soil Properties and Winter Triticale Performance in Organic Farm at Wageningen, the Netherlands

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJRCS/2023/v8i3170

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/97610

Original Research Article

Received: 21/01/2023
Accepted: 22/03/2023
Published: 30/03/2023

ABSTRACT

There is an increased need of identifying reduced tillage method that improves soil organic matter and soil fertility and at the same time best crop performance in organic farming. This study assessed the effects of organically managed reduced tillage and conventional tillage on dynamic soil properties and winter triticale performance. Organic farm that has been treated with three different tillage systems for six consecutive years was used in this study at Drovendaal organic facility of

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Wageningen University and Research. The tillage systems included two reduced tillage NIT at 10 cm and ECO up to 20 cm deep and CON at a depth of 30 cm. The parameters evaluated are soil physico-chemical properties, leaf area index (LAI), plant dry matter, ear number per area, plant height and chlorophyll content (SPAD) at ear formation stage . Use of NIT led to higher SOM and N-NO_3 of 13.03 mg kg^{-1} at 0-10 cm soil depth. Also, shallow soil depths had lower bulk density and penetration resistance compared to deeper depths but NIT had higher penetration resistance in all soil depths compared to ECO and CON. Based on crop performance, ECO and CON revealed a better crop performance than NIT. Therefore, ECO having intermediate potentials in soil properties and crop performance could be the right tillage system for organic crop production compared to NIT and CON. Moreover, ECO will be a suitable tillage system that improves soil fertility, mitigates greenhouse gases and at the same time influence high crop performance.

Keywords: Tillage; soil properties; crop performance; organic farm.

1. INTRODUCTION

Tillage is the best-known method to modify the soil structure and soil aggregation [1]. There are two types of tillage namely inversion and non-inversion tillage [2]. The latter constitutes conservation tillage which is among the principles of conservation agriculture and subset of organic agriculture together with crop rotation and soil cover [3]. In this study, there were two types of conservation tillage which include; Non-inversion tillage (NIT) that cultivate at a depth of 10 cm and ECO-mouldboard plough tillage (ECO) that cultivate up to a depth of 20 cm. The ECO was developed by Rumptstad Industries in Europe having seven or eight bottoms with plough depth of 12-20 cm, a working width of 210 cm and a speed of 1.7 m/s [4]. Conversely, inversion tillage constitutes conventional tillage (CON) which involves the use of mouldboard plough as a primary tillage followed by secondary tillage with disk, field cultivator, and or harrowing. It overturns soil during primary tillage operations to control weeds, incorporate organic material, and loose topsoil [3]. However, successive use of CON has been reported to have negative environmental impacts, as it may cause soil degradation, soil erosion, and water and air pollution [5,6]. Furthermore, high soil nutrient contents under CON can lead to nitrate leaching thereby affecting surface and groundwater bodies [7]. To rescue the situation, conservation tillage practices that include no tillage and reduced tillage have been adopted to increase the organic matter content and aggregate stability of the topsoil [8], bulk density and penetration resistance [9]. Soil organic matter is the most important soil quality indicator relative to tillage because of its influence on other soil physical, chemical and biological properties [10]. However, non-inversion tillage favours soil organic carbon (SOC) accumulation [11], soil porosity [12], and reduces soil disturbance [2]. Reduced tillage also increases the soil nitrogen (N) retention and thereby reducing off-site effects of nutrient losses and hence increase plant N availability [13], gross N mineralization, nitrification and mobilization [7].

Several studies have addressed soil change based on degrees of change in soil morphology, chemistry, hydrology, and repeated measurements through short-interval monitoring that reflect seasonal variation in soil properties [8]. The current study focuses on dynamic soil properties that change in response to management, natural and anthropogenic disturbances, thereby used to compare two or more different management practices on the same soil and vegetation. The dynamic soil properties measured include; organic matter, pH, bulk density, penetration resistance, total N, and mineral nitrogen. These soil properties are vital for reflecting management effects as well as soil and vegetation dynamics, interpreting soil function, to identify positive and negative critical management thresholds and are measured in one point in a time [14]. Soil and crop sampling were replicated to provide data that meet acceptable levels of certainty, to obtain an estimate of error and to allow data to be tested for statistical differences between tillage systems.

Winter triticale (*X Triticosecale* Wittm.) which is a hybrid of wheat and rye has recently become important in Europe as a feed grain. This is because of its richness in amino acids [15], higher amounts of the above-ground yields and ability to resist some unfavourable biotic and abiotic environmental factors [16]. Winter triticale has the ability to accumulate a large amount of N in the form of dry matter and reduces the rate of N leaching during heavy rains [17]. More often the crop is grown during autumn and stays in the field during winter to utilize N left in the soil by previous crops and prevent soil erosion during high rainfall [18]. All the mentioned agronomic advantages of the winter triticale are the key reasons why it is highly grown in Europe especially during winter seasons than wheat. Unlike this study, many studies have evaluated effects of soil properties and performance of potato crop. Hence, little is known on how the performance of winter triticale is affected by tillage systems as contributed by dynamic soil properties in the temperate climate.

Organic farming involves use of the soil as an ecosystem, leading to the protection of soils and groundwater, operational hygiene and preventive crop protection, which reduce the dependence on chemical pesticides contributing to a cleaner environment [19]. The principles guiding organic crop production are constant soil fertility, ample crop rotation, mulching, biodiversity in and around the farm, and to enhance mineral, water, and energy cycles. Many studies have evaluated no-tillage and reduced tillage in conventional farming systems which are normally characterized by increased use of more herbicide applications for weed control [20]. Little is known about the effect of reduced tillage on soil properties and crop performance for organic farming systems considering different crop species under varying climatic conditions. Besides, in temperate regions reduced tillage is not mostly recognized in organic farming though the guidelines recommend reduction of tillage intensity [12]. This is because tillage is important in organic agriculture to incorporate organic residues into the soil for rapid mineralization, release of nutrients to the crop and eradication of weeds. Likewise, numerous studies have compared only inverted and non-inverted tillage systems in organic farming [12]. This current study evaluated effects of tillage practices on dynamic soil properties and yield performances of winter triticale in the organic farm.

2. MATERIALS AND METHODS

2.1 Study Site and Experimental Setup

This study was at Droevendaal Farm (51°59'33.68"N, 5°39'34.59"E), a certified organic research facility of Wageningen University, the Netherlands during autumn, winter and spring. The farm has a total of 50 hectares and its climate is temperate maritime with mean annual rainfall of 830 mm and an average temperature of 11 ^{0}C. Moreover, the farm is divided into various fields with different sizes. This research was conducted in the field number 3 with two hectares (220 m by 90 m) and the field has silt sand soil with 82% sand, 15% silt, and 3% clay. The field number 3 have been divided into three main plots representing three tillage systems, namely; non-inversion tillage (NIT), shallow mouldboard-plough (ECO) and deep mouldboard–plough (CON) for six consecutive years. Each main plot was further divided into 18 blocks each having a measurement of 30 m by 8 m (240 m^2) resulting to 54 sampling units in all three main plots with buffer zone of 1 m width and 20 m length per each main plot.

2.2 Cultural Practices and Weather Conditions

Winter triticale (*X. Triticosecale* Wittm., cv. Tulus) was planted on 12th October at a seeding rate of 200 kg seeds ha^{-1}. The entire crop growth and development was under rainfall condition (no irrigation conducted). Furthermore, the field had been rotated with different crops for six consecutive years. The crops rotated were maize (*Zea mays* L.), summer wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*), potatoes (*Solanum tuberosum*) and winter triticale in ascending order from 2010 to 2016 and catch crop mixtures included rye grass, radish, and mustard. Besides, the field had been managed with organic manure from cattle slurry and solid cattle manure. The weather conditions during winter triticale production from October 2015 to May 2016 when crops were in late ear emergence stage are as shown in Fig. 1.

2.3 Soil Sampling and Laboratory Analysis

The soil samples were collected from NIT, ECO and CON plots at three soil layers of 0-10 cm, 10-20 cm and 20-30 cm during dry periods in November and December 2015. Thirty sub-samples were collected from each block by a soil gouge auger with three layers each of 10 cm long following a systematic pattern. The sub-samples were put in one container then mixed to get a composite sample per each soil layer. Therefore, three composite soil samples, each from 30 sub-samples, were collected in each block resulting to a total of 162 composite samples. However, all samples were not collected in one day/week or simultaneously due to their large numbers and unstable weather, respectively. Walking in the wet field might have caused much damage to crops and it was also difficult to walk due to sinking of feet. Therefore, the samples were temporarily stored in 4 ^{0}C cold room until all 162 samples were completely collected. Afterwards, the samples were separated according to the type of indicator to be measured that is samples for SOM, TN and pH were dried at 40 ^{0}C and passed through a 1.8 mm sieve then sent to a laboratory for analysis but those of N_{min} were sent to the laboratory for analysis while wet. For bulk density, three rings or cones of 5 cm diameter each were used to collect the three soil samples from one hole per each block in March 2016 when the soil was not too wet. The soil layers used for SBD measurements were 5-10 cm, 15-20 cm and 25-30 cm instead of 0-10 cm, 10-20 cm and 20-30 cm. Moreover, three cones instead of six per each hole starting from 5 cm depth instead of 0 cm depth, respectively were adopted because it was only 3-5 days after weed ridging. So top 5 cm per each level was omitted to replace the ridged upper top soil and create uniformity in all three layers. The samples from each ring were put in the bag, dried in the oven at 105 ^{0}C for 48 hours then weighed. The weights of oven dried soil samples (g) were divided by the volume (cm^3) of the ring to compute SBD per each soil layer [9]. Soil penetration resistance was measured using the methods described by [4] whereby a digital Eijkelkamp penetrologger (Agrisearch Equipment, the Netherlands) was used. Ten penetrations were made per each block using cones of 1.0 cm^2 60^0 at a speed of 2 cm/s and at a depth of 60 cm with a total of 360 penetration points in 12 blocks per each main plot. The measurements were conducted when the whole soil profile was at field capacity that is one to two days after rainfall in early May 2016.

The SOM was determined using loss-on-ignition (LOI) method as described by [21]. About 20 g of each soil sample were combusted in a furnace at 550 ^{0}C for ignition duration of three hours and a tray turning at around 1.5 hours to avoid the effect of uneven temperature between furnaces door side and the opposite side. Soil organic carbon (SOC) was computed from the SOM by using the conversion factor of 0.55 [21]. Soil available N-NO_3 and N-NH_4 were determined using the methods described in [22] from wet soil stored at 4 ^{0}C. About 4 g samples were extracted by shaking in 0.01 M $CaCl_2$ for about 2 hours at 20 ^{0}C and then analysed by a segmented system (Technicon Autor-analyzer II). The same soil samples used for SOM determination were digested with a mixture of conc. H_2SO_4–Se and salicylic acid [10] to measure total N. The actual digestion started by H_2O_2 and in this step most of the organic matter was oxidized. After decomposition of the excess H_2O_2 and evaporation of water, the digestion was completed by concentrated H_2SO_4 at elevated temperature (330 °C) under the influence of Se as a catalyst. In these digests total N was measured spectrophotometrically with a segmented-flow system (Auto-analyzer II, Technicon). Salicylic acid was added purposely to prevent loss of nitrate-N by coupling the nitrate to salicylic acid, a reaction which proceeds easily in the acid medium. The same soil samples used to measure SOM and total N were used to measure both pH-H_2O and pH-$CaCl_2$ using a pH/mV meter. The soil samples were first shaken for about two hours after putting the relevant solvent before pH was measured in the settling suspension.

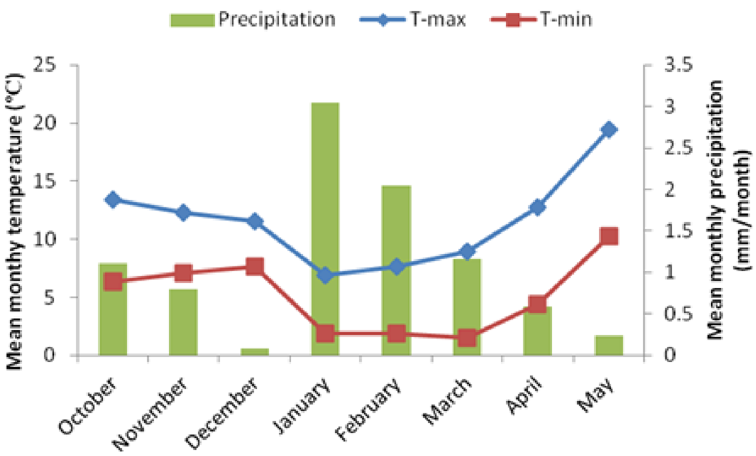

Fig. 1. Monthly mean precipitation, maximum temperature, and minimum temperature

2.4 Measurement of Crop Performance Parameters

All crop performance parameters were measured at ear emergence stage when the plants were vegetative, very succulent and with high nutritive value [23]. Above-ground plants were harvested purposely for the measurements of leaf area index (LAI), total plant dry weight, ear dry weight and ear number/m^2. These measurements were done in six middle blocks of 30 m × 8 m per each tillage system or main plot. At ear formation stage, all crops within a 50 cm × 50 cm quadrant were harvested and sorted separately into leaves, stems and ears. This is because yield of winter triticale is perfectly predicted by dry matter during anthesis [24]. Leaf area was measured by LI-COR LI-3100, AREA METER. Separated leaves, stems and ears were weighed then dried at 70 ^{0}C for 72 hours and their dry weights were summed to obtain total plant dry weight. Plant height and chlorophyll content were measured in a zig-zag pattern so as to have a broad representation of almost all crops. Four plants per block were measured for their heights using a tape measure from the ground level to the head and chlorophyll content was taken as average of 20 crops per block was measured using a chlorophyll meter (SPAD-502PLUS, KONICA MINOLTA). The measurements were conducted during spring May 2016 when the crops were at the ear forming stage.

2.5 Statistical Analysis

All data were first processed by Microsoft Excel 2010 before statistical analysis using IBM SPSS Version 25. The normality test was tested for all data before statistical analysis and all data were normally distributed. Analysis of Variance (ANOVA) was conducted to test the effects of tillage systems on soil properties and crop growth performance. One way ANOVA was used for the analysis of all measured parameters. Differences among means were compared using Post Hoc Tests of Multiple Comparisons at 5% level of probability.

3. RESULTS

3.1 Soil Properties

3.1.1 Bulk density and penetration resistance

Bulk density and penetration resistance increased with increase in soil depth and were higher in reduced tillage systems (NIT and ECO) than in CON. The differences of bulk density between each tillage systems (NIT, ECO and CON) (g cm^{-3}) were statistically significant (P= 0.03 and 0.005) at both soil depths 5-10 cm and 15-20 cm respectively (Fig. 2). Nevertheless, the differences between each tillage systems (NIT, ECO and CON) were not significant (P =0.218) at 25-30 soil depth (Fig. 2). The highest (1.6 g cm^{-1}) and lowest (1.48 g cm^{-1}) SBD were observed in ECO at 25-30 cm and CON at 5-10 cm soil depth. Soil strength increased after 20 cm up to 60 cm depth for NIT and after 40 cm to 60 cm for ECO and CON tillage systems (Fig. 3).

3.1.2 Soil Organic Matter (SOM)

There was significance difference (P = 0.004) between NIT and CON tillage systems, no significant difference (P = 0.057) between ECO and CON and (P = 0.366) between NIT and ECO at 0-10 cm soil layer (Fig. 4). Furthermore, there were no significant differences (P = 0.273 and 0.805) among three tillage systems in both 10-20 cm and 20-30 cm soil layers respectively (Fig. 4).

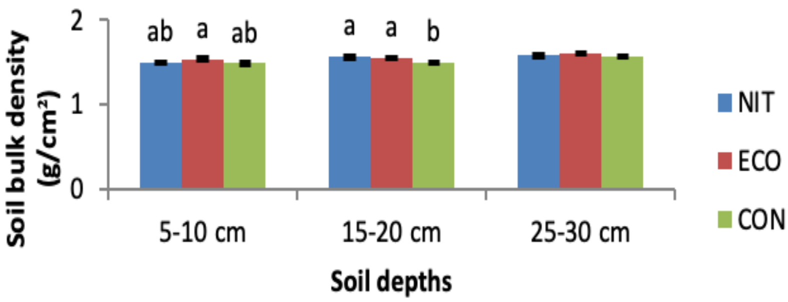

Fig. 2. Effects of NIT, ECO and CON at 5-10 cm, 15-20 cm and 25-30 cm soil layers on soil bulk density. Means followed by different letters differ significantly between each tillage systems at each soil layer

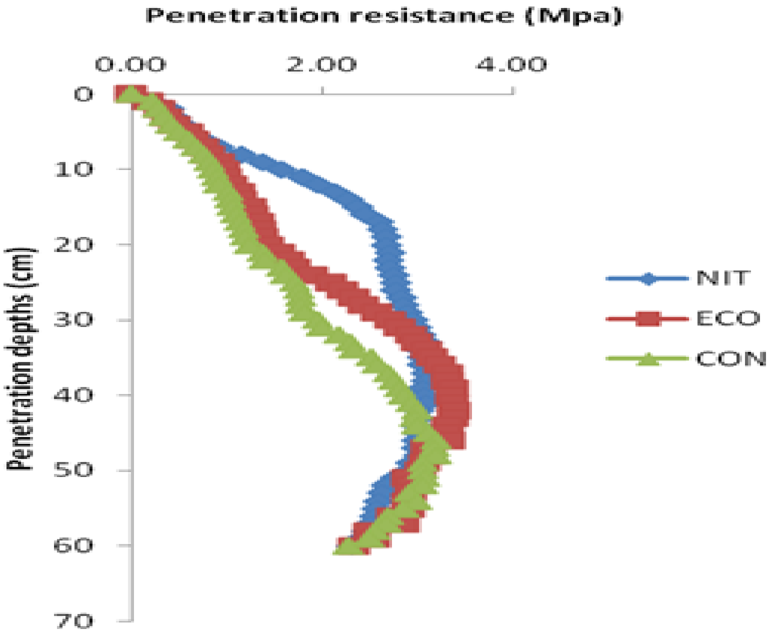

Fig. 3. Effects of tillage systems on penetration resistance throughout the 0-60 cm soil profile. Average values for 10 samplings per 6 replicates are presented

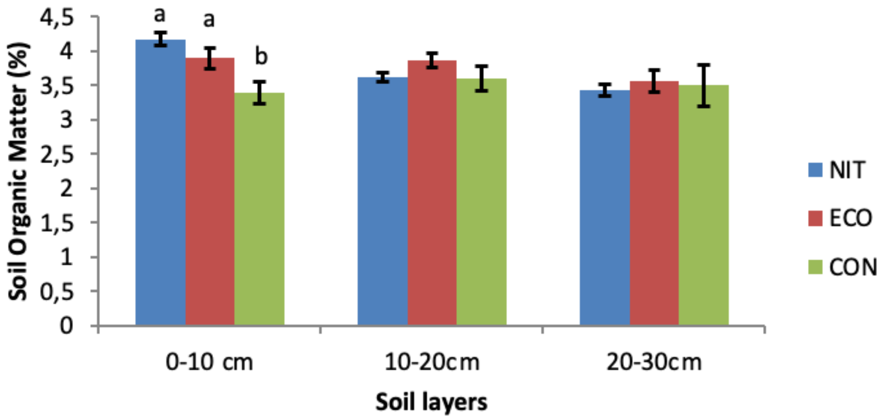

Fig. 4. Differences in amount of soil organic matter (SOM) between each tillage systems (NIT, ECO and CON) at each soil layers (0-10 cm, 10-20 cm and 20-30 cm). Means followed by different letters differ significantly between each tillage systems at each soil layer

3.1.3 Soil available nitrogen minerals (Nmin) - Nitrate-Nitrogen (N-NO_3)

There was a statistically significant concentration of N-NO_3 between each tillage systems at all soil layers (0-10 cm, 10-20 cm (P <0.001) both and 20-30 cm (P =0.001) (Fig. 5). Highest and lowest concentrations of N-NO_3 were observed in NIT (13.03 mg kg^{-1}) and CON (3.82 mg kg^{-1}) respectively at 0-10 cm (Fig. 5). The concentrations of N-NO_3 differed significantly (P =0.001) between NIT & ECO and NIT & CON at both 0-10 cm and 10-20 cm. There were also significant differences between NIT & ECO (P =0.001) and NIT & CON (P =0.01) at 20-30 cm (Fig. 5). Moreover, concentrations of N-NO_3 in NIT were higher at all three soil layers 0-10 cm (13.03 mg kg^{-1}), 10-20 cm (9.78 mg kg^{-1}) and 20-30cm (7.61 mg kg^{-1}) (Fig. 5). Nevertheless, there was no significance difference in N-NO_3 between ECO and CON at 0-10 cm (P =0.242), 10-20 cm (P =0.966) and 20-30 cm (P =0.688) soil layers (Fig. 5).

3.1.4 Total Nitrogen (TN)

There was statistically different effect of each tillage systems at 0-10 cm soil layer (P <0.001). The highest and lowest concentrations of TN were observed in NIT (10.83 mg kg^{-1}) and CON (8.64 mg kg^{-1}) respectively at 0-10 cm soil layer (Fig. 6). However, there was no significant difference at both 10-20 cm (P =0.228) and 20-30 cm (P =0.303) soil layers for all three tillage systems NIT, ECO and CON (Fig. 6).

3.1.5 Soil pH

The differences in pH-H_2O between each tillage systems were not statistically different (P =0.733, 0.085 and 0.817) at each three soil layers 0-10 cm, 10-20 cm and 20-30 cm respectively. On the other hand, the means of pH-$CaCl_2$ were statistically different (P <0.001) at both soil layers 0-10 cm and 20-30 cm (Fig. 7). The mean values of pH-$CaCl_2$ between each tillage systems at 10-20 cm soil layer were not significant (Fig. 7).

3.2 Crop Performance Parameters

All crop performance indicators; leaf area index (LAI), total plant dry matter (TDM), ear dry matter (EDM), ear m^{-2}, height and chlorophyll content (SPAD) were statistically affected by tillage systems (Table 1). The values of LAI, TDM, EDM, ear m^{-2}, height and SPAD were lower in NIT compared to ECO and CON. Moreover, the values of LAI, TDM, EDM, ear m^{-2}, height and SPAD had no significance differences (P =0.975, 0.957, 0.598, 0.868, 0.574 and 0.384 respectively) between ECO and CON (Table 2). Furthermore, the highest values for all variables measured were observed in both ECO and CON while the least values were recorded in NIT (Table 2).

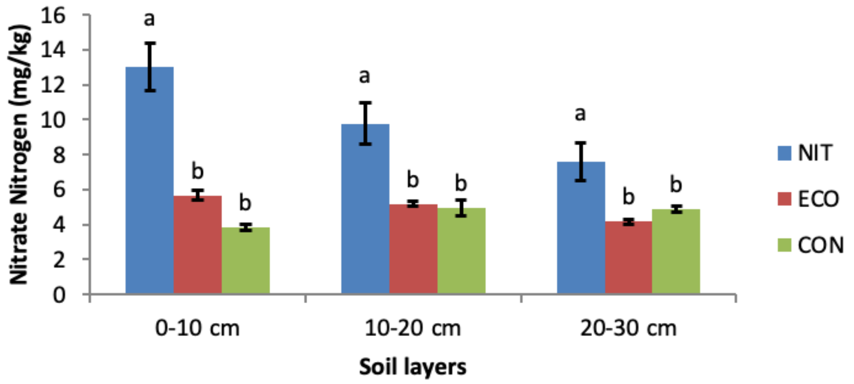

Fig. 5. Effect of NIT, ECO) and CON at 0-10 cm, 10-20 cm and 20-30 cm soil levels on soil available nitrogen in mg/kg. Means followed by different letters differ significantly between each tillage systems at each soil layer

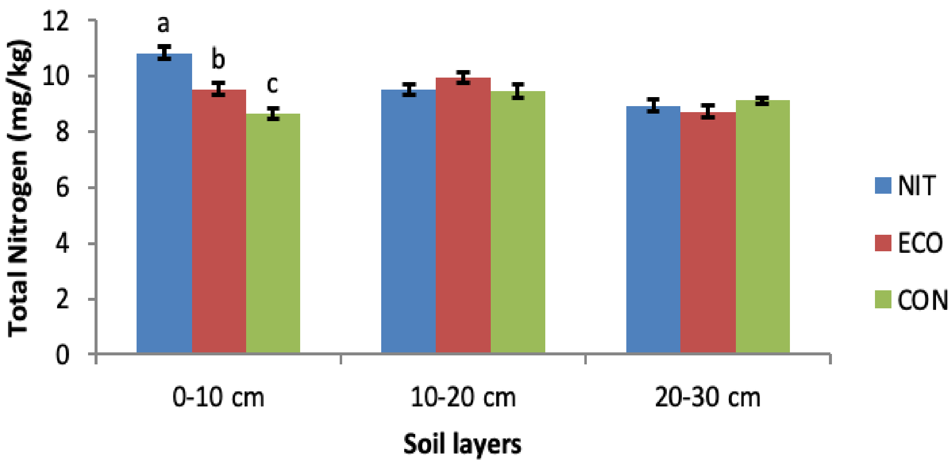

Fig. 6. Effects of NIT, ECO and CON at 0-10 cm, 10-20 cm and 20-30 cm soil levels on total nitrogen in mg/kg. Means followed by different letters differ significantly between each tillage systems at each soil layer

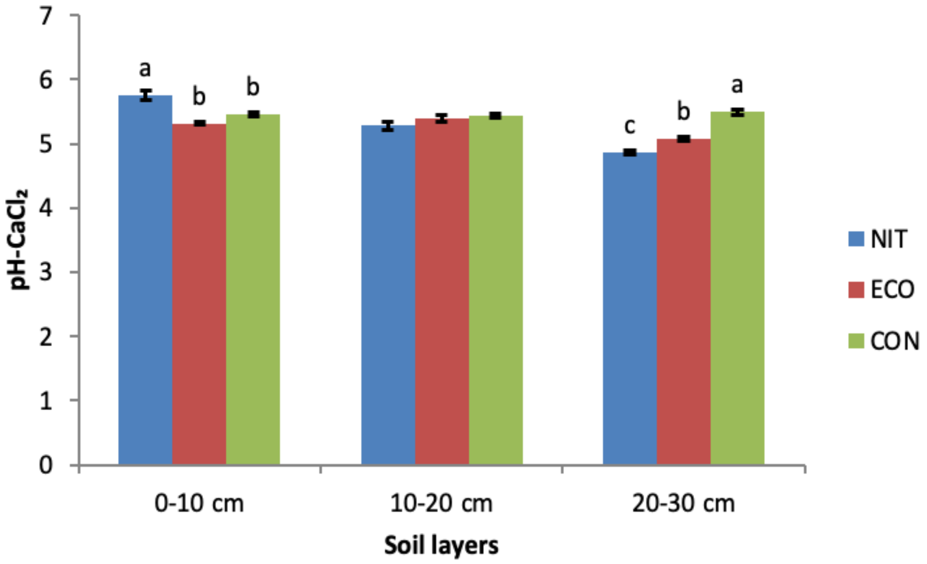

Fig. 7. Effects of NIT, ECO and CON at 0-10 cm, 10-20 cm and 20-30 cm soil levels on soil pH-$CaCl_2$. Means followed by different letters differ significantly between each tillage systems at each soil layer

Table 1. Effects of tillage on crop performance

Dependent variables	Tillage systems	
	F-value	**P-value**
LAI	9.728	0.002 *
Total plant DM (Mg/ha)	6.581	0.009 *
Ear dry DM (kg/ha)	7.210	0.006 *
Ear number (Ear/m^2)	10.031	0.002 *
Plant height (cm)	7.591	0.002 *
SPAD (Chlorophyll content)	12.762	0.000078 **

Table 2. Effect of tillage systems on LAI, total DM, ear DM, Ear/m2, plant height and chlorophyll content

Dependent variables	Tillage systems		
	NIT	**ECO**	**CON**
LAI	0.37^b	0.69^a	0.67^a
Total plant DM (Mg/ha)	1.67^b	2.82^a	2.73^a
Ear dry DM (kg/ha)	204^b	393.4^a	462.73^a
Ear number (Ear/m^2)	78.67^b	154^a	144.67^a
Plant height (cm)	57.25^b	64.88^a	67.72^a
SPAD (Chlorophyll content)	36.63^b	40.26^a	41.62^a

Means followed by different letters differ significantly between each tillage systems

3.3 Correlations

SOM had a fairly strong positive and a perfect positive correlation between N-NO3 and TN respectively and a slight positive correlation between pH. However, there were fairly strong positive and perfect negative correlations between SOM and all crop performance parameters. All crop performance parameters showed high positive correlations between themselves (Table 3).

Table 3. Correlations between SOM and other parameters

	SOM	**N-NO3**	**TN**	**pH**	**LAI**	**TPDM**	**EDDM**	**EN**	**PH**	**SPAD**
SOM	1									
N-NO3	**0.883645**	**1**								
TN	**0.973319**	**0.967491**	**1**							
pH	**0.52581**	**0.862845**	**0.706958**	1						
LAI	-0.7484	-0.97182	-0.88062	-0.95768	1					
TPDM	-0.73863	-0.96828	-0.8736	-0.96178	**0.999893**	**1**				
EDDM	-0.9181	-0.99683	-0.98455	-0.81988	**0.949979**	**0.945316**	**1**			
EN	-0.70867	-0.95651	-0.85165	-0.97276	**0.998317**	**0.999057**	**0.930265**	**1**		
PH	-0.9195	-0.99654	-0.98517	-0.81784	**0.948865**	**0.944154**	**0.999994**	**0.928958**	**1**	
SPAD	-0.92005	-0.99642	-0.9854	-0.81704	**0.948423**	**0.943692**	**0.999988**	**0.92844**	**0.999999**	1

4. DISCUSSION

4.1 Soil Physico-chemical Properties

The higher bulk densities and penetration resistance in shallow upper soil layers and reduced tillage than lower soil layers and conventional tillage respectively have been reported by other studies [17]. Penetration resistance (Mpa) in NIT at 0-10 cm soil depth was higher than in ECO and CON at the same soil depth contrary to the hypothesis. This indicates higher soil compaction in NIT for all soil depths in comparison to ECO and CON. These results are supported by two studies one conducted in Denmark and another in the Netherlands. Both studies were carried out in an organically managed sandy loam soil and revealed higher penetration resistance in NIT [25,26]. Generally, both bulk density and penetration resistance are key indicators in determining soil strength and therefore ability of the roots to grow through the soil. These are directly proportional to soil texture and soil moisture content but inversely proportional to porosity and soil water filled pore space. Several studies have reported that reduced tillage increases both bulk density and penetration resistance leading to decrease in porosity and soil water filled pore space. Moreover, increased compaction caused by high penetration resistance in NIT indicates higher vulnerability to soil erosion, decreased air and water movement leading to unfavourable plant growth conditions [27].

The two reduced tillage systems (NIT and ECO) had higher SOM, N-NO_3 and TN at 0-10 cm and 10-20 cm, respectively, and in agreement with the first hypothesis (Figs. 4, 5 and 6). The possible reason for less SOM in CON at both 0-10 cm and 10-20 cm soil layers might be due to accumulation of plant residues and their incorporation deep into the soil. It could also be due to SOM oxidation and release of nutrients accelerated by tillage practices [28]. Moreover, the decrease of SOM in CON might be due to high rate leaching and mineralization [29]. On the other hand, the accumulation of SOM on the soil surface was a result of the surface placement of crop residues and lack/low soil disturbance that retained residues isolated from the rest of the soil profile [30]. These results concur with what has been reported by many authors that the concentration of SOM is stratified in NIT and the concentration decreases with increase in soil depths [5] and decrease or increase in soil disturbance [12]. Other studies indicate that soil carbon can be accumulated on the top under reduced tillage but least amount at deeper depths leading to slight differences in total carbon stocks [31]. Higher N-NO_3 in NIT could be attributed to the non-incorporation of the applied solid cattle manure (SCM) and catch crops residues deep in the soil. The high rate of decomposition caused by the organic residues and soil organisms could be another reason for high N-NO_3 in NIT. On the other hand, low concentration of N-NO_3 in CON could be due to nitrate leaching, run-off and denitrification. Nitrate leaching and denitrification might have been caused by high rainfall during soil sampling duration, type of soil texture (silt sand) and high mobility of N-NO_3 in the soil solution. Additional reason for the loss of N-NO_3 in CON could be because of the sampling which took place when the crops were very young (about 30 days after sowing) and low anion exchange capacity in the soil. High rates of denitrification are the challenges to global warming and climate change mitigation since it is a major source of N_2O, a greenhouse gas that contributes to depletion of ozone in the stratosphere. However, ammonium-nitrogen (N-NH_4) was not significantly affected by tillage systems and soil depths. The deficiency of N-NH_4 could be due to factors such as low rate of mineralization, high rate of immobilization and nitrification. The higher concentration of TN in both NIT and ECO than in CON at 0-10 cm and 10-20 cm soil layers might be due to high leaching, run-off and mineralization in CON. The higher TN concentrations in the topsoil under NIT might be due to the minimum soil disturbance [32]. Likewise, the accumulation of the cover crops on the top surface of the soil could be another reason for high TN in top soil. Additionally, the trend of increase in SOM, N-NO_3 and TN reveals the contribution and interaction of the SOM with both available and total nitrogen. For instance the higher the SOM the higher the available N-NO_3 and TN. The findings of this study are consistent with a study conducted by [32] on the effects of tillage systems on soil organic carbon and total nitrogen rice-wheat cropping system in China. The study also revealed high concentrations of SOC and total N in the topsoil under no-tillage due to minimum soil disturbance and the mulches of residues of rice.

Results of pH-H_2O were not in agreement with the first hypothesis among the tillage systems at each soil layer 0-10 cm, 10-20 cm and 20-30 cm soil depths. The pH-H_2O was not affected by both reduced and conventional tillage systems.

These results were in agreement with the outcomes of other studies reported on effects of tillage systems on pH [28]. However, the results for pH-$CaCl_2$ were partly in agreement to the first hypothesis for all tillage systems at 0-10 cm soil layer. These results of pH-$CaCl_2$ were contrary to with the results of pH-H_2O and most studies on soil pH [28]. Unique increase in pH-$CaCl_2$ was observed in CON at 20-30 cm soil layer. The higher pH in CON at 20-30 cm soil layer might be due to the acidifying effect of nitrification and mineralization [29].

4.2 Crop Performance Parameters

Values of LAI, total plant DM, ear DM, ear/m^2, plant height and chlorophyll content were similar in both ECO and CON in comparison to NIT. Dry matter and nitrogen accumulation of winter triticale has been reported to vary according to differences in weather conditions, field location, planting date and type of cultivar [33]. However, in the present study the crop was grown in the same conditions mentioned above. This evidently shows that the lower dry matter and perhaps lower nitrogen capture of winter triticale in NIT than in ECO and CON might be due to other factors such as weed pressure caused by differences in tillage systems. Plant height as one of the parameters for interpreting the crop growth vigour and completion was lower in NIT than in ECO and CON. Probably, this is indicating a lower growth vigour and higher weed pressure in NIT compared to ECO and CON. Chlorophyll content or greenness of the leaves is associated to photosynthesis process, nitrogen status, stress or senescence caused by both abiotic and abiotic factors [22]. Furthermore, SPAD meter readings have been reported in cereals as the best predictor of nitrogen status, crop yield and grain quality especially for newly fully expanded leaves [34]. The lower chlorophyll content in NIT indicates a lower nitrogen content and susceptibility to weeds, therefore leading to a poor crop performance in comparison to both ECO and CON. The higher values of all crop performance parameters described above showed perfect crop growth and development in both ECO and CON than in NIT during ear emergence crop growth stage. These results are in agreement with the growth performance of spring wheat cultivated in the same field in the year 2014 [22].

4.3 Correlations

The negative correlation between SOM and crop performance parameters indicates that SOM mostly influences SOC sequestration and greenhouse gases mitigation than crop production [29,35]. This is positively supported by low and high crop performance in NIT and CON respectively. The possible reason for low crop performance in NIT may be caused by much weed pressure and slow mineralization of the organic residues. Therefore, the best tillage that mitigates greenhouse gases and at the same time improves crop performance is ECO which further lead to sustainability and climate resilience.

5. CONCLUSION

NIT and ECO improves soil through high SOM hence greenhouse gases mitigation. In terms of crop performance ECO and CON did better than NIT. Therefore, ECO having intermediate potentials in soil properties and crop performance could be the right tillage system for organic crop production compared to NIT and CON. Moreover, ECO will improve soil fertility, increase crop productivity and at the same time mitigates greenhouse gases. Future research for economics of the three tillage systems under organic farming is very important to confirm their economic suitability based on sustainability and climate resilience.

ACKNOWLEDGEMENTS

The authors honestly acknowledge Hennie Halm, Andries Siepel, Dine Volker, Frans Bakker, Pleun van Velde, Wim van der Slikke, Herman Meurs and Rianne Prinsen for their sincere assistance in this study. The corresponding author gratefully appreciates the funding from Netherlands Fellowship Program (NFP) in the context of the MSc programme 'Plant Sciences' for the academic year 2014 – 2016.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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