Effects of organically managed tillage systems on soil quality, weed competitiveness, and winter triticale performance

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Preface

This research was conducted as part of my MSc Plant Science in Natural Resource Management at Wageningen University and Research Centre (WUR) in The Netherlands. Field work took place at Droevendaal Farm an Organic research facility, samples preparation at UNIFARM and soil analysis in Farming Systems Ecology (FSE) laboratory; all are premises of WUR. The objective of this study was to assess the effects of three organically managed tillage systems (non-inversion, eco-plough and conventional) on soil quality indicators, weed competitiveness and winter triticale performance. Since organic crop production does not entertain the use of inorganic herbicides for weed control. There is a global requirement of a tillage system that reduces weed pressure and at the same time improves soil quality. Therefore, the great concern of this research was to investigate the most appropriate tillage method in organic crop production in a temperate climate.

Honestly, I highly value and appreciate this opportunity I was given by my supervisor Egbert Lantinga of FSE group to conduct my research in WUR. It enabled me to implement scientific research using most current and easily accessible research facilities. Besides, I gained great knowledge, skills and experience on soil sampling, field and laboratory measurement techniques, statistical data analysis and report writing. Moreover, the chance to work on a research topic that may bring remedy to the global threat in organic crop production (fewer weeds and good soil quality) is very important to my future research career.

I would like to express my heartfelt thanks and appreciation to my supervisor Egbert Lantinga for organising and supervising this thesis project. I would like to thank Hennie Halm for his assistance in soil analysis. Special thanks to Andries Siepel, Dine Volker, Frans Bakker and Pleun van Velde for their inputs on soil sampling protocol and experimental design formulation. I would like to thank other people from Unifarm especially Wim van der Slikke and Herman Meurs for their assistance and making available all facilities required for samples processing. I also thank my fellow MSc student Rianne Prinsen who was very courageous enough when we were collecting soil samples during cold and rain. Furthermore, I thank all students who assisted me in one way or the other. Similarly, I thank my mother Dorsila Amara, my wife Joyce Ryoba, my daughters (Alicia and Rozalia), relatives and friends for their prayers, encouragement, and patience.

Abstract

This study was carried out in autumn, winter and spring (2015-2016) during the growth development of organic winter triticale. The research was conducted at Droevendaal Farm, the organic experimental facility of Wageningen University and Research Centre, The Netherlands. The study assessed the effects of three organically managed tillage systems namely non-inversion (NIT), eco-plough (ECO) and conventional (CON) on soil quality indicators, weed suppression potential and winter triticale performance. A field that has been treated with three different tillage systems and crop rotation for six consecutive years was used in this study. The field was divided into different parts separating each tillage systems and parts that were left bare (pre-bare) and where potatoes (pre-potato) were grown during previous season. The tillage systems included two reduced tillage methods; NIT at 10 cm and ECO up to 20 cm deep and one intensive tillage method; CON at a depth of 30 cm. Soil samples for determination of soil organic matter (SOM), mineral nitrogen (N_{min}), total nitrogen (TN) and soil pH were collected during autumn in 2015 while bulk density and penetration resistance were measured during late winter and spring, respectively. Likewise, the measurements of early weed population density were conducted in late autumn, late weed population density and dry matter and crop performance parameters during late spring. The crop performance measured parameters were leaf area index (LAI), plant dry matter, ear number per area, plant height and chlorophyll content (SPAD). Late weed population density and weed dry matter together with all crop growth parameters were measured when the crops were in ear formation stage. Results of SOM indicated that there was no gradient between east and west pre-bare subplots. Besides, no difference in amount of SOM was observed between pre-bare and pre-potato subplots. The use of ECO tillage system favoured the reduction of weed pressure and at the same time had higher crop performance than NIT. On the other hand, use of NIT gave higher SOM and N-NO_3, higher soil compaction, higher weed occurrence and least crop performance. ECO had the intermediate effects on soil qualities, weed competitiveness and crop performance between NIT and CON. For the purpose of better chemical and physical soil qualities, less weed abundance and better crop growth and development in organic crop production, ECO could be the best choice. Moreover, for a higher SOM the best option would be NIT while for better weed suppression and crop performance ECO would fit most. This is for the comparison between two reduced tillage systems (NIT and ECO). However, integration of other principles of conservation tillage such as crop rotation and catch crops remains most vital for sustainable organic crop production.

Keywords: Tillage systems, winter triticale, weed competitiveness, soil quality, and organic production

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1 Introduction

1.1 Tillage

Tillage is a major component of farm management practices, which evolved after early men have shifted from hunting and gathering to farming. Then later in the nineteenth century after initiation of the industrial revolution, tillage practises advanced through the use of mechanical power and a traction engine. The main objectives of tillage in agricultural production are seedbed preparation, weed control, and incorporation and mixing of crop residues, fertilizers or other amendments. Likewise, tillage speeds up decomposition and mineralization of crop residues (Paustian *et al.,* 2000). However, intensive tillage has been reported to cause a gradual loss of stable soil aggregates leading to soil erosion and compaction in the long term. Soil compaction increases soil strength and decreases soil fertility by reducing storage and supply of water and nutrients. As a result, this leads to additional fertilizer requirement and increasing production costs (Hamza and Anderson, 2005).

There are two types of tillage namely inversion and non-inversion tillage (Morris *et al.,* 2010). The former 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. Thus, it leaves the soil surface with little plant residues by turning the soil upside down (inversion). Moreover, CON overturns soil during primary tillage operations to control weeds, incorporate organic material, and loose topsoil (Fasinmirin and Reichert, 2011). Primary tillage is applied to improve soil workability and tends to produce a rough surface finish. While secondary tillage has a tendency to produce a smoother surface to make a good seedbed for weed removal and enhance seed germination and seedling development. Harrowing and rototilling often combine primary and secondary tillage into one operation (Cannell, 1985). Non-inversion tillage is a type of conservation tillage that does not turn the soil and has different forms varying in tillage depths. Conservation tillage is among the principles of conservation agriculture together with crop rotation and soil cover (Stagnari, 2009). For instance, in this study, there were two types of conservation tillage; 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. These two forms of conservation tillage are referred to reduced or minimum tillage in this report (Table 5 in the appendix; Morris *et al.,* 2010). 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 (Kouwenhoven *et al.,* 2002).

Other forms of conservation tillage that are not included in the current study are strip tillage and no-tillage or direct drilling (Morris *et al.,* 2010). No-tillage is a tillage system with no pre-plant tillage process that causes soil disturbance other than planting operation (Buhler, 1995). It also modifies the profile of soil nutrient distribution (Six *et al.,* 1999) and induces organic carbon stratification (West and Post, 2002). In addition, Conservation Technology Information Centre (CTIC) of USA also defines no tillage as one of the types of conservation tillage practices that cover about 30% or more of the soil surface with crop residues after planting. No-tillage results in decreased fuel, labour, and equipment costs, conservation of soil and water by improving soil moisture retention and reducing surface runoff and erosion (Hendrix *et al.,* 1986). There has been reluctance in adopting no-tillage in organic crop production due to weed pressure because the latter does not use any chemical herbicides for weed control. Therefore, non-inversion tillage with different tillage depths has been adopted. However, it is still not known which form of reduced tillage could perform better in organic crop production in terms of fewer weeds and better soil quality.

Few studies have compared reduced tillage with conventional tillage mostly in terms of soil quality and crop yields in organic crop production (Maeder and Berner, 2012). A meta-analysis conducted by Cooper *et al.* (2016) reported about 7.6 % yield reduction in organic reduced tillage method compared to a yield loss of 2.8 % in conventional tillage system (Cooper *et al.,* 2016). The main cause of the difference in yield between organic reduced tillage and conventional reduced tillage could be due to higher weed abundance in organic reduced tillage. However, the effects induced by weeds in crop performance have been left behind in reduced organic crop production. Together with the use of crop rotations and catch crops in organic crop production (Watson *et al.,* 2002; Balasubramanian *et al.,* 2004), still the use of mechanical weed control is inevitable (Melander *et al.,* 2013). This is because reduced tillage leaves weed seeds in upper soil layers thereby leading to easy weed germination, emergence and hence greater weed abundance (Legere et al., 2011).

Little is known about the effect of reduced tillage on soil quality and crop performance for organic farming systems considering different crop species under varying climatic conditions (Peigné *et al.,* 2007; Vakali *et al.,* 2011). In 2007, the organic farming area in Europe accounted for 4.1% of the total agricultural area following a steady increase in importance across Europe during the last decades (Eurostat, 2010). Besides, in temperate regions reduced tillage is not mostly recognized in organic farming though the guidelines recommend reduction of tillage intensity (Vakali *et al.,* 2015). Furthermore, high soil nutrient contents under conventional tillage can lead to nitrate leaching thereby affecting surface and groundwater bodies (Vakali *et al.,* 2015). Thorough systematic soil sampling and analysis has never been done in three different types of tillage managements (NIT, ECO, and CON) in The Netherlands.

The current study was carried out in the organic field that has been adapted to three different tillage practices for six years. The field has been divided into three equal parts cultivated with different tillage systems. The first part with non-inversion tillage (NIT), the second was cultivated by ECO shallow mouldboard-plough (ECO) and third cultivated by deep mouldboard–plough (CON). The NIT is a reduced tillage treatment which levels 10 cm upper layer of the soil by rototilling. The ECO is also a reduced tillage with shallow mouldboard plough with a depth of 15-20 cm and width of 210 cm. This ECO was designed by Rumptstad Industries for conservation tillage purposes in Europe while CON is a conventional tillage at a depth ≥30 cm. Moreover, the field has been rotated with five different crops since the year 2010 and the crop for 2015-2016 was winter triticale. Besides, for all six years the field has been treated with various mixtures of catch crops when the main crops are not in the field to avoid extended bare soil. Furthermore, solid cattle manure (SCM) and cattle slurry were applied in the field (Table 2).

1.2 Chemical and physical soil quality

Soil quality is normally assessed by physical, chemical and biological factors (Karlen *et al.,* 1997). Subsequently, it is defined as "the capacity of a soil to function within ecosystem and land-use boundaries, to sustain biological productivity, maintain environmental quality and promote plant and animal health'' (Doran and Parkin, 1994). Tillage is the best-known method to modify the soil structure and soil aggregation (Davidson and Janssens, 2006). No-tillage and reduced tillage practices can increase the organic matter content and aggregate stability of the topsoil (Cannell and Hawes, 1994). However, bulk density and penetration resistance are also increased, especially with no tillage

(Lampurlanés and Cantero-Martinez, 2003). 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 (Reeves, 1997). Furthermore, non-inversion tillage favours soil organic carbon (SOC) accumulation (Lal, 2004), soil porosity (Peigné *et al.,* 2007), and reduces soil disturbance (Morris *et al.,* 2010).

Reduced tillage can increase the soil nitrogen (N) retention and thereby reducing off-site effects of nutrient losses and hence increase plant N availability (Beare *et al.,* 1997; Spargo *et al.,* 2008), gross N mineralization, nitrification and mobilization (Muruganandam *et al.,* 2010). Moreover, a study conducted near Wageningen in the Netherlands in the year 2004 showed that the nitrate-N concentration (50 mg/l) in leachate at 80 cm depth in an arable crop rotation on sandy soil exceeded the European Union (EU) standards for drinking water. However, systematic cultivation of catch crops helps to decrease this concentration to values near or below that of EU standards (Vos and Van Der Putten, 2004). Furthermore, a study conducted in the Netherlands for four years by Crittenden *et al.* (2015) showed higher aggregate stability and penetration resistance in NIT than mouldboard ploughing in both organic and conventional farming. In addition, this four years study showed improvement of soil water retention and carbon stocks by NIT in both organic and conventional farming. Besides, they reported a higher crop yield in NIT than with the mouldboard plough in the organic wheat/faba bean mixture (Crittenden *et al.,* 2015b). Hence, there was a need to set up a study that combined organic amendments, crop rotation, and different tillage systems for more than four years. Summarizing, only a few studies on organically managed tillage systems with the combination of crop rotation and catch crops for winter triticale growth performance have been done. Moreover, systematic soil sampling has not been used in many studies of tillage systems and soil quality.

1.3 Weed competitiveness

Changes in tillage systems may affect weed population dynamics, including weed seed distribution and abundance in the soil seed-bank (Buhler and Mester 1991; Chauhan *et al.* 2006a; 2006b; Blaise *et al.,* 2015). Weed response to tillage involves a complex interaction between other factors for example; weather, duration of the experiment, and long-term field history (Mohler, 1993; Nichols *et al.,* 2015). Furthermore, mechanical cultivation is a common method of managing weeds in organically managed farms (Bond and Grundy, 2001; Bajgai *et al.,* 2013). However, need to reduce the environmental impact of agriculture and to improve soil quality has increased the necessity of reduced tillage. Several studies have stated that reduced tillage decreases CO_2 release from the soil into the atmosphere (Chen and Huang 2009; Gronle *et al.,* 2015). Moreover, reduced-tillage systems allow more efficient use of fossil fuel, greater conservation of soil moisture and less risk of soil erosion (Coolman and Hoyt, 1993; Bond and Grundy, 2001). On the other hand, many studies have shown that reduced tillage increases the annual and perennial weed infestation (Gruber and Claupein, 2009; Brandsæter *et al.,* 2011; Gronle *et al.,* 2015).

Weeds are one of the most yield-limiting factors (Blaise *et al.,* 2015) and about 50% of the total expenditure on crop production goes to weed control (Sidhu *et al.,* 2004). Weed management is ranked as the number one constraint to organic production and research on weed management is a top priority for UK farmers (Turner *et al.,* 2007; Bajgai *et al.,* 2013). A study conducted in Netherlands by Kruidhof *et al.* (2008) also indicated that weed control in organic farming systems is the foremost production related problem (Kloen and Daniels, 2000; Kruidhof *et al.,* 2007). Several weed management strategies in organic farming have been studied including agronomic practices such as crop rotation, intercropping, use of cover crops and cultural practices like use of hand hoes and weeding tractors. For efficient weed management, the method and timing of soil cultivations and the choice of the crop are essential factors to consider (Bond and Grundy, 2001).

Numerous studies have compared weed competitiveness by assessing population density and above ground biomass in various circumstances. For instance; comparing cover crops suppressive potential to weeds in organic and conventional no-tillage (Pollnac *et al.,* 2008; Baumgartner *et al.,* 2008; Yagioka *et al.,* 2015) and soil properties and crop yields (Bajgai *et al.,* 2013; Welch *et al.,* 2016). No study has quantified the weed responses in NIT, ECO, and CON for organic winter triticale production. Therefore, the current study investigated the effect of tillage systems on the status of weeds density and dry matter in the organically managed field after six years in relation to crop performance.

1.4 Winter triticale

Cereals are most important agricultural crops in the temperate climate of Central Europe in terms of the total area cultivated and their use in crop rotation (Zajak *et al.,* 2014). 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 (Tams *et al.,* 2004), higher amounts of the above-ground yields (Giunta and Motzo, 2004; Glab *et al.,* 2013) and ability to resist some unfavourable biotic and abiotic environmental factors (Tams *et al.,* 2004; Glab *et al.,* 2013). 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 (Schwarte *et al.,* 2005). Crop diversification and rotation have been reported by many studies, to improve soil quality, reduce weeds, to increase crop yield and growth performance. Winter triticale is mostly mixed and rotated with various crops and catch crops (Askegaard *et al.,* 2011). 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 (Nance *et al.,* 2007) and prevent soil erosion during high rainfall (Schwarte *et al.,* 2005). 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. Furthermore, ample studies have focused on triticale forage dry matter (DM), yield and quality (Royo *et al.,* 1994; Delogu *et al.,* 2002; Toliver *et al.,* 2005), sowing rate and cultivars effects on total biomass and grain yield (Giunta and Motzo, 2004) and effects of weather and soil conditions on yield (Erekul, 2006) and planting date effects on DM and N accumulation (Aaron *et al.,* 2005). No study has compared organically managed tillage systems on soil quality, weed responses, and performance of winter triticale. Consequently, it was important to investigate whether growth performance of winter triticale was affected by different tillage systems or not in terms of weed abundance and soil quality. Therefore, the current study compared the rate of growth of organically managed winter triticale in three tillage systems (NIT, ECO, and CON) for the sixth year.

1.5 Purpose of the study

1.5.1 Problem statement

Successive use of deep mouldboard plough has been reported to have negative environmental impacts, as it may cause soil degradation, soil erosion, and water and air pollution (Triplett and Dick, 2008; Drakopoulos *et al.,* 2015). No-tillage and reduced tillage have been minimally adopted in Europe compared to America, and Australia (Chatskikh and Olesen, 2007). Moreover, no-tillage and reduced tillage are characterized by increased use of more herbicide applications due to an increased weed appearance (Deike *et al.,* 2008). The inclusive meta-analysis of 5463 paired yield observations from 610 studies suggests that no-till in itself results in a yield penalty of around 10% overall (Giller *et al.,* 2015; Pittelkow *et al.,* 2015). Most of these studies were conducted in conventional farming systems (Singh and Malhi, 2006; Vakali *et al.,* 2011).

1.5.2 Aim of the study

The main aim of this research was to assess the effects of three organically managed tillage systems (non-inversion, eco-plough and conventional) on soil quality indicators, weed competitiveness or suppression potential and winter triticale performance. Specifically, the study was carried out to quantify the effects of three tillage systems (NIT, ECO, and CON) and three soil depths (0-10 cm, 10-20 cm and 20-30 cm) on both chemical and physical soil qualities. Furthermore, this study identified the most efficient tillage system for better weed pressure reduction and better above-ground crop performance. Finally, the study compared and identified the tillage system that improves the soil and at the same time increases the ability of crops to suppress weeds in organic crop production. The outcome of this research is meant to contribute a lot in fulfilling the principles of conservation tillage and reduction of the weed problem in organically managed reduced tillage.

1.5.3 Research questions

a) Which type of organically managed tillage system improves soil quality, controls weeds, and gives better plant growth performance after six years of application?

b) Is there a difference in weed response and crop performance for six years among each tillage systems?

1.5.4 Hypotheses

1. The upper soil layer of 0-10 cm for NIT and two first layers of 0-20 cm for ECO would have a higher amount of SOM, N_{min}, TN and pH in comparison to all layers of CON due to the accumulation and incorporation of soil residues deep in the soil by CON.
2. There would be both higher bulk density and penetration resistance in the layers 10-30 cm and 20-30 cm for NIT and ECO, respectively. At the 0-10 cm layer of all three tillage systems, there would be the same bulk density and penetration resistance.
3. There would be higher weed density in NIT and ECO than in CON during early plant growth stage and fewer weeds and same late density and dry matter in all three tillage systems during plant late growth stage. Because CON enables incorporation of weed seedlings and organic residues while nutrients from organic residues would enable the crops to resist weeds in NIT and ECO.
4. There would be the same crop performance in all tillage systems during the crop late growth stage crop because the lowest weed pressure in CON would be compensated by better chemical and physical soil qualities in NIT and ECO.

2 Materials and methods

2.1 Experimental setup

This research was conducted during autumn, winter and spring (November 2015 to May 2016) at Droevendaal Farm (51°59'33.68"N, 5°39'34.59"E), which is the organic experimental farm. The farm has total of 50 hectares and is a certified organic research facility of Wageningen University in Wageningen, the Netherlands. 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 (USDA, 1987)

For the purpose of this study, the field was divided into main plots, subplots, and blocks using orange sticks and there were three main plots representing three tillage systems (NIT, ECO, and CON). Each main plot was divided into three sub-plots in which in the middle subplot potatoes were grown in the previous season (pre-potato) and the remaining two subplots were left bare (pre-bare) (Fig. 16 in the appendix). When taking the measurements, buffer zones of 1 m width and 30 m length for each strip of three parts of the field with different tillage systems were excluded. The experimental unit was therefore 240 m^2 (30 m by 8 m) with 18, 12 and 6 replicates for chemical soil quality and bulk density, penetration resistance, height, and SPAD, and other crop performance measurements, respectively (Fig. 1). There were two factors, tillage systems and soil layers, each with three levels of NIT, ECO and CON, and 0-10 cm, 10-20 cm and 20-30 cm, respectively for chemical and physical soil qualities (Table 1). A systematic sampling method was used to collect soil samples in all blocks and sub-plots. Figure 15 in the Appendix shows a systematic sampling layout for each sampling block, the intervals from one sampling point to another and the number of subsamples. Many replicates were used purposely to evaluate if there is a gradient between east and west pre-bare subplots per each tillage system plots. Besides, the gradient between east and west pre-bare plots was assessed because the replicates used were not true replicates.

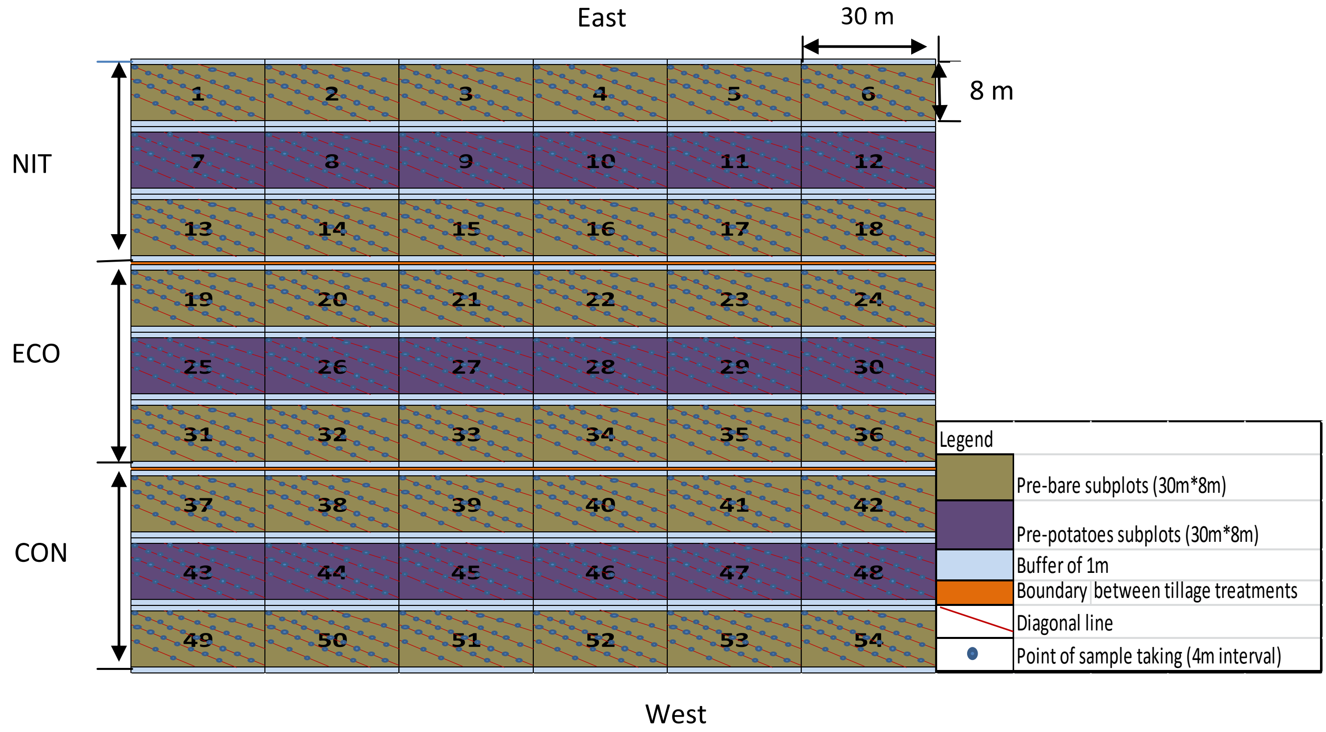


Figure 1 Experimental layout for field measurements

Factors	Levels
Tillage systems	**3 levels:** Deep mouldboard plough(CON) Shallow mouldboard plough (ECO) Non-inversion tillage (NIT)
Layers	**3 levels:** 0 – 10 cm 10 – 20 cm 20 – 30 cm

2.2 Cultural practices and weather conditions

Winter triticale (*X. Triticosecale* Wittm., cv. Tulus) was planted on 12th October 2015 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 (Table 1). Before the crop winter triticale was grown, the field had a strip of potatoes at the centre in each part of the field (Fig. 16 in the Appendix). 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 Figure 2.

Table 2 Type of crops and catch crops rotated and the type of manure applied in the field no. 3 for six consecutive years

Year	Crop	Catch crops mix	Manure
2010	Maize	-	-
2011	Summer wheat	Mustard and rye (7/9)	SCM (10 kg/ha)
2012	Summer barley	Mustard and rye (10/9)	SCM (10 kg/ha)
2013	Summer barley	Radish, rye, and mustard	SCM (10 kg/ha)
2014	Summer wheat	Radish, rye, and mustard	Cattle slurry (15 m^3/ha)
2015	Potatoes	Rye and mustard	SCM (10 kg/ha)
2016	Winter triticale		Cattle slurry (20 m^3/ha)

Source: Farm manager of Droevendaal Farm, 2016 (SCM stands for Solid cattle manure)

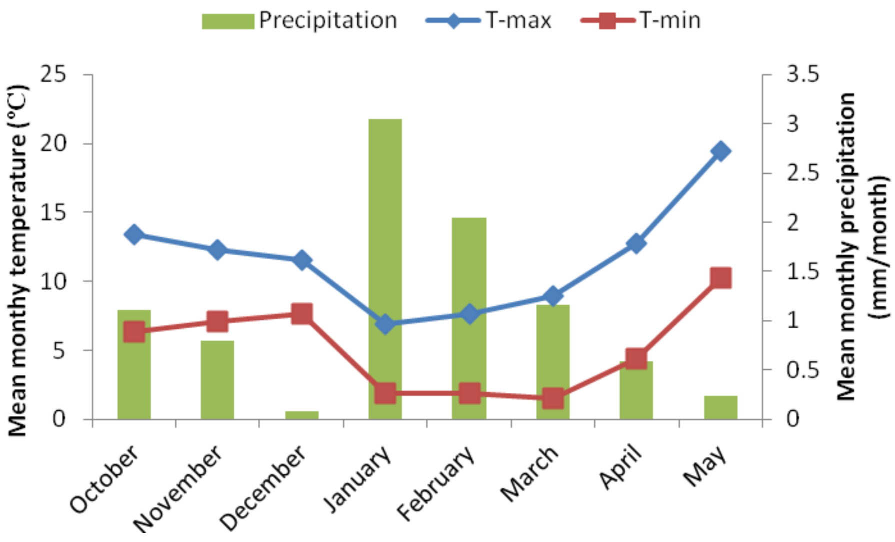


Figure 2 Monthly mean precipitation, maximum temperature, and minimum temperature

2.3 Field measurements and laboratory analyses

2.3.1 Soil chemical quality measurements

The soil chemical quality indicators measured included soil organic matter (SOM), soil mineral nitrogen contents (N_{min}), total nitrogen (TN) and soil pH. 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 treatment, per block and depth, (3 plots/systems x 3 layers/depths x 18 blocks/replicates). Total of 162 composite samples were collected but not all samples were 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 for about two weeks 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.

2.3.2 Soil chemical quality laboratory analysis

Soil Organic Matter (SOM)

The SOM was determined using loss-on-ignition (LOI) method as described by Hoogsteen *et al.* (2015). 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 (Hoogsteen *et al.,* 2015).

Soil available Nitrogen Minerals (Nmin)

Soil available N-NO_3 and N-NH_4 were determined using the methods described in Houba *et al.* (2000) and ICARDA (2013) 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).

Total Nitrogen (TN)

The same soil samples used for SOM determination were digested with a mixture of conc. H_2SO_4–Se and salicylic acid (Novozamski *et al.,* 1983). 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.

Soil pH

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.

2.3.3 Soil physical quality measurements

In this case, soil bulk density (SBD) and penetration resistance (PR) were measured at different times. SBD was measured in the three main plots, 18 sub-plots and 54 blocks. 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 (Avnimelech *et al.,* 2001).

Soil penetration resistance was measured using the methods described by Kouwenhoven *et al.* (2002) whereby a digital Eijkelkamp penetrologger (Agrisearch Equipment, the Netherlands) was used. Total of 36 subplots were sampled with total of 360 penetration points and three plots of different tillage systems (NIT, ECO and CON) were divided into two parts each. The first part was the one used to grow potatoes (pre-potatoes) while the second was left bare (pre-bare) during the previous season. Each part was further sub-divided into six replicates (subplots). Ten penetrations were made per each subplot using cones of 1.0 cm^2 60^0 at a speed of 2 cm/s and at a depth of 60 cm. 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 measurements of soil bulk density and penetration resistance were conducted far apart due unavailability of digital penetrologger in time. Another reason was because of the necessity of measuring penetration resistance at field capacity thus a day after rainfall.

2.4 Weeds and Crop measurements

2.4.1 Weed population density and biomass

Assessment of weeds was conducted in two phases which were during early crop growth stage before first weeding and the second was during late crop growth stage before the last weeding. Both phases of weed assessments were conducted in six pre-bare sub-plots (30 m by 8 m) per each tillage method (Fig. 1). The first was through visual observation, counting of individual weeds within 40 cm x 40 cm quadrant for population density determination. The second phase of weed assessment involved visual observation, counting of individual weeds within 50 cm x 50 cm quadrant for weed population density and dry matter determination. All above-ground weeds within a 50 cm x 50 cm quadrant were collected and dried in the oven at 70 ^{0}C for 24 hours. The first phase of weed assessment was conducted in December 2015 one day before first weeding while the second was done in May 2016 one day before the last weeding.

2.4.2 Crop growth performance

All crop performance parameters were measured at ear formation stage when the plants were very succulent and with high nutritive value (Mickan, 2008). Above-ground plants were harvested only from pre-bare strips due to the interruption of the weed measurements by pressure of weeding time caused by weather variations. This was because of the aim of comparing the dry matter of both crops and weeds in the same quadrants before weeds were ridged. Besides, because there were no statistical differences in SOM content between pre-bare and pre-potato subplots, use of only pre-bare subplots was valid. Due to these reasons all weed and crop performance measurements were conducted in pre-bare subplots. Crops 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 pre-bare strips that were divided into six subplots (30 m x 8 m) per each tillage system (Fig. 1). At ear formation stage, all crops within a 50 cm x 50 cm quadrant were harvested and sorted separately into leaves, stems and ears. This was according to Santiveri *et al.* (2004), who reported that yield of winter triticale is perfectly predicted by dry matter during anthesis.

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 per cattle slurry treatment (large amount in tractor paths and small amount in non-paths). Four plants per subplot 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 subplot 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 22. The normality test was tested for all data before statistical analysis. All data were normally distributed with exception of N-NO_3 and N-NH_4 that were transformed using natural logarithm. However, even after transformation the data for N-NO_3 and N-NH_4 were still not normally distributed that lead to re-use of the original data. Independent Samples T-test was used to find out the differences between pre-bare subplots within each tillage system or treatment (NIT, ECO and CON). This was necessary to assess the gradient between east and west pre-bare subplots for each tillage systems. Likewise, the T-test was carried out to find the statistical differences between pre-bare and pre-potato subplots per each tillage system at each soil layer. This was because the replicates used were not true replicates. The T-tests analyses were conducted purposely to decide whether it is scientifically valid to carry out the measurements of other parameters in only bare subplot per each tillage treatment. Analysis of Variance (ANOVA) was conducted to test the effects of tillage systems on soil quality, weed competitiveness and crop growth performance. One way ANOVA was used for the analysis of SOM in pre-potato subplots per each tillage systems. Likewise, One way ANOVA was used to analyse chemical soil quality indicators (Nmin, TN and pH) and physical soil quality indicator (SBD), the independent variables tested were three tillage systems (NIT, ECO and CON) at three soil layers (0-10 cm, 10-20 cm and 20-30 cm). However, soil layers 5-10 cm, 15-20 cm and 25-30 cm were applied for SBD measurements. Besides, one way ANOVA was used also to analyse the effects of tillage systems on weed population density and weed dry matter, LAI, total plant dry matter, ear dry matter, ear/m^2, chlorophyll content and plant height. Differences among means were compared using Post Hoc Tests of Multiple Comparisons at 5% level of probability.

3 Results

3.1 Effects of tillage systems on chemical and physical soil quality

3.1.1 Soil Organic Matter (SOM)

The was no statistical differences (P >0.05) in amounts of SOM between east and west pre-bare subplots per each tillage treatments (NIT, ECO and CON) at soil layers 0-10 cm, 10-20 cm and 20-30 cm (Fig. 3). Likewise, there were no statistical differences (P >0.05) between pre-bare and pre-potato subplots for each tillage system and at each soil layer (Table 3). However, SOM content per each tillage treatment was statistically different (P =0.004) at 0-10 cm soil layer (Fig. 4). Moreover, the Post Hoc Tests results between each tillage systems showed significance difference (P =0.004) between NIT and CON (Fig. 4). Conversely, no significant difference was observed between ECO and CON (P=0.057) and between NIT and ECO (P =0.366) 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).

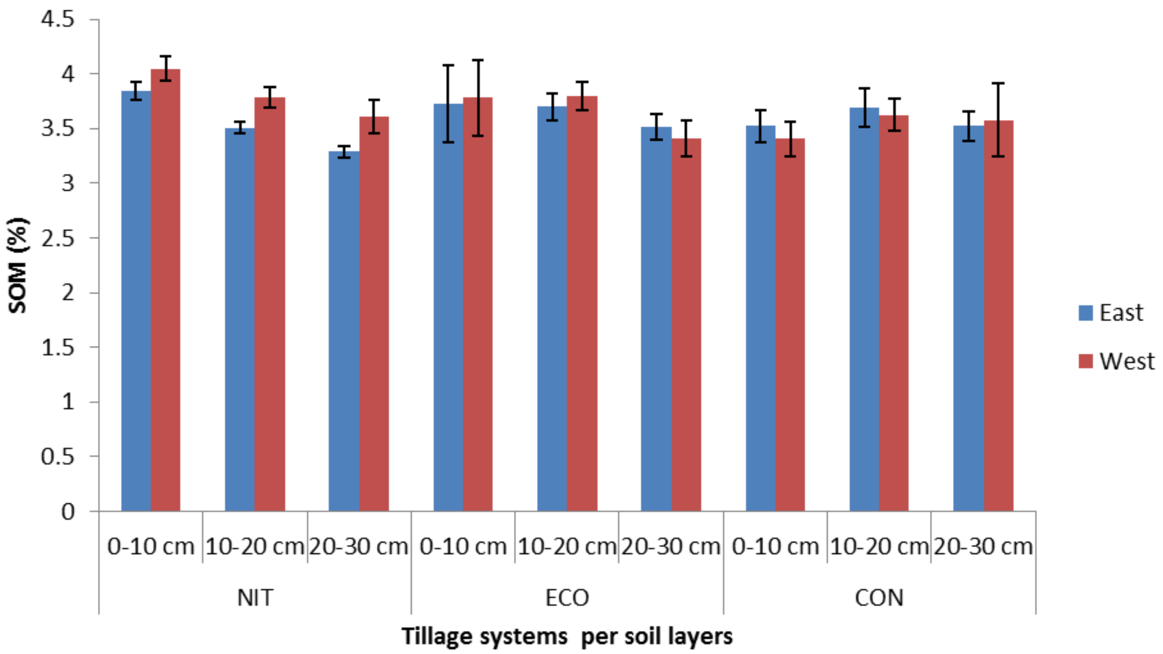


Figure 3 Differences in amount of soil organic matter (SOM) between east and west pre-bare subplots within each tillage systems (NIT, ECO and CON) at all three soil layers (0-10 cm, 10-20 cm and 20-30 cm).

Table 3 T-test comparison of SOM (%) between pre-bare and pre-potato subplots for each tillage systems at different soil layers

SOM (%)	Soil layers					
Plots and sub-plots	0-10 cm		10-20 cm		20-30 cm	
	P-value	Sig.	P-value	Sig.	P-value	Sig.
Pre-bare & Pre-potato in NIT	0.09	ns	0.77	ns	0.94	ns
Pre-bare & Pre-potato in ECO	0.44	ns	0.45	ns	0.61	ns
Pre-bare & Pre-potato in CON	0.68	ns	0.55	ns	0.74	ns

The abbreviation "ns" refer to not significant

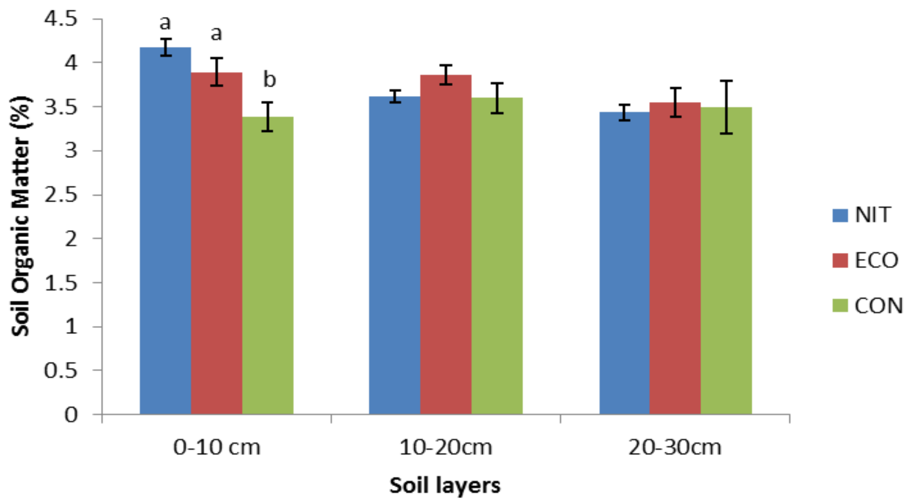


Figure 4 Differences in amount of soil organic matter (SOM) between pre-potato subplots per each tillage systems (NIT, ECO and CON) at each soil layers (0-10 cm, 10-20 cm and 20-30 cm). Error bars indicate standard error. Means followed by different letters differ significantly between each tillage systems at each soil layer.

3.1.2 Soil available Nitrogen Mineral (N_{min})

Nitrate-Nitrogen (N-NO_3)

There was a statistically significant difference in 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).

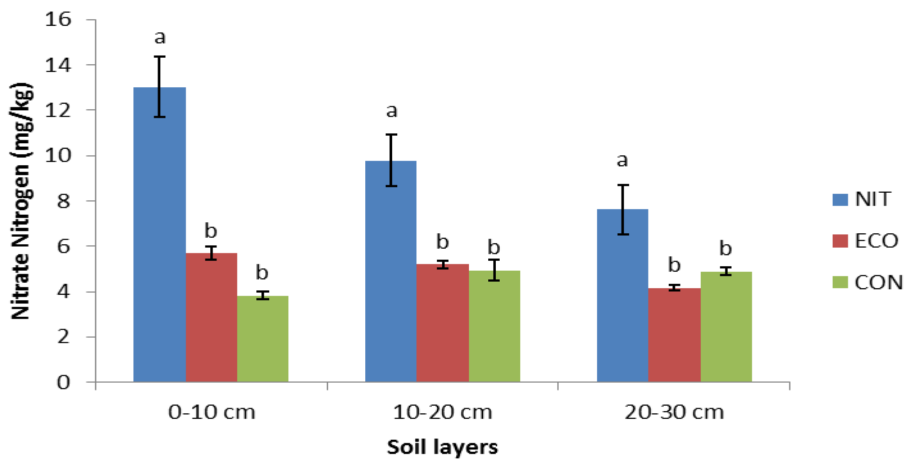


Figure 5 Effect of three tillage systems (Non-inversion tillage (NIT), Eco-shallow mouldboard plough (ECO) and Conventional tillage (CON) at each three soil layers (0-10 cm, 10-20 cm and 20-30 cm) on soil available nitrogen in mg/kg. Error bars indicate standard error. Means followed by different letters differ significantly between each tillage systems at each soil layer.

Ammonium-Nitrogen (N-NH_4) concentration

There were no significant differences between each tillage systems at all soil layers 0-10 cm (P =0.698), 10-20 cm (P =0.155) and 20-30 cm (P =0.132) (Fig. 19 in the appendix).

3.1.3 Total Nitrogen (TN)

There was statistical difference between each tillage systems at 0-10 cm soil layer (P <0.001). The highest and lowest concentrations of TN were observed in NIT and CON 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).

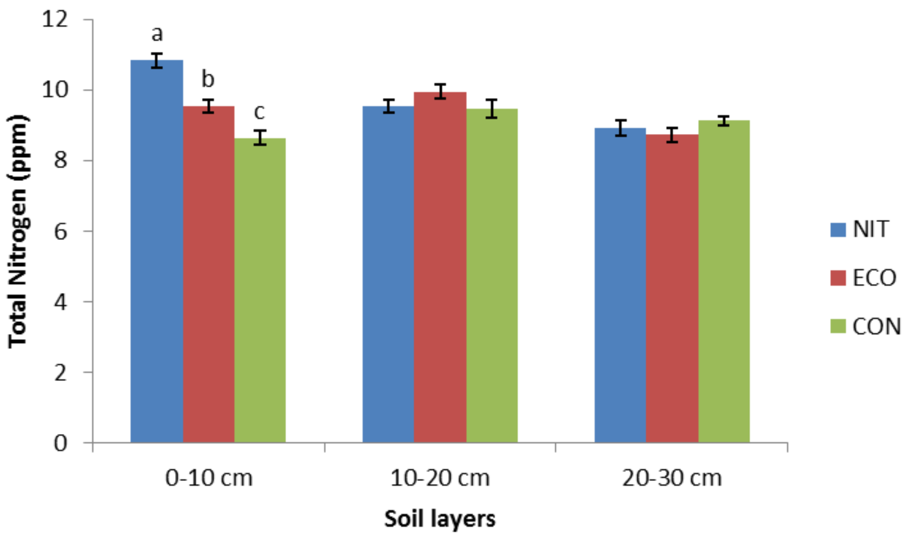


Figure 6 Effects of three tillage systems (Non-inversion tillage (NIT), Eco-shallow mouldboard plough (ECO) and Conventional tillage (CON) at each three soil layers (0-10 cm, 10-20 cm and 20-30 cm) on total nitrogen in mg/kg. Error bars indicate standard error. Means followed by different letters differ significantly between each tillage systems at each soil layer.

3.1.4 Soil pH

The pH-H_2O values between each tillage systems were not statistically different (P =0.733, 0.085 and 0.817) at each three soil layers (Fig. 7). 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. 8). The mean values of pH-$CaCl_2$ between each tillage systems at 10-20 cm soil layer were not significant (Fig. 8).

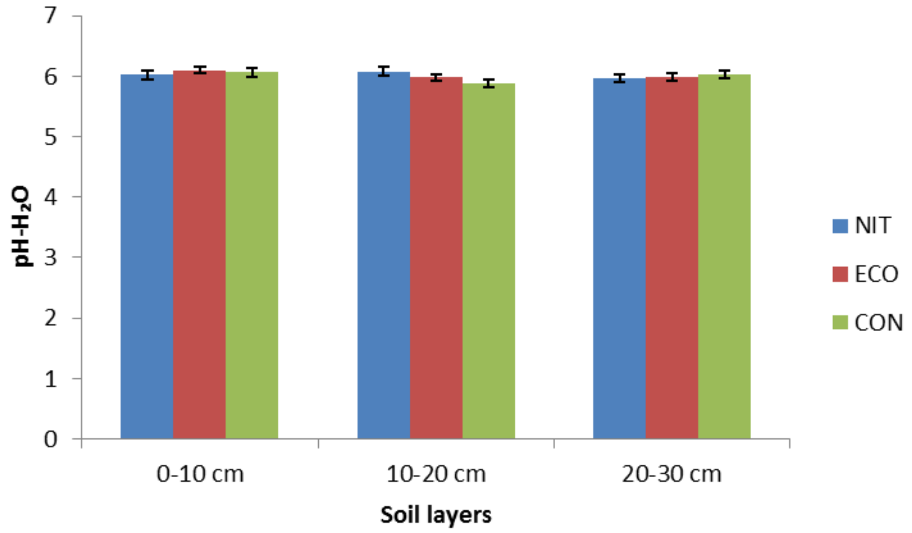


Figure 7 Effects of three tillage systems (Non-inversion tillage (NIT), Eco-shallow mouldboard plough (ECO) and Conventional tillage (CON) at each three soil layers (0-10 cm, 10-20 cm and 20-30 cm) on soil pH-H_2O. Error bars indicate standard error.

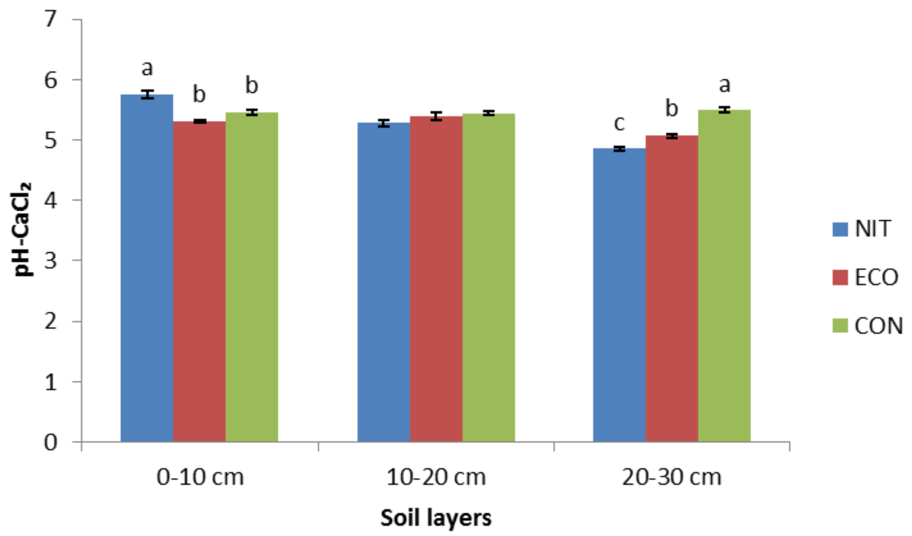


Figure 8 Effects of three tillage systems (Non-inversion tillage (NIT), Eco-shallow mouldboard plough (ECO) and Conventional tillage (CON) at each three soil layers (0-10 cm, 10-20 cm and 20-30 cm) on soil pH-$CaCl_2$. Error bars indicate standard error. Means followed by different letters differ significantly between each tillage systems at each soil layer.

3.1.5 Soil bulk density and Penetration resistance

Soil bulk density (SBD)

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. 9). Nevertheless, the differences between each tillage systems (NIT, ECO and CON) were not significant (P =0.218) at 25-30 soil depth (Fig. 9). The highest and lowest SBD were observed in ECO at 25-30 cm and CON at 5-10 cm soil depth.

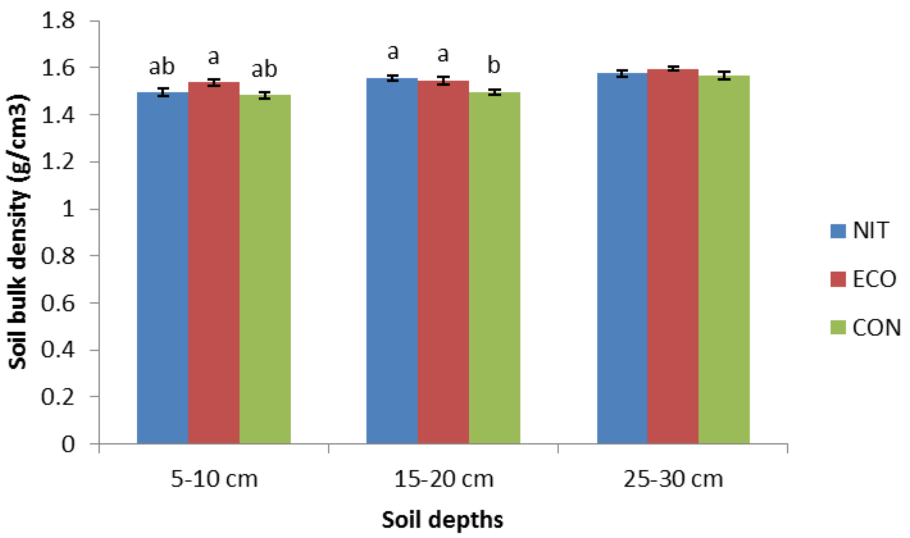


Figure 9 Effects of three tillage systems (Non-inversion tillage (NIT), Eco-shallow mouldboard plough (ECO) and Conventional tillage (CON) at three each soil layers (5-10 cm, 15-20 cm and 25-30 cm) on soil bulk density. Error bars indicate standard error. Error bars indicate standard error. Means followed by different letters differ significantly between each tillage systems at each soil layer.

Penetration resistance (PR)

In both pre-potato and pre-bare plots the strength of soil decreased after 40 cm up to 60 cm depth for all three tillage systems (Fig. 10 A and B). However, pre-bare plots had the highest penetration resistance in NIT under all soil depths from 0-60 cm in comparison to pre-potato plots (Fig. 10 A and B). Besides, higher penetration resistance was observed between 10-30 cm soil depths in pre-potato subplots (Fig. 10 B).

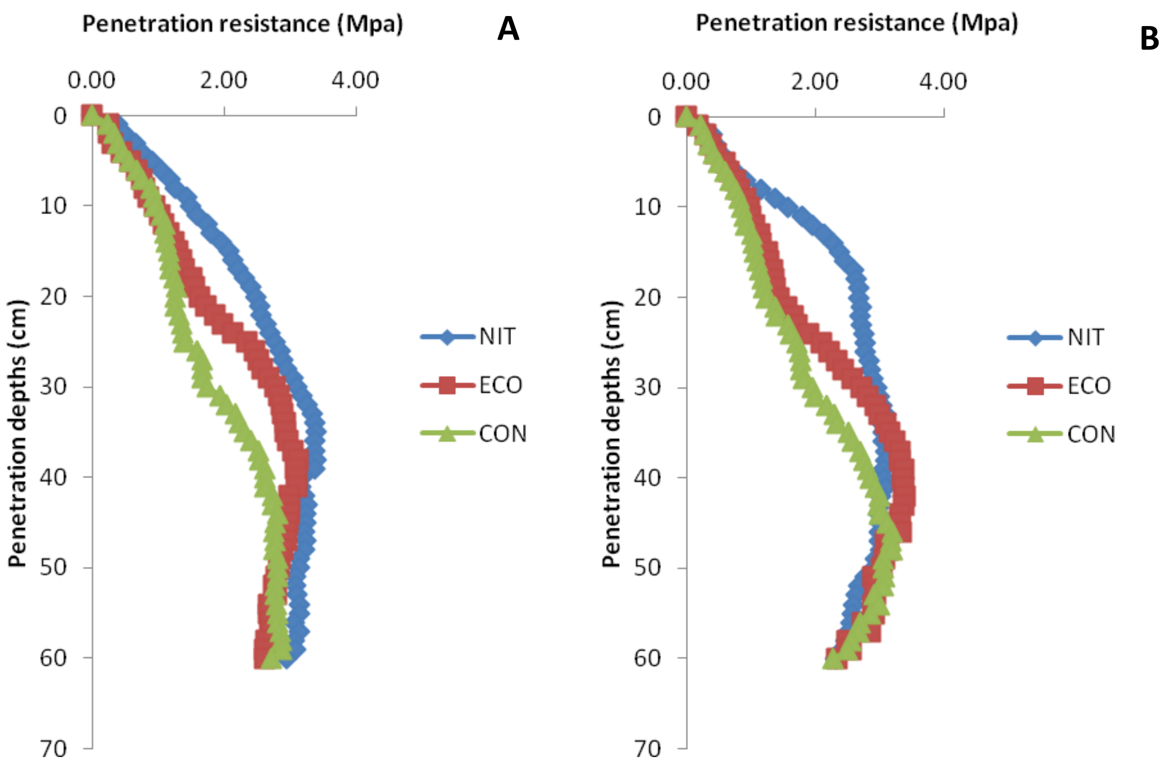


Figure 10 Effects of tillage systems on penetration resistance throughout the 0-60 cm soil profile in pre-bare (A) and -pre-potato subplots (B). Average values for 10 samplings per 6 replicates are presented.

3.2 Effects of tillage systems on weed population density and dry matter

Both visual assessment and physical counting of individual weeds per quadrat at an early and late crop growth stages showed a higher weed population in NIT. The results showed there were statistically significant effects among tillage systems on both weed population density and dry matter (Table 4). There were no significant difference between weed population density in ECO and CON during both early and late crop growth stages. The highest weed population density (191.67 weed m^{-2}) was in NIT which was almost double of the lowest weed population density (96.86 weed m^{-2}) in CON during early growth stage (Fig. 11 A). Likewise, the least weed population densities (121.33 and 115.33 weed m^{-2}) during late crop growth stage were observed in ECO and CON (Fig. 11 B). The dry matter of weeds measured when the crops were in ear formation stage showed higher DM in NIT (1112.67 kg ha^{-1}) greater than the sum (668 kg ha^{-1}) of ECO and CON (Fig. 12). There were no significant difference in DM between ECO and CON (Fig. 12).

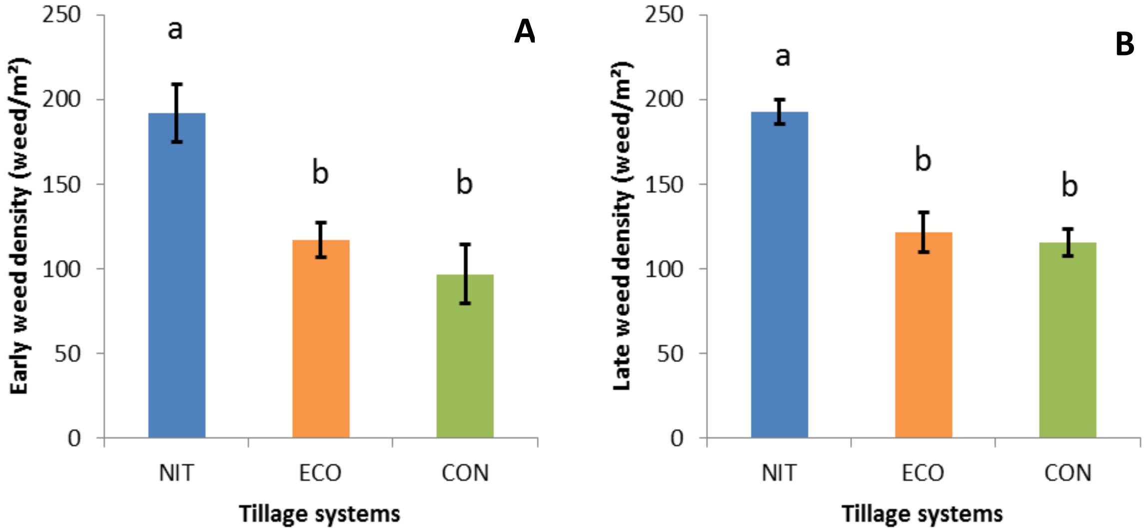


Figure 11 Early (A) and late (B) weed population density for three tillage systems. Error bars indicate standard error. Means followed by different letters differ significantly between each tillage systems.

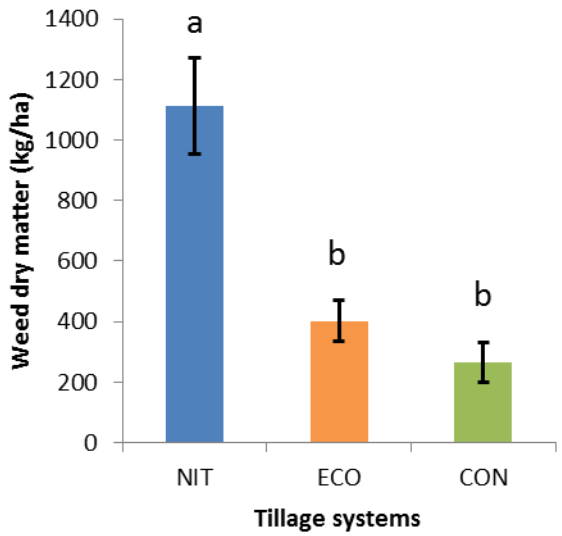
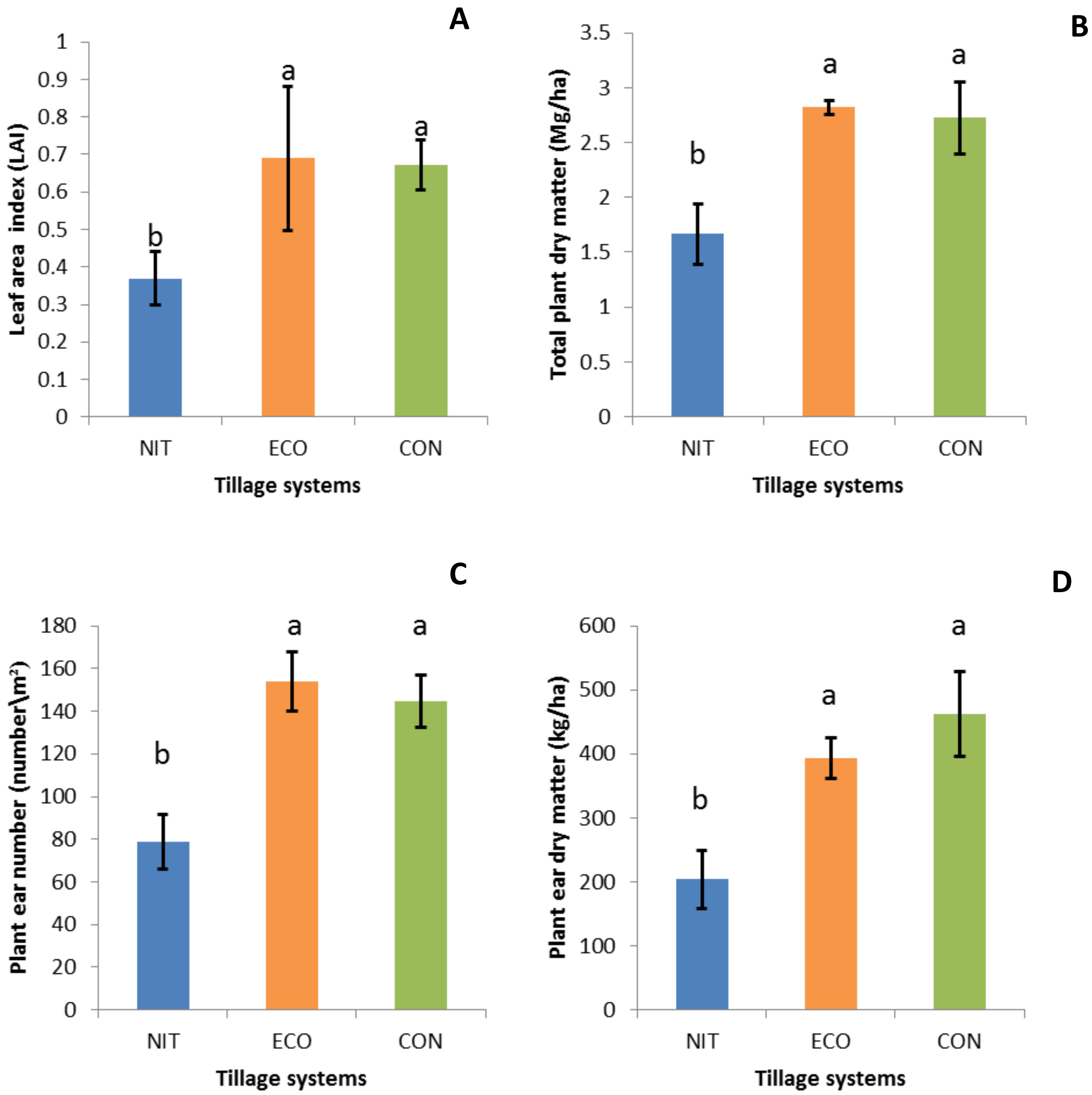
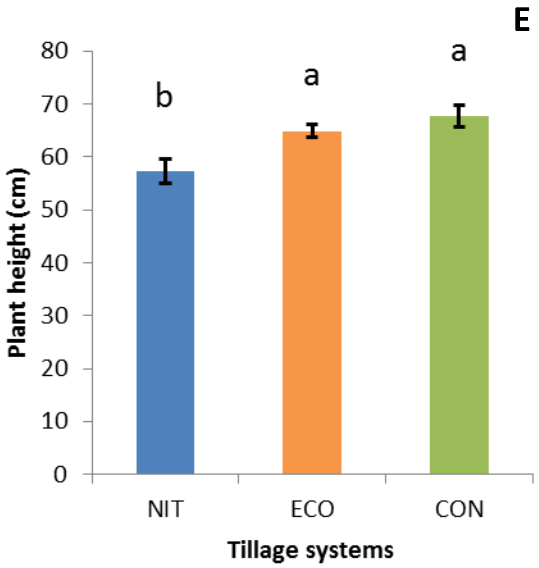


Figure 12 Effect of tillage systems on weed dry matter during late crop growth stage. Error bars indicate standard error. Means followed by different letters differ significantly between each tillage systems.

3.3 Effect of tillage systems on winter triticale performance

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 4). 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 (Fig. 13 A-F). The highest and lowest LAI values were observed in ECO (0.69) and CON (0.37) respectively (Fig. 13 A). The highest total plant dry matter was showed in ECO (2.82 Mg ha^{-1}), intermediate in CON (2.72 Mg ha^{-1}) and the lowest (1.67 Mg ha^{-1}) in NIT (Fig. 13 B). CON had higher EDM (462.73 kg ha^{-1}) than both ECO (393.4 kg ha^{-1}) and NIT (204 kg ha^{-1}) but there was no significance difference between ECO and CON (Fig. C). Larger numbers of ears were formed earlier in ECO (154 ear m^{-2}) and CON (144.67 ear m^{-2}) than in NIT (78.67 ear m^{-2}) (Fig. 13 D). The highest and lowest average plant heights (67.72 cm and 57.25 cm) were shown in CON and NIT, respectively (Fig. 13 E). The highest chlorophyll contents of the leaves were observed in both CON (41.63) and ECO (40.26) while the lowest (36.62) was in NIT (Fig. 13 F).





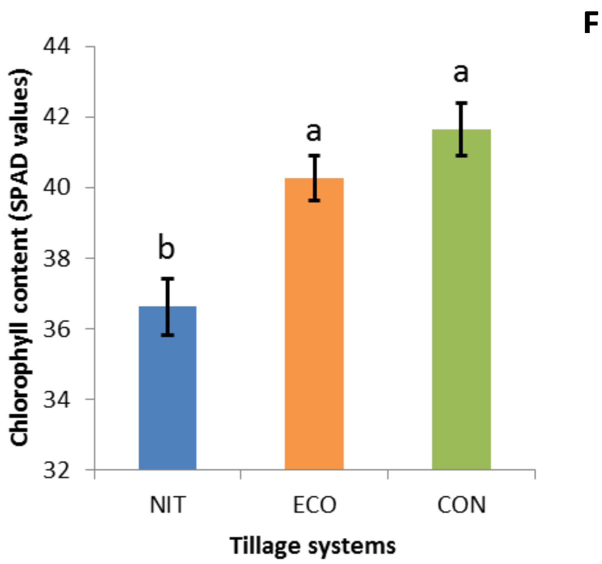


Figure 13 Effect of tillage systems on crop performance (A, B, C, D, E and F for LAI, Total DM, ear DM, Ear/m2, height and SPAD respectively). Error bars indicate standard error. Means followed by different letters differ significantly between each tillage systems.

Table 4 Effects of tillage on weed population density, DM and crop performance

Dependent variables	F-value	P-value
Early weed population density (weed/m^2)	10.825	0.001 **
Late weed population density (weed/m^2)	22.198	0.000033 **
Weed DM (kg/ha)	17.960	0.000104 **
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)	F-value	0.002 *
Chlorophyll content (SPAD values)	12.762	0.000078 **

*, and ** refer to P values ≤ 0.01 and ≤ 0.001, respectively. Degree of freedom (df) between groups was 2 and 15 within groups for all variables with exception of height and SPAD that had 2df between groups and 33df within groups.

3.4 General visual observations on the field at different stages

One month after crop sowing when soil sampling for chemical quality were conducted, there was no visible differences in growth of the crops between ECO and CON compared to NIT was observed. Crops were vigorously growing with visible weeds in NIT compared to ECO and CON (Fig. 14 A and B). Figure 14 C and D show the appearance of crops and weeds in NIT and ECO, respectively, at the late ear emergence two weeks after measurements on crop performance had been taken. There were no visible differences between weed abundance and crop growth vigour between ECO and CON during early and late growth stages. There were visible differences in slurry application within the tractor paths and outside as shown in Figures 17 and 18 in the Appendix. Furthermore, grass species of weeds were mostly observed in tractor paths with large quantity of slurry. In addition, broad leaved weeds were abundant in NIT compared to ECO and CON. The most dominant weed observed during early (autumn) and late (spring) crop growth stage was Chamomile or Mayweed (*Matricaria chamomila*). During autumn 2015 the most common weeds in the field were chickweed (*Stellaria media*), corn spurry (*Spergula arvensis*) and grass species. However, during spring 2016 the most dominant weeds were perennial sowthistle (*Sonchus arvensis* L.), red poppy (*Papaver rhoeas* L.), *Chinopodium spp* and grass species.

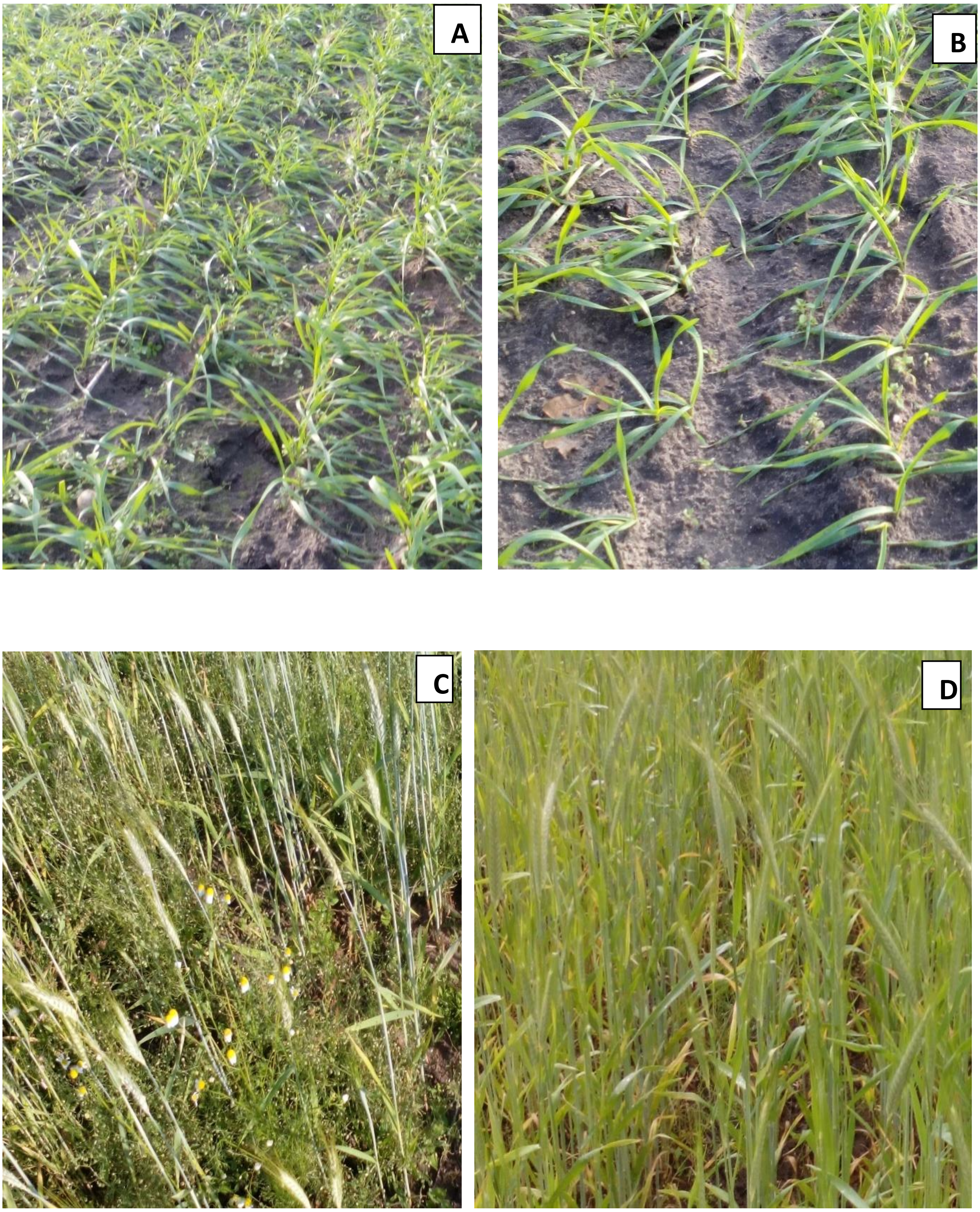


Figure 14 Appearance of the field during early growth stage of the crops during November, 2015 (A and B) and during late growth stage of the crops June, 2016 (C and D) for NIT and ECO, respectively.

4 Discussion

4.1 Effects of tillage systems on chemical and physical soil quality

The statistical analysis results for soil organic matter (SOM) between east and west pre-bare subplots per tillage systems gave evident that there is no gradient from east to west pre-bare subplots (Fig. 3). In that manner, it is apparent that the differences in SOM contents were due to differences in tillage systems. Therefore, the decline of SOM from NIT plots down to CON plots was due to effects of tillage systems and not due to the gradient between east and west pre-bare subplots. Moreover, because the field had no true replicates, the results of SOM were used to validate the measurements of weeds and crop performance parameters in one pre-bare subplot only per each tillage system plot. Additionally, the analysis of other soil parameters (N_{min}, TN and pH) only compared tillage systems per each soil layer without taking into consideration pre-bare and pre-potato subplots. This is because no statistical differences were observed between pre-bare and pre-potato subplots for each tillage system and at each soil layer.

Generally, results for chemical soil quality (N_{min}, TN and pH) between tillage systems at each soil layers were partly in agreement with the first hypothesis. The two reduced tillage systems (NIT and ECO) had higher SOM, N-NO_3 and TN at 0-10 cm in agreement with the first hypothesis (Fig. 4, 5 and 6). The possible reason for less SOM in CON at 0-10 cm soil layer might be due to incorporation of crop residues deep into the soil. It could also be due to SOM oxidation and release of nutrients accelerated by tillage practices (Triplett & Dick, 2008; Naderi *et al.,* 2016). 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 (Franzluebbers, 2002). 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 (Wander *et al.,* 1998; Six *et al.,* 2004) and decrease or increase in soil disturbance (Willekens *et al.,* 2014). 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 (Luo *et al.,* 2010). Higher N-NO_3 in NIT could be attributed to the non-incorporation of the applied solid cattle manure (SCM), catch crops and potatoes 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. Nitrate leaching 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 (Xue *et al.,* 2015). Likewise, the accumulation of the cover crops and potato residues 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.

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 (Willekens *et al.,* 2014; Naderi *et al.,* 2016). Rasmussen (1999) also stated in his review that several experiments have shown no effects of tillage systems on soil. A ten-year study conducted by Aase and Pikul (1995) about tillage systems on a sandy loam also showed no effect on soil pH-H_2O. 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 (Willekens *et al.,* 2014; Naderi *et al.,* 2016). 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 (Blevins *et al.,* 1983; Paul *et al.,* 2001; Willekens *et al.,* 2014).

Bulk density and penetration resistance were in and partly in agreement with the second hypothesis, respectively. Higher bulk density in reduced tillage systems (NIT and ECO) than in CON is in agreement with the results of other studies at upper soil layers (Malecka *et al.,* 2012). Mean values of 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 by Munkholm *et al.* (2001) and another by Crittenden *et al.* (2015) in the Netherlands. Both studies were carried out in an organically managed sandy loam soil and revealed higher penetration resistance in NIT. 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 (Jones and Kunze, 2004).

4.2 Effect of tillage systems on weeds and crop performance

Results of early and late weed population density and dry matter rejected the hypothesis of weed population density and weed dry matter. Higher weed population density and dry matter in NIT compared to ECO and CON could be due to large quantity of weed seeds and more weed competitiveness to crops, respectively. Higher weed seeds in NIT occurred probably because of non-incorporation of the summer weeds inside the soil due to shallow cultivation depth. Moreover, higher late weed population density and dry matter showed that weed ridging stimulated more weed emergence in NIT compared to ECO and CON.

On the other hand, results on the performance of winter triticale were partly in agreement with the fourth hypothesis. Values of LAI, total plant DM, ear DM, ear/m^2, plant height and chlorophyll content were higher in both ECO and CON than in 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 (Schwarte *et al.,* 2005). 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 (Heady, 1957) was lower in NIT than in ECO and CON. Probably, this is indicating a lower plant growth vigour and higher weed competitiveness 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 (Penuelas and Filella, 1998). 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 (Giunta *et al.,* 2002; Zhao *et al.,* 2007). 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 (Wang and Lantinga, 2014).

It is obvious that higher weed population density and dry matter was in line with lower crop performance in NIT in comparison to ECO and CON show that variations in weed competition to crops or weed suppression by crops varies with differences in tillage intensity. Therefore, these findings indicate that the higher the tillage intensity the lesser the weed number and competition ability. These results are in agreement with what various studies have reported that ploughing reduces weed problems in organic cultivation (Gruber and Claupein, 2009; Vakali, 2011; Vakali., 2015). Many weeds especially grass species in strips where large quantity of cattle slurry was applied could be due to presence of viable weed seeds in slurry that have endured the passage in rumen and processes of slurry making. This is similar to previous studies that reported higher incidence of weed seeds in farmyard manure, slurry and composts not been treated perfectly before application in the field (Barberi, 2002).

5 Conclusions and Recommendations

The aim of this research was to assess the effects of three organically managed tillage systems (non-inversion, eco-plough and conventional) on soil quality indicators, weeds and winter triticale performance. There was no decline in SOM between east and west pre-bare subplots proving that the differences in SOM were due to tillage systems. Moreover, no difference in amount of SOM was observed between pre-bare and pre-potato subplots. Results of chemical soil quality indicated that two reduced tillage systems (NIT and ECO) had higher SOM and TN at 0-10 cm compared to CON. However, at 20-30 cm soil depth all three tillage systems had the same amount of SOM and TN. Concentrations of $N\text{-}NO_3$ were higher in NIT at each soil layer (0-10 cm, 10-20 cm and 20-30 cm). Results of soil $pH\text{-}H_2O$ per each tillage system were similar at each soil layers (0-10 cm, 10-20 cm and 20-30 cm). However, the values of $pH\text{-}CaCl_2$ were variable between tillage systems at 0-10 cm and 20-30 cm soil depths. The use of $pH\text{-}CaCl_2$ instead of $pH\text{-}H_2O$ would be recommended when assessing effects tillage management. This is because $pH\text{-}CaCl_2$ has showed difference between tillage systems at 0-10 cm and 20-30 cm unlike $pH\text{-}H_2O$ in the current study. Upper 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 weeds occurrence and crop performance, ECO and CON revealed higher crop competition ability to weeds and better crop performance. Therefore, ECO having intermediate potentials in soil quality, weed suppression capacity and crop performance could be the right tillage system for organic crop production compared to NIT and CON. However, when one has to choose between increasing the amount of SOM in the field and increasing crop performance. The two reduced tillage methods (NIT and ECO) may be opted, for instance NIT would be better option for increasing amount of organic matter in the soil. On the other hand, ECO would be sufficient for improving the growth performance of the crop with aim of increasing yield. Due to current global campaigns on nature conservation, climate and global warming mitigations, this study offers basis for further studies on integrated winter triticale with organic and conservation agriculture. The reduced tillage methods increase organic matter while winter triticale provides convenient use of nitrate that reduces nitrate leaching especially during winter season.

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Appendixes

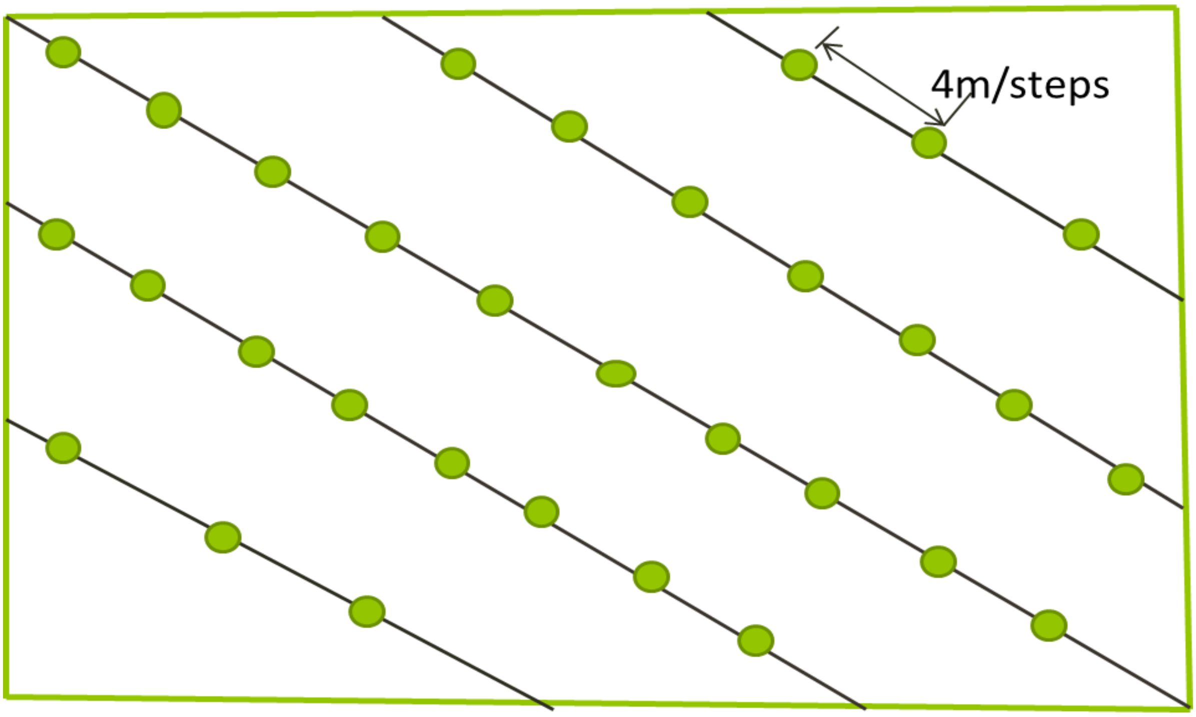

Figure 15 Systematic soil sampling layout for each sampling block, showing the intervals from one sampling point to another and the number of subsamples.

Figure 16 Subplot of potatoes in the main plot treated by NIT. The picture was taken from south to north direction of the field.

Figure 17 Appearance of the field within tractor path after cattle slurry application April 2016

Figure 18 Appearance of the field after cattle slurry application April 2016

Table 5 Three forms of tillage practices and their description

Conventional Tillage (CT)		**Soil operation:** (moldboard) plowing **Result:** Soil invertion (± 25 cm) prior to planting, little or no plant residues remain on the soil surface
Conservation Tillage (CsT) Conservation Agriculture (CA)	Reduced Tillage (RT)	**Soil operation:** A range of superficial, mechanical soil loosening operations (disks, chisels, sweeps, etc.) **Result**: Loosing of top soil (5-10 cm), leaving a large (> 30%) amount of plant material on the soil surface **Synonym**: minimal tillage **Specific variants**: Mulch tillage, Ridge tillage, Strip tillage (zie paragraaf 3.1)
	No Tillage (NT)	**Soil operation:** No soil operations prior to planting, seeds are put in narrow grooves cut into the soil **Result**: virtual all crop residues are left on the soil surface **Synonyms:** direct drill, Zero Tillage (ZT)

Source: Hollemans (2012) based on Van der Weide et al., 2008.

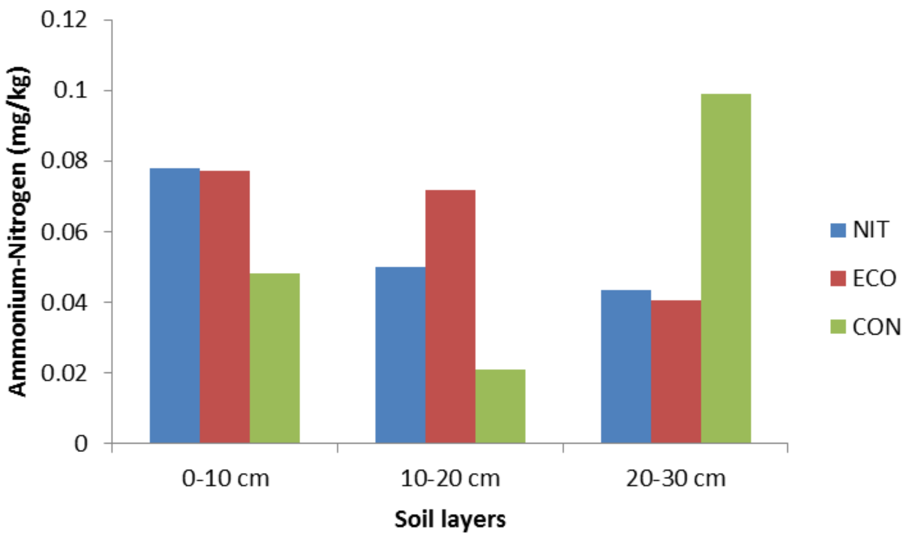

Figure 19 Effect of three tillage systems (Non-inversion tillage (NIT), Eco-shallow mouldboard plough (ECO) and Conventional tillage (CON) and the three soil layers (0-10 cm, 10-20 cm and 20-30 cm) on soil available nitrogen in mg/kg.