Tillage and residue management effects on soil quality in maize and wheat systems in the highlands of Central Mexico

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Abstract

Intensively cropped highlands areas in the tropics and sub-tropics are susceptible to erosion and declining soil fertility resulting in unsustainable agriculture. Conservation Agriculture has been proposed as an alternative to maize wheat production systems in these agro-ecological zones. A field experiment at CIMMYT's experimental station in Toluca (Mexico) comparing permanent raised beds and conventional tilled beds with different residues management under rain fed conditions was started in 2000. The objective of the research project carried out as part of my internship at CIMMYT was to evaluate the effect of different management practices on chemical and physical soil properties. The challenge was to do this for a trial that was originally designed for technology development and not for scientific research. As a consequence the statistical design was not optimal. ANOVA applied to the whole set of treatments revealed that K concentrations were higher in permanent beds. In addition C was higher in the soils with permanent beds with wheat as crop. Permanent beds showed higher water stable aggregates (wet-sieving) compared to conventionally tilled beds. PCA analysis was performed to assess the underlying structure of the physicochemical variables influenced by tillage, residues and crop. The PC 1 and PC2 of the top-layer (0-5 cm) and sub-layer (5-20 cm) separated conventionally tilled beds from semi- and permanent beds and PC3 separated permanent beds from semi-permanent and conventionally tilled beds. These clear separations suggest that tillage and residue management have an effect on soil processes. The research indicates that permanent raised beds increases mainly soil physical soil quality and can be a sustainable production alternative for the (sub)tropic highlands in Mexico when looking at it from a soil quality perspective. Recommendations for future work include recommendations for statistical analyses and comparison of soil quality and yield data to evaluate the feasibility of different management systems in a more unbiased manner.

Keywords: *Zero-tillage, Conventional-tillage, permanent beds, semi-permanent beds wheat, maize, physical soil quality, chemical soil parameters*

1. Introduction

1.1 General Introduction

Tropical and subtropical highlands of the world have been densely populated and intensively cropped for centuries. Soil erosion and fertility decline cause serious problems with respect to crop production, such is the case in the Toluca region and other parts of the altiplano of central Mexico. In the region there is a predominance of continuous maize monoculture in combination with livestock. The major limitations to agricultural production are periodical drought, periodical excess moisture, wind and water erosion and diseases in crop varieties. Most of the soils are bare for much of the year, since most crop residues are used as fodder, pastured or burned. As a result, erosion occurs on the unprotected soil and the fertile top layer is lost. In time erosion leads to a decrease in soil organic matter, soil fertility and crop yields (Fowler and Rockstrom, 2001). An even more acute problem is the limited infiltration capacity of the bare and crusted soils. During the rainy seasons much water will be lost due to runoff (Govaerts et al., 2005; Govaerts et al., 2007b). In addition the soil fertility and structure becomes very poor which also results in reduced crop yields. In order to reduce erosion and increase soil fertility and crop yields, the use of minimum tillage and residue retention is proposed as an alternative and more sustainable management system. Ideally, this system is combined with crop rotation. The combination of these three management principles is commonly known as Conservation Agriculture (CA) referring to resource-conserving crop production. CA, is considered as an agricultural system that helps to sequester carbon and improves the sustainability of temperate as well as tropical agro-ecosystems (Denef et al., 2007; Kern and Johnson, 1993; Lal, 1997). Mechanical interventions for tillage are reduced to a minimum and the external inputs optimized.

CA has been widely adopted in the US and Brazil. Long-term use of CA can lead to increased soil organic matter (SOM), improved soil structure and increased aggregation compared to intensively tilled soils (Rasmussen and Rohde, 1988; Six et al., 2002a). Stable aggregation regulates air and water infiltration and soil stability and thus can be associated with permeability and erodibility (Feller and Beare, 1997). Positive effects have been observed of zero tillage in combination with proper crop rotation and crop residue management (Govaerts et al., 2006). Crop and root residues are a source for organic matter which is important for formation of aggregates, water infiltration and biological activity. Increase of SOM contents increases fertility of the soil by immobilization of nutrients through organic and inorganic processes (Portela et al., 2006; Sainju, 2008; Sainju et al., 2006). Furthermore, an important benefit (of higher immediate relevance to the farmer) of CA is that average returns over costs can be higher as compared to conventionally tilled (CT) systems due to savings on fuel and labor (Sayre and Hobbs, 2003).

Intensive conventional tillage is commonly used under cooler, temperate climates such as in northwestern Europe regions where 500-600 mm of relatively low intensity rainfall are uniformly distributed throughout the year. In the tropics CT is extremely harmful since storms with rainfall exceeding 150 mm h^{-1} are not uncommon (Pedro et al., 2001). Leaving residues behind, with ZT management, provides protection against surface sealing and at the same time increases the water infiltration rate, which is very important in the control of water erosion.

In CA cultivation on beds is a widely adopted management system. Raised beds cultivation has been used since time immemorial by farmers all over the world. The origin and use have been associated with water management issues, by providing opportunities to reduce adverse access of water on crop production or to irrigate crops in semi-arid and arid regions (Sayre, 2004; Sayre and Hobbs, 2003).

In 2000 a field trial was started at the experimental station of CIMMYT in Toluca. Several management systems were tested in order to find sustainable management practices to support CIMMYT in intense crop breeding activities in the station. In this design several agronomic practices were incorporated, comparing reduced tillage systems and conventional tillage. The experiment compares raised bed planting based on extensive tillage with the formation of new raised beds for each succeeding crop versus an approach where raised beds were formed for the initial crop after a final tillage cycle and are then reused as permanent raised beds with only superficial reshaping in the furrow as needed before planting of each succeeding crop. The experiment includes also crop rotation (maize and wheat) and different levels of crop residue retention in order to see if those practices can increase the sustainability of the maize-based cropping systems in the target zone. Because the field experiment was originally designed for technology development some treatments were changed in 2005 in response to practical problems.

1.2 Theoretical background on crop management and soil properties

Aggregate stability is used as an indicator of soil structure (Six et al., 2000). The formation of stable soil aggregates is influenced by mineralogy, texture, land use management and the quality and quantity of organic matter inputs (Feller and Beare, 1997). The organic matter (OM) acts as a binding agent and as a nucleus in the formation of aggregates, while biota and their organic products contribute to the development of soil structure (Bronick and Lal, 2005). Aggregates are secondary particles and occur in a variety of manners and sizes. These are often grouped by size: macroaggregates (>250 μm) and microaggregates (<250 μm) (Tisdall and Oades, 1982). Tillage is widely used for seed bed preparation and weed control. However, the effects are detrimental for soil structure by continually exposing new soil to the erosive impact of rain drops, wind, wetting and drying at the soil surface (Barthes and Roose, 2002; Six et al., 1999). Thereby aggregates are disrupted.

According to research done by (Barthes and Roose, 2002) runoff and erosion were decreased with increasing aggregate stability. Their result showed that soil susceptibility to runoff and erosion was linked to topsoil aggregate resistance against slaking. In addition, increased aggregate stability feeds back to increased infiltration and reduces the erosion potential. Increased changes in soil moisture and wet-dry cycles have a variable effect on aggregation disruption. Dispersion or slaking caused by wet-dry cycles can be reduced by amending soils with humic substances (Piccolo et al., 1997). Lower aggregation due to heavy tillage in the past results in a reduction of the infiltration and storage capacity of the soil by forming a relatively impermeable layer by sealing of pores. Therefore in the long-term benefits such as higher infiltration and reduced evaporation are obtained with ZT over CT.
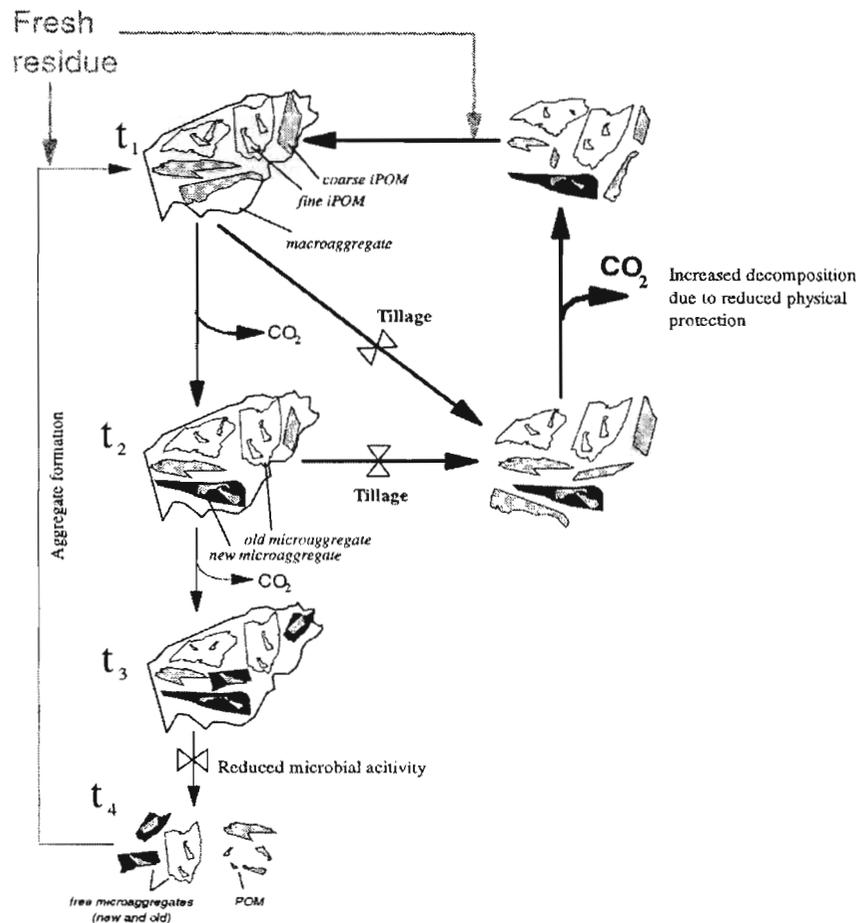
Figure 1. Conceptual design aggregation (Six et al., 2000) with t₁: formation of macroaggregates; t₂: decomposition and defragmentation of intra-aggregate particular OM (iPOM); t₃: formation of microaggregates within macroaggregates; t₄: decrease microaggregate stability with release of stable microaggregates

Cultivation of soils through tillage results in a speed up of the mineralization of SOM (von Lutzöw et al., 2006). Organic matter which is occluded in stable soil aggregates is physically protected against decomposition due to reduced access for microorganisms, reduced diffusion of enzymes into intra-aggregate space and restricted aerobic decomposition due to reduced diffusion of oxygen (Figure 1). These mechanisms influence soil fertility in a direct way.

Oxidation of OM due to tillage, results in nutrient mineralization (Christensen et al., 1994). An improved soil structure protects OM from degradation by occlusion of OM by aggregation (Six et al., 2000; Six et al., 2002b; von Lutzöw et al., 2006). Occluded OM is spatially protected against (a) decomposition due to reduced access for the microorganisms and their enzymes, which control further food web interactions, (b) reduced diffusion of enzymes into the intra-aggregate space and (c) restricted aerobic decomposition due to reduced diffusion of oxygen (von Lutzöw et al., 2006). Tillage also increases the release of mineral N from active and physically protected N pools. With decreased soil disturbance a higher accumulation of OM is stimulated. Therefore in ZT with combination of proper residue retention higher C content immobilizes more N in the soil due to a higher C to N ratio compared to conventional tilling.

In addition ZT influences soil quality in a positive way. Soil quality means the capacity of soil to function effectively at present and in the future or as the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran and Parkin, 1994). The quality of the soil includes an inherent component, determined by soils physical and chemical properties within the constraints set by climate and ecosystem. In addition, soil quality includes a component affected by management and land-use. High soil quality, in the framework of agricultural production, equates to the maintenance of a high productivity without significant soil or environmental degradation of C, N, P and micro and macronutrients.

1.3 Aims and hypothesis

The aim of this study was to evaluate the effect of different raised bed planting systems (tilled raised beds vs. permanent raised beds), with different levels of residue retention (full, partial and no retention of crop residues) on physical and chemical soil quality after seven years of maize and wheat cropping. More specifically:

- Determine the effect of current crop type (in year of sampling) on physical and chemical soil quality;
- Determine the effect of conventional tillage versus zero tillage with different residue retention levels on physical and chemical soil quality.

These aims lead to the following hypotheses:

- Crop type has an influence on the soil physicochemical parameters;
- Zero tillage has positive effects on physical and chemical quality over conventional tillage, when combined with increasing levels of residue retention;

2. Materials and Methods

2.1 Characterization of the Toluca experimental station

Toluca experimental station is situated in the semi-arid highlands of Central Mexico, near the inactive volcano Nevado de Toluca. The station has a mean annual temperature of 15 °C and an average rainfall of 800 mm during the growing season between May and October. Intense rain followed by dry spells typify the rainy season. The soil texture defined by USDA Soil Taxonomy is classified as a loam to loamy clayey soil. The soil is characterized by relatively good chemical and physical conditions for farming. Major limitations are periodical drought, periodical water excess, wind and water erosion and pests and diseases.

2.2 Description of the field experiment

The rain fed experiment was started in 2000. Individual plots measured 8 m ⅹ 25 m with ten beds of 75 cm from furrow to furrow. The experiment is complex as it was never designed for scientific research purposes and combines different management practices in a non-balanced design (Table 1). The experiment included ten treatments and three replicates in a block design. Three management factors were investigated in the field trial. The first factor was tillage whereby conventional tillage with beds formed after each crop (CB), reduced tillage where zero tillage beds were reshaped after each crop (SPB) and zero tillage with continued reuse of the existing beds (reshape if required) (PB) were compared. The second factor was residue management, whereby all crop residues chopped and retained on the field (+R) was compared to all crop residues removed for fodder (-R) and crop residues partly removed (+PartR). The third factor was the rotation of maize and wheat. In fact some of the treatments were partially changed in 2005 (Table 1) but for the purpose of this report we considered all of them as static treatments, based on the management system that was in place at the time of sampling.

Standard practices in the study included the use of currently recommended crop cultivars with maize planted at 60,000 plants ha^{-1} in one row on top of the 75-cm beds and two rows of wheat planted in 20-cm rows on top of the beds at 90 kg seed ha^{-1}. Both crops were fertilized at the rate of 120 kg N ha^{-1} using urea with all N applied to wheat at the 1st node growth stage (broadcast) and to maize at the 5-6 leaf stage (surface-banded). Weed control used appropriate, available herbicides as needed and no disease or insect pest controls were applied, except for seed treatments applied by commercial seed sources. Planting of both maize and wheat depended on the onset of summer rains, usually between May and June.

Table 1. Treatments at the CIMMYT bed-planted sustainability trial in Toluca, Mexico

Treatments	Year	Rotation	Tillage	Straw management
1	2000	W-W[a]	Conventional	Retained
2	2005	M-M[a]	Permanent beds	Retained
3	2008	W-M	Semi-permanent beds[b]	Partial[c]
4	2000	M-W	Semi-permanent beds	Partial
5	2000	W-M	Permanent beds	Partial
6	2005	M-W	Permanent beds	Partial
7	2000	W-M	Permanent beds	Removed
8	2005	M-W	Permanent beds	Removed
9	2000	W-M	Permanent beds	Partial
10	2000	M-W	Permanent beds	Partial

[a] W--Wheat; M--Maize

[b] Semi-permanent--Tillage and formation of new beds in winter for wheat; No tillage with reshaping of existing beds for maize

[c] Partial--Wheat straw cut by the combine removed; kept maize residue

2.3 Soil physical and chemical properties

Soil chemical analyses

Ten cores were taken at random from both the 0-5 cm and 5-20 cm soil layer of the beds in each plot. The ten cores were pooled to give a composite sample. Sampling was done during the fallow after the 2007 harvest. Samples were air-dried, passed through a 2-mm sieve and characterized. Table 2 gives the analytical protocols used.

Table 2. Protocol of measurements for each indicator

Indicator	Protocol	Reference
Ca, Mg, K	Ammonium acetate extraction, AAS[a] detection	(Schollenberger and Simon, 1945)
Total N	Semimicro-Kjeldahl	(Bremner, 1965)
NO3-	KCl extraction	(Stieg, 1993a)
NH4+	KCl extraction	(Stieg, 1993b)
Total Organic Carbon	Combustion	(Walkley, 1947)
P	Olsen extraction	(Olsen et al., 1954)
Fe, Mn, Zn, Cu	DTPA-TEA[b] extraction, AAS detection	(Viets and Lindsay, 1973)
pH	Soil paste	IRENAT laboratory protocol
Electrical conductivity	Soil paste	IRENAT laboratory protocol

[a]AAS = Atomic Absorption Spectroscopy
[b]DTPA-TEA = diethylenetriaminepentaacetic acid-triethanolamine

Soil aggregation

A composite of seven sub-samples, with a weight of 500 g, was taken randomly from the 0-5 cm after the 2007 harvest. To avoid breakdown of the aggregates, sampling was done with a small shovel. Samples were air-dried for a few hours and big clods (>5 cm) were gently crumbled, and then air-dried further for two weeks. Soil was then hand sieved through an 8-mm sieve. To determine dry aggregate distribution, a subsample of 500 g was separated by shaking the samples through a set of sis sieves with opening of 4.0, 2.0, 1.0, 0.85, 0.5, 0.25 mm at speed of 210 cycles min^{-1} for 5 minutes. Soil remaining on each sieve was collected and weighted (Kemper and Chepil, 1965). The determination of water stable aggregates distribution was performed by the method based on (Kemper and Rosenau, 1986) which was further developed by (Barthes and Roose, 2002). Air-dried soil (40g, <8 mm) was immersed in deionized water for 5 min. Samples were placed three times on the top of sieve with openings consisting of 2.0, 0.25 and 0.053 mm. Sieves were immersed in water and moved up and down through a vertical distance of 3 cm at a rate of 25 strokes per minute for 2 minutes. All fractions were dried in an oven at 105°C and weighted. In order to correct the fractions for 'real aggregate weight' all fractions were corrected for sand by shaking of the respective soil fraction (<10 g) with 30 ml NaOH for 24 h and weighting the soil retained on the respective screens (Barthes et al., 2000; Kemper and Rosenau, 1986). The aggregate size distribution after dry and wet sieving was expressed as the mean weight diameter (MWD) (Equation 1) (Kemper and Chepil, 1965; Van Bavel, 1949):

$$MWD = \sum_{i=1}^{n} \langle d \rangle_i w_i \qquad [1]$$

where $\langle d \rangle$ is the mean diameter of each size fraction (i), w is the proportion of the total sample weight occurring in the size fraction (i) and n is the number of size fractions.

Infiltration

Direct surface infiltration (time-to-pond) was determined with a metallic ring made out of wire placed on top of the raised bed (0.1 m^2), but not impeding water to flow out of this area. The area was watered using a watering pot with outflow of 0.18 mm s^{-1} from a height of 50 cm. The shower was stopped when water began to run out of the marked area. The time-to-pond (TTP) and the amount of water added onto the soils were measured. Per plot four measurements were performed (Govaerts et al., 2006; Govaerts et al., 2007a).

2.4 Statistical approach

This experiment was an un-randomized block design. Significant difference for the factors treatment and crop type were determined by analysis of variance (ANOVA) and based on the difference using the Tukey's test using the General Linear Model

procedure (Leech et al., 2005). This procedure can be used for an ANOVA for unbalanced data. The effects of tillage were looked at by comparing conventionally tilled, semi-permanent beds and permanent beds with different and without residue management (Table 1).

Multivariate statistics were conducted in two steps. The first step determined whether there was a significant effect of a class factor on at least one of the physical and chemical variables assessed. Wilk's lambda and derived F statistics were used to test the null hypothesis of no overall treatment effect. Once this criterion was met, the second step consisted of interpreting the univariate ANOVA's, as described above.

Under principal component analysis (PCA) all variables were then further explored. The PCA data analysis was performed with the statistical software package R 2.7.1 using the PRCOMP function (R, 2008). With this tool the number of independent variables could be reduced and problems of multi-collinearity solved. Variables were auto-scaled prior to PCA (Govaerts et al., 2007a; Sena et al., 2002). Components with Eigenvalues >1 and explaining >10% of the variance were retained. A scree test was performed to corroborate. A VARIMAX rotation was performed to enhance interpretability of the uncorrelated components. All meaningful loadings (i.e. loading > 0.50) were included in the interpretation of principal components (PC). The PCA analysis is interpreted graphically by constructing biplots. Samples were projected into the PC space by computing PC scores for each sample. Interpretation of the biplot can be noted by the position of the coordinates of the samples in the PC space.

3. Results

3.1 Soil chemical analytical results

Crop type (maize or wheat) had a significant effect on concentrations of P which was higher for wheat compared to maize in the 5-20 cm layer (Table 3 and 4). Permanent beds without residues in the 0-5 cm for wheat had significant higher concentrations of P and decreased with increasing residue retention and tillage.

Type of crop had no significant effect on concentrations of K. Concentrations of K were significant higher with the use of permanent beds compared to conventional tillage in the 0-5 cm and 5-20 cm layer. In addition, residue retention had significant effects in the 0-5 cm and 5-20 cm layer. Concentrations of K increased with increasing residues. The concentrations of Ca and Mg were not affected by crop type in the 0-5 cm layer but showed significant effects with maize in the 5-20 cm layer where concentrations were higher for Ca and Mg. Tillage had no significant effect on concentrations of Ca and Mg in the 0-5 cm layer. In contrast with Ca, tillage had a significant effect on concentration of Mg in the 5-20 cm layer with increasing concentrations of Mg by decreasing residues in the field (Table 3 and 4).

In contrast to the 0-5 cm layer, concentration of Fe was significantly affected by type of crop in the 5-20 cm layer where the concentration of Fe was higher with wheat as crop (Table 3 and 4). Tillage had no significant effect on concentration of Fe. Crop and tillage did not have a significant effect on extractable Cu and Zn. In contrast to Cu and Zn, crop had a significant effect on concentration of Mn, where wheat had higher concentrations compared to maize in both layers 0-5 cm and 5-20 cm. Tillage in combination of the crop wheat had significant effect on concentration of Mn in the 0-5 cm layer. Concentration of Mn decreased with increasing tillage. Opposite occurred in the 5-20 cm layer, where tillage with maize had a significant effect on concentration of Mn. Mn concentration increased with an increase in tillage.

C concentration was, in contrast to the 0-5 cm layer, significant affected in the 5-20 cm layer with wheat as crop type (Table 4). Concentration of C was increased in the 5-20 cm layer with wheat as crop type (Table 3). Similarly tillage with crop wheat had significant effect on the concentration of C where concentrations were higher with decreasing tillage in the 0-5 cm layer. In contrast to the 0-5 cm layer the concentration of C was elevated in the 5-20 cm layer when tillage was increased. Concentration of N was not significantly affected by crop type in 0-5 cm and 5-20 cm layer and for tillage in 0-5 cm layer. Tillage with wheat in 5-20 cm layer significantly affected N concentration, where conventional tillage with residues had higher concentration of N compared to permanent and semi-permanent beds with residue. N concentrations further decreased with a decrease of residue retention.

The pH of the soil was not significantly affected by type of crop and tillage in the 0-5 cm layer (Table 3 and 4). In contrast to the 0-5 cm layer, the crop in the 5-20 cm layer had a significant higher effect on pH with maize as crop. Tillage did not have any effect on the pH in the 5-20 cm layer. Electrolytic conductivity (EC) was not affected by crop and tillage practices in the 0-5 cm layer, but was significantly higher with wheat as crop in the 5-20 cm layer. In addition, the EC was significantly affected by tillage with wheat in the 5-20 cm layer. EC was higher for semi-permanent beds and conventional beds with residues and decreased with decreasing residues in the field and with zero tillage.

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Table 3. Total P, extractable, macro- and micro-nutrients, soil organic matter, Total N, pH, EC and organic nitrogen of the 0-5 cm and 5-20 cm soil layer for the long-term trial comparing crop and tilled- and permanent beds.

	n	P	K	Ca	Mg	Fe	Cu	Zn	Mn	C	N	pH	EC	NO_3^-	NH_4^+
		(mg kg⁻¹)								(g kg⁻¹)			(dS m⁻¹)	(mg N kg⁻¹)	
0-5 cm layer															
Crop															
Maize	15	37.79 a	436.09 a	1681.64 a	368.91 a	168.60 a	0.95 a	0.76 a	39.26 b	24.06 a	2.00 a	5.41 a	0.07 a	2.79 a	9.18 a
Wheat	15	41.51 a	503.95 a	1674.96 a	362.45 a	179.29 a	0.90 a	1.87 a	45.96 a	24.19 a	2.03 a	5.33 a	0.08 a	2.42 a	6.19 b
Tillage maize															
PB[a] + R[b]	3	35.29 a	560.02 a	1649.81 a	374.27 a	174.99 a	0.95 a	1.14 a	37.51 a	24.61 a	2.05 a	5.50 a	0.07 a	2.48 a	7.10 a
PB + PartR[b]	6	35.76 b	368.69 b	1686.58 a	364.47 a	165.54 a	0.97 a	0.85 a	41.06 a	23.99 a	1.99 a	5.32 a	0.07 a	2.13 a	9.88 a
SPB[a] + PartR	3	44.36 a	446.97 ab	1703.57 a	372.43 a	168.30 a	0.92 a	0.19 a	37.42 a	23.68 a	1.98 a	5.53 a	0.06 a	4.44 a	9.85 a
PB - R[b]	3	35.68 a	411.98 ab	1585.67 a	400.90 a	175.07 a	0.95 a	1.24 a	46.01 a	25.80 a	2.02 a	5.32 a	0.08 a	1.96 a	13.73 a
Tillage wheat															
PB + PartR	6	46.49 ab	589.87 a	1516.30 a	318.44 a	182.56 a	0.82 a	1.50 a	53.62 a	25.73 a	2.03 a	5.23 a	0.09 a	2.19 a	7.04 a
SPB + PartR	3	38.22 b	382.97 b	1700.36 a	387.38 a	183.53 a	0.98 a	0.46 a	36.05 b	22.12 c	1.88 a	5.53 a	0.07 a	1.94 a	4.85 a
PB - R	3	60.52 a	433.75 a	1602.05 a	420.98 a	178.56 a	0.96 a	0.99 a	45.45 ab	24.89 ab	1.97 a	5.18 a	0.07 a	3.38 a	7.26 a
CB[a] + R	3	34.82 b	453.10 a	1966.86 a	425.53 a	168.53 a	0.97 a	2.44 a	40.56 b	23.19 cb	2.16 a	5.33 a	0.07 a	3.36 a	5.85 a
5-20 cm layer															
Crop															
Maize	15	17.23 b	236.96 a	2036.16 a	471.05 a	139.02 a	0.94 b	0.29 a	20.11 b	18.60 b	1.51 b	5.61 b	0.08 a	1.18 b	2.32 a
Wheat	15	29.09 a	277.46 a	1789.29 b	373.56 b	158.42 a	0.97 a	1.16 a	31.72 a	19.85 a	1.61 a	5.24 a	0.09 b	1.53 a	2.61 a
Tillage maize															
PB + R	3	17.79 a	340.72 a	2050.81 a	452.78 b	142.91 a	0.96 a	0.36 a	19.08 b	18.32 a	1.67 a	5.66 a	0.07 a	0.28 a	1.62 a
PB + PartR	6	15.21 a	183.52 b	2128.80 a	478.78 ab	131.14 a	0.93 a	0.28 a	18.87 b	18.70 a	1.34 a	5.61 a	0.08 a	1.68 a	2.42 a
SPB + PartR	3	20.71 a	240.10 ab	1944.21 ab	473.87 ab	150.90 a	0.92 a	0.24 a	23.61 a	18.68 a	1.69 a	5.58 a	0.08 a	1.07 a	2.81 a
PB - R	3	18.42 a	207.50 b	1963.82 b	562.00 a	137.13 a	0.80 a	0.54 a	20.56 ab	18.77 a	1.45 a	5.61 a	0.07 a	1.11 a	1.69 a
Tillage wheat															
PB + PartR	6	28.89 a	326.53 a	1726.86 a	335.61 b	158.71 a	0.94 a	0.85 a	34.67 a	19.57 b	1.56 ab	5.15 ab	0.08 ab	0.89 ab	1.68 a
SPB + PartR	3	28.05 a	165.60 b	1868.75 a	418.23 ab	159.75 a	1.07 a	0.29 a	26.28 a	20.66 a	1.57 ab	5.31 a	0.09 a	2.23 a	3.27 a
PB - R	3	26.57 a	221.85 ab	1960.46 a	456.33 a	153.26 a	1.00 a	0.47 a	29.64 a	18.93 b	1.52 b	5.30 b	0.07 b	0.70 b	0.74 a
CB + R	3	30.50 a	291.18 a	1834.69 a	404.80 ab	156.51 a	0.96 a	2.63 a	31.27 a	19.61 ab	1.74 a	5.36 a	0.09 a	2.13 a	3.80 a

[a] PB: permanent beds; SPB: semi-permanent beds; CB: conventional beds
[b] +R: Residues kept in the field; +PartR: Partially removed residues; -R: residues removed

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Table 4. ANOVA results of variables total P, extractable macro- and micro-nutrients, soil organic matter, Total N, pH, EC, organic nitrogen, mean weight diameter and time-to-pond of the 0-5 and 5-20 cm soil layer for the long-term trial comparing tillage, residue and plant management

	DF	P	K	Ca	Mg	Fe	Cu	Zn	Mn	C	N	pH	EC	NO3-	NH4+	MWD[a] Dry	MWD[a] Wet	TTP[b]
Toplayer																		
Plant	1	NS	NS	NS	NS	NS	NS	NS	*[c]	NS	NS	NS	NS	NS	*	NS	NS	*
Tillage	1	NS	*	NS	NS	NS	NS	NS	**[c]	**	NS	NS	NS	NS	NS	NS	*	NS
Residue	2	NS	**	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*	NS
Residue * plant	1	NS	**	NS	NS	NS	NS	NS	**	*	NS	NS	NS	NS	NS	NS	NS	NS
Tillage * Plant	1	NS	**	NS	NS	NS	NS	NS	**	**	NS	NS	NS	NS	NS	NS	**	*
Tillage system maize	3	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
Tillage system wheat	3	**	**	NS	NS	NS	NS	NS	**	**	NS	NS	NS	NS	NS	*	**	*
Sublayer																		
Plant	1	**	NS	**	**	**	NS	NS	**	**	NS	**	**	NS	NS	.	.	.
Tillage	1	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	.	.	.
Residue	2	NS	**	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	.	.	.
Residue * plant	1	NS	*	*	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	.	.	.
Tillage * Plant	1	NS	**	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	.	.	.
Tillage system maize	3	NS	**	NS	*	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	.	.	.
Tillage system wheat	3	NS	**	NS	*	NS	NS	NS	NS	**	*	NS	*	NS	NS	.	.	.

[a] MWD--Mean weight diameter for sieving

[b] TTP--Time-to-pond

[c] *-- $p < 0.05$; **-- $p < 0.01$

There was a significant effect of crop type on the concentration of NH_4^+ in the 0-5 cm layer (Table 3 and 4). In contrast, NO_3^- was not significant affected by crop type in the 0-5 cm and 5-20 cm layer. In addition, in the 5-20 cm layer crop did not have any effect on the concentration of NO_3^- and NH_4^+. Tillage also did not have any significant effect on the concentration of $NO3^-$ and NH_4^+ in the 0-5 cm and 5-20 cm layer.

3.2 Soil physical parameters

Crop did not have a significant effect on mean weight diameter (MWD) for wet and dry sieving (Table 4 and 5) (Figure 2). However tillage with wheat had significant effect on the MWD with dry and wet sieving. MWD was lower with permanent beds (PB) without residues for dry sieving compared to conventional tilled beds and semi-permanent beds with residue and partial residues. The MWD with wet sieving showed opposite results. Permanent beds with partial residues had a significant higher MWD compared to conventional tilled and semi-permanent beds.

Time-to-pond (TTP) was significantly affected by crop (Table 4 and 5). Wheat showed higher TTP compared to maize. In addition, tillage had significant effects on TTP. Permanent beds with maize keeping residues showed significant longer TTP compared to permanent beds without residues. For tillage with wheat, TTP was significantly lower for conventionally tilled beds compared to permanent and semi-permanent beds.

Table 5. Soil physical characteristics of the 0-5 cm layer for the long-term trial comparing crop and tilled and permanent beds

	n	MWD[a] sieving				TTP[b]	
		Dry		Wet			
		(mm)				(s)	
Crop							
Maize	15	3.88	a	1.58	a	11.34	b
Wheat	15	4.00	a	1.35	a	16.23	a
Tillage maize							
PB[c] + R[d]	3	3.86	a	1.86	a	10.97	ab
PB + PartR[d]	6	3.80	a	1.39	a	14.44	a
SPB[c] + PartR	3	4.08	a	1.66	a	5.52	b
PB - R[d]	3	3.71	a	1.46	a	6.07	b
Tillage wheat							
PB + PartR	6	3.92	ab	1.64	a	18.94	ab
SPB + PartR	3	4.06	a	0.91	c	23.23	a
PB - R	3	3.40	b	1.39	ab	20.40	ab
CB[c] + R	3	4.10	a	1.20	bc	3.81	b

[a] MWD: Mean weight diameter for sieving

[b] TTP: Time-to-pond

[c] PB: Permanent beds; SPB: Semi-permanent beds; CB: Conventionally tilled beds

[d] +R: Residues kept in the field; +PartR: Partially removed residues; -R: Residues removed

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a (dry sieving)
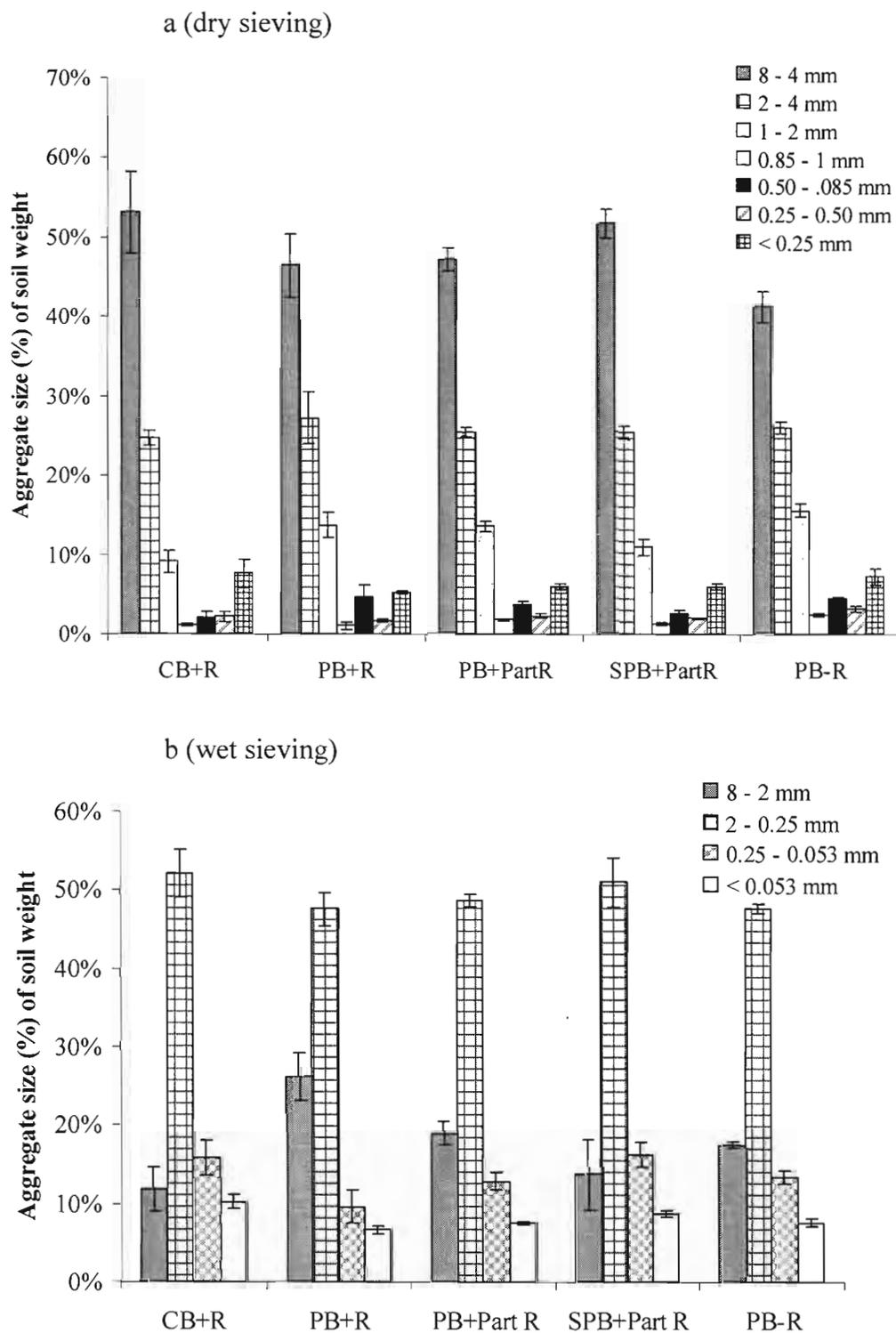
b (wet sieving)

Figure 2. Aggregate size distribution for (a) dry sieving and (b) wet sieving with CB—conventional tilled beds; PB—permanent beds; SPB—semi-permanent beds; +R—with residues; +PartR—partial residues; -R—residues removed.

3.3 PCA analysis

Principal component analysis with VARIMAX rotation was conducted to asses the underlying structure for the 17 physicochemical variables in the 0-5 cm layer and the 14 physicochemical variables for the 5-20 cm layer in the soil of the long-term trial

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which were influenced by crop and tillage (Table 6). Only principal components (PC) with Eigenvalues > 1 explaining > 10% of the total variance were retained. This resulted in three PC's for the 0-5 cm layer and two PC's for the 5-20 cm soil layer. PC1 explained 25% of the variability of the 0-5 cm layer and had significant positive loadings on Mn and C. PC2 which explained an additional 13% of the variability of the 0-5 cm layer had significant loadings from Cu, electrolytic conductivity (EC) and NH_4^+. An additional of 12 % was further explained by PC3 with significant loadings on Cu, mean weight diameter (MWD) dry sieving and time-to-pond. PC1 of the 5-20 cm layer explained 40% of the variability and had significant loadings on Total P, Mg Mn and pH. In addition PC2 of the 5-20 cm layer explained 18% of the variability with significant loadings on EC, NO_3^- and NH_4^+. The PCA biplot of the 0-5 cm layer of PC1 and PC2 separated the conventionally tilled beds from other treatments (Figure 3a). Within the group of the permanent beds maize and wheat were separated along the Y-axis. The PCA biplot of PC1 and PC3 of the 0-5 cm layer clustered conventionally tilled beds and semi-permanent beds with at least partial residue retention (Figure 3b). The PCA biplot of the 5-20 cm layer with PC1 and PC2 separated conventionally tilled beds and semi-permanent beds with residues, permanent beds with partial or no residues and permanent beds with full residue retention (Figure 3c). Within the group of treatments maize and wheat were separated along the X-axis.
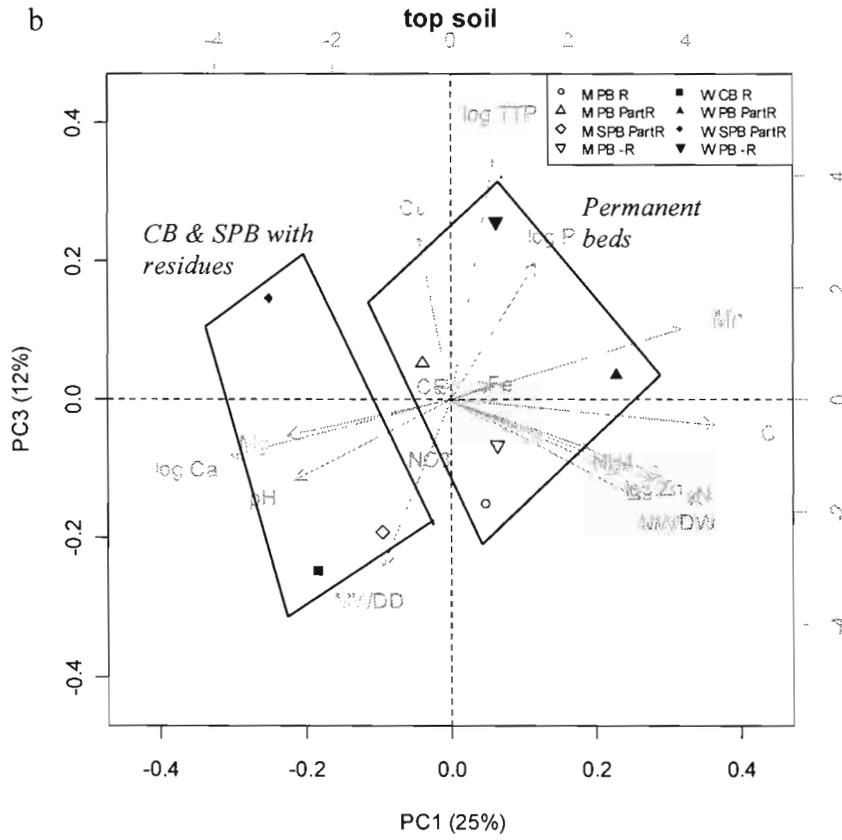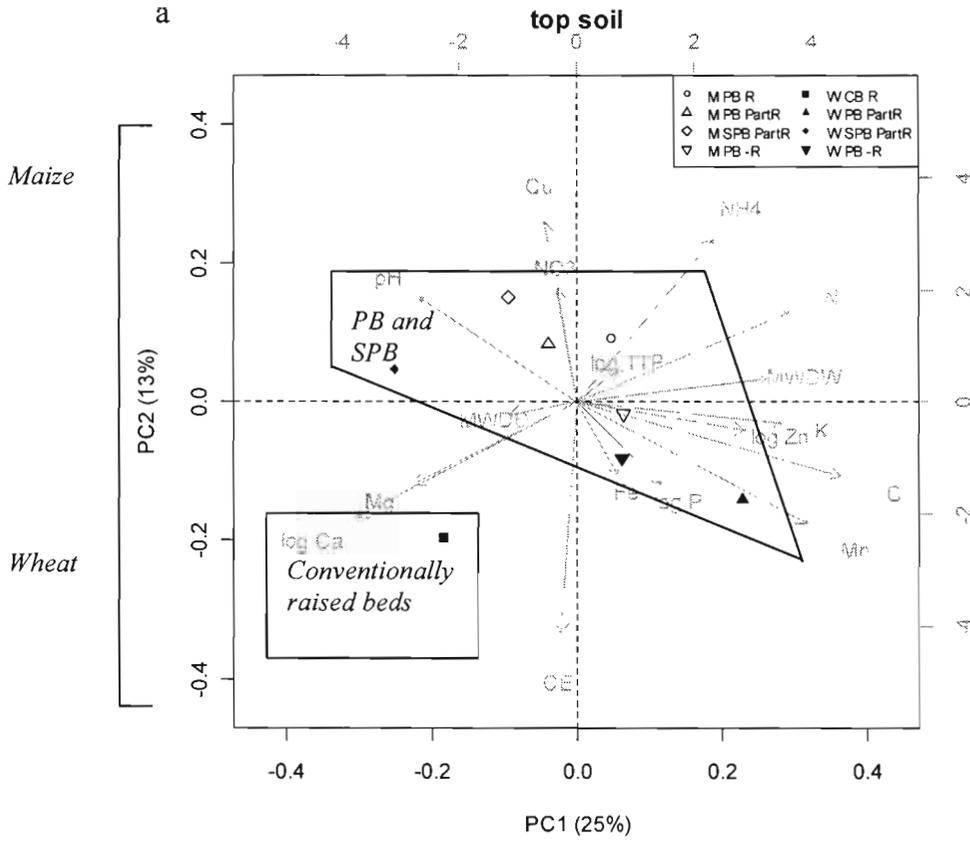
Table 6. Rotated loadings on the principal components

Measurements	Principal components[a]				
	Top layer (0-5 cm)			Sub layer (5-20 cm)	
	PC1	PC2	PC3	PC1	PC2
Eigenvalues	4.22	2.28	2.04	5.67	2.51
Proportions (%)	24.84	13.39	11.97	40.48	17.95
Total P	0.13	-0.18	0.32	0.37 *	0.05
K	0.32	-0.05	-0.19	0.21	-0.22
Ca	-0.34	-0.26	-0.13	-0.32	0.08
Mg	-0.26	-0.18	-0.08	-0.35 *	0.12
Fe	0.06	-0.16	0.04	0.34	-0.15
Cu	-0.05	0.41 *	0.38 *	0.18	0.04
Zn	0.26	-0.06	-0.17	0.09	0.06
Mn	0.36 *	-0.27	0.17	0.38 *	-0.08
C	0.41 *	-0.16	-0.06	0.28	0.26
Total N	0.33	0.20	-0.18	0.19	-0.01
pH	-0.25	0.23	-0.19	-0.36 *	0.12
EC[b]	-0.03	-0.52 *	0.03	0.21	0.42 *
NO_3^-	-0.03	0.26	-0.11	0.03	0.58 *
NH_4^+	0.21	0.37 *	-0.12	0.05	0.55 *
MWD[c] dry	-0.11	-0.03	-0.39 *		
MWD wet	0.30	0.05	-0.23		
Time-to-pond	0.07	0.08	0.57 *		

[a] Only principal component with Eigenvalues > 1 and that explain > 10% of the total variance were retained

[b] EC: Electrolytic conductivity

[c] MWD: Mean weight diameter

* Symbol identifies parameters with significant loading (> 0.35)

Figure 3. Biplot of (a) principal components 1 and 2 of the 0-5 cm layer; (b) principal components 1 and 3 of the 0-5 cm layer and (c) principal components 1 and 2 of the 5-20 cm layer of the principal component analysis of all soil parameters with M—Maize; W—Wheat; CB—conventionally tilled beds; PB—permanent beds; SPB—semi-permanent beds; R— residues retained; PartR—partial residues retained; –R—residues removed

4. Discussion

4.1 Plant effects on physicochemical properties

Plant had an influence on the soil physicochemical parameters. However due to constraints in the experimental setup, results related to plant are turbid. In the statistical analysis plant rotation (wheat and maize) and continuous wheat or maize were analyzed as similar rotations at time of measurement. So, this means that rotation was not accounted for, resulting in possibly different results when specifically looked at effects of rotation versus continuous cropping systems.

Extractable Mn in the 0-5 and 5-20 cm layer were higher when wheat was grown as crop. Mn is an essential micronutrient for plants as it plays a major role in photosynthesis, respiration and activation of several enzymes (Peng et al., 2008). Although Mn has not been considered to be a polluting metal, various soil conditions often present in acid and volcanic soils can lead to Mn reduction and create Mn toxicity in natural and agricultural systems (Lidon and Teixeira, 2000). Bioavailability of Mn is strongly dependent on plant species and soil pH (Adams, 1984). An increase in extractable Mn could indicate soil acidification. This is reflected by a slight decrease in pH in the 5-20 cm soil layer. Similarly the pH and Mn showed opposite loadings on the second PC of the 5-20 cm layer (Table 6, Figure 3c), supporting the above mentioned assumption. Similarly to Mn, Fe was increased with decreasing pH indicating that previously non available Mn and Fe were released from soil minerals. In addition, excessive Mn can induce oxidative stress catalyzing the oxidation of Fe (Gonzalez et al., 1998). Extractable concentrations of Ca and Mg were higher when maize was grown as crop. Also these concentrations were correlated to the higher pH in the soil with maize compared to the pH of the soil with wheat (Table 6, Figure 3c). P concentrations were higher in the soils planted to wheat in the 5-20 cm layer. The decrease in the concentration of P could partly be ascribed to the accumulation of P in the top layer (0-5 cm). Application of P is usually done on top of the surface where a part of P will be directly fixed by soil particles (Duiker and Beegle, 2006). Since wheat has a more developed root-system concentrations in the 5-20 cm layer were higher compared to maize.

Infiltration was enhanced by wheat compared to maize. Infiltration is related to soil organic carbon, vegetation cover and residues retained in the field. At time of measuring the vegetation (wheat or maize) was not very much developed yet in the plots. For this reason their influence to infiltration can be neglected. Wheat plants have a denser root-system compared to maize plants, increasing the porosity of the soil. In addition plant roots and their system have many effects on soil aggregation. Aggregation tends to increase with increasing root length density, microbial associations, glomalin and percent cover significantly affect soil aggregate stabilization (Bronick and Lal, 2005; Rillig et al., 2001).

4.2 Tillage effects on physicochemical properties

Tillage did have an effect on the concentration of P in the top-layer. Permanent beds had higher concentrations of P, which could be explained by less mixing of P with soil. Less P could be fixed by the soil particles which results in accumulation in the topsoil as mentioned earlier. Accumulation of P at the surface of continuous zero-

tillage is commonly observed (Eckert and Johnson, 1985; Follett and Peterson, 1988). The increase in tillage will result in a lower P concentration in the top-layer and a more homogeneous distribution of P through the soil profile, due to physical mixing with soil.

Tillage effects on K showed higher concentrations with permanent beds compared to conventional tilled beds due to mixing of the soil. In all tillage systems K accumulates more in the top-layer (Duiker and Beegle, 2006; Follett and Peterson, 1988). However zero-tillage in the top-layer compared to conventional tillage which declines with increasing soil depth (Du Preez et al., 2001).

Similarly to the plants Mn within tillage systems was influenced by pH. Figure 3a shows the negative correlation between Mn and pH. In addition Mn concentrations are influenced positively by higher soil organic matter (SOM) contents (Peng et al., 2008).

Organic carbon levels were increased in the 0-5 cm layer with permanent beds when wheat was grown as crop. Accumulation of soil organic C at the soil surface was a result of surface placement of crop residues and a lack of soil disturbance that kept residues isolated from the rest of the soil profile (Franzluebbers, 2002; Franzluebbers, 2005). Even removing residues in combination with permanent beds showed an increase of organic C. According to the PCA analysis (Figure 3a) organic C is correlated to the aggregates stability (Figure 2b). Macro-aggregates often form around particles of SOM, protecting them against mineralization (Six et al., 2000). Soil structure disturbance due to tillage increases mineral N release form active and physically protected N pools (Kristensen et al., 2000). For this reason soil aggregation is correlated to soil organic carbon (SOC) levels, because of the binding action of humic substances and other microbial by products (Bronick and Lal, 2005; Su et al., 2006) and to a lesser extent to N. In addition the PCA analysis showed similar results to N levels in the soil. N and aggregate stability (wet sieving) showed a correlation (Figure 3a and 3b). In addition the PCA supports the idea that zero-tillage increases aggregate stability, higher SOC and lower mineralization of N since conventionally tilled beds and permanent beds are anti-correlated. In addition NH_4^+ concentrations were related to PB, indicating that mineralization is decreased under zero-tillage. This was supported by the PCA analysis in Figure 3a and 3b. In contrast to the top-layer, C contents were lower. Reasons for the larger contrast of top-layer and sub-layer could be the difference in disturbance. Similar results were found by (Duiker and Beegle, 2006), where differences in the top-layer were higher with zero-tillage compared to conventionally tilled soils. In the PCA analysis the sub-layer of conventionally tilled beds is correlated to organic carbon and NO_3^- and NH_4^+, indicating that mineralization is speeded up with tillage since zero-tillage and conventional tillage are negatively correlated. As mentioned earlier tillage is detrimental to soil structure by disrupting soil aggregates with as result induced mineralization of OM and N (Six et al., 2002b; von Lutzöw et al., 2006)

4.3 Residue effects on physicochemical properties

Accumulation of K in the top-layer is partly related to residue retention. As mentioned earlier that K accumulation is mainly attributed to soil mixing, K leaching from residues takes place increasing the K concentration in the top-layer differently with different tillage systems.

Residues had a more visible effect on soil physical than chemical aspects. SOM and residues are closely related to each other, since primary plant production is a biological process governing inputs and outputs of SOM (Six et al., 2002b). An increase in residue retention supports an increase in SOM. Residue retention treatments showed a higher infiltration rate, indicating that residues protect soil surface from sealing. Compared to conventionally tilled beds this protective barrier disappeared by incorporating the residues into the soils which could lead to further disruption of aggregates into the soil.

In addition, it should be noted that these results with respect to residues were based on observations. Due to the non-optimal setup of the trial no clear statements can be made about residue retention. However, results from this research did show that residues possibly have positive influences on water infiltration and nutrients in the soil.

4.4 Restrictions experimental design

As stated above, some critical remarks can be made to the experimental setup and the related results. Due to practical restrictions this experiment was not randomized. Initially this field plot was designed for plant breeding and not for soil science analyses. Therefore the treatments measured in this research were not complete. Vital importance to statistics is to complete the treatments so that similar treatments can be compared. This means that there is an algo-categorical distribution of treatments necessary in order to compare different treatments. In this research there was no balance between the treatments meaning that there are some constraints with comparing and analyzing. In this research CB treatment was only present in the treatment with crop wheat. Comparisons with maize cannot be made without bias, because of possible effects of plant type on the soil (Figure 3a and 3c). In addition, the plot of CB was laying on the boarder of the experimental field what could explain why soil physicochemical parameters were different compared to the other treatments due to practical reasons (i.e. fertility of soil close to a fence or boarder is always lower since machines are not able to put fertilizer close to the fence). This means that place where people would sample is of vital importance, since the area close to the boarder will be differently influenced than inside part the field-plot.

5. Recommendations

In this research there was no randomization. To be able to analyze effects of management on soil physicochemical properties in a fair way, results with respect to wheat could be taken into account. All possible management treatments (tillage and residues) are included. However, still the results will mean little, since maize is a cash crop in Mexico. Results of growing maize with different management systems is necessary, in order to make a fair and clear statement about zero-tillage (ZT). Another possibility is to neglect type of crop (maize and wheat) since most of the field plots have a rotation. All management systems are available (tillage and residues), but unfortunately conventional tillage (CT) is present once as a control. This means that it is tricky to make statements about CT. A change in the experimental setup is desired.

In order to reduce possible effects of spatial variation in soil properties, it is important to randomize a future experiment at the same experimental station. There are three possibilities to achieve this:

1. Plow and restructure the field experiment into a complete randomized block design;
2. Reserve a new plot and develop a new complete randomized block design.
3. Develop a field experiment (i.e. in the mountains) on agricultural soils.

Restrictions to possibility 1 are that valuable information will be lost, but in the end there will be a statistical considered field experiment. However results of ZT will be notable after ca. five years. In the meanwhile no research can be done what is not desired. Possibility 2 will give valuable information, since results found in the new developed field plot can be compared to results found in the initial non optimal field experiment. In addition in combination with the possibility 2 there can be developed a field experiment based on realistic properties at farmers (possibility 3). A field experiment at a farm can give valuable information with respect to erosion, infiltration etc., since these soils are not placed in optimal conditions as compared to the experimental farm. At the experimental farm the soils are leveled off and irrigated when necessary. This is not the case at many agricultural soils at local farmers due to financial restrictions.

Future research could be done about yield and soil properties. There are yield results available but they are not linked to soil parameters per year. Evaluation of the distribution of yield linked to tillage practices and changes in tillage practices could give valuable information about the feasibility of different management systems at the experimental farm and farmer fields.

Acknowledgements

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Appendix 1 Data N, P and micro- and micronutrients

Top layer (0-5 cm)

Plot nr	pH	CE	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
		dS m⁻¹	(g/kg)	(mg/kg)							
101	5.39	0.07	2.67	36.77	501.90	1656.80	385.50	148.31	1.07	7.22	43.48
102	5.56	0.07	2.16	42.15	591.50	1716.89	369.90	156.77	1.01	2.09	35.35
103	5.54	0.06	2.12	33.53	416.70	1809.58	366.30	153.35	0.98	0.42	36.00
104	5.37	0.07	1.92	41.07	410.90	1610.50	363.60	163.07	1.02	0.92	36.04
105	5.31	0.05	2.23	31.17	426.05	1478.77	354.80	166.35	1.02	1.87	48.49
106	5.31	0.07	2.15	38.27	647.95	1285.31	270.70	186.56	1.06	1.25	47.88
107	5.53	0.07	2.10	36.77	391.10	1467.43	428.10	161.58	0.93	2.25	40.65
108	5.19	0.07	2.09	53.78	439.10	1431.15	398.60	194.07	0.93	1.93	49.80
109	5.34	0.07	2.15	40.00	434.65	1814.99	338.60	150.38	0.88	1.40	38.83
110	5.14	0.06	2.14	61.00	553.25	1413.12	303.75	194.00	0.88	2.40	64.00
201	5.32	0.06	1.87	31.97	419.45	1710.96	362	178.73	0.94	4.15	36.89
202	5.52	0.06	2.01	32.68	555.25	1552.56	409.7	184.53	0.91	0.84	37.57
203	5.52	0.06	1.91	31.27	588.50	1477.34	373.3	178.77	0.92	0.10	35.43
204	5.30	0.07	1.87	36.00	436.75	1576.96	376.65	187.00	0.97	0.40	35.63
205	5.29	0.08	1.96	49.07	370.40	1344.89	390.8	158.16	0.93	0.39	41.57
206	5.29	0.08	1.86	43.92	513.45	1624.40	312.3	170.99	1.04	0.32	52.86
207	5.34	0.09	1.98	39.24	392.35	1791.39	455.4	158.79	1.03	0.05	46.86
208	5.23	0.07	1.89	60.79	452.50	1531.81	366.2	164.60	1.02	0.25	46.56
209	5.33	0.08	1.84	30.10	341.80	1954.70	381.5	156.68	0.99	0.49	35.57
210	5.34	0.11	2.05	38.30	593.25	1620.52	346.7	164.24	0.86	2.18	53.65
301	5.28	0.09	1.94	35.72	437.95	2532.82	529.1	178.55	0.90	0.72	41.32
302	5.42	0.07	1.98	31.04	533.30	1679.99	343.2	183.68	0.93	0.49	39.60
303	5.52	0.07	1.92	68.28	335.70	1823.78	377.7	172.79	0.86	0.05	40.84
304	5.93	0.08	1.84	37.60	301.25	1913.61	421.9	200.51	0.95	0.05	36.47
305	5.24	0.07	1.86	36.43	288.80	1606.00	339.1	193.89	1.12	0.39	43.72
306	5.07	0.10	2.01	53.76	662.85	1494.71	289	203.34	0.31	0.88	52.15
307	5.10	0.09	1.98	31.04	452.50	1498.19	319.2	204.83	0.89	1.42	50.53
308	5.12	0.08	1.93	67.00	409.65	1843.20	498.15	177.00	0.92	0.80	40.00
309	5.38	0.08	1.88	27.76	350.45	1920.15	382	167.79	0.87	0.54	38.15
310	5.21	0.10	1.98	43.69	568.45	1659.76	388.2	176.21	0.76	1.96	51.16

Sub layer (5-20 cm)

Plot nr	pH	CE	N	P	K	Ca	Mg	Fe	Cu	Zn	Mn
		dS m⁻¹	(g/kg)	(mg/kg)							
101	5.59	0.09	1.63	25.42	263.30	1763.59	434.10	144.12	0.98	1.85	30.37
102	5.84	0.08	1.58	19.00	388.95	1863.68	425.25	130.00	1.03	0.10	19.63
103	5.54	0.08	1.69	25.42	236.80	1900.43	454.50	148.49	0.97	0.28	23.80
104	5.26	0.09	1.56	34.32	188.80	1777.90	393.00	160.77	1.14	0.05	28.08
105	5.55	0.08	1.54	21.38	237.65	1925.16	488.80	135.26	1.05	0.24	20.01
106	5.13	0.08	1.61	31.97	385.30	1601.20	288.50	179.67	1.03	0.50	36.40
107	5.77	0.08	1.34	19.56	232.30	1917.80	588.30	118.97	0.76	0.76	19.44
108	5.45	0.07	1.55	29.16	244.75	2134.36	524.70	146.87	1.10	0.67	27.18
109	5.70	0.07	1.65	10.66	209.05	2167.77	392.10	128.37	0.89	0.09	16.98
110	5.14	0.09	1.66	28.23	345.45	1617.76	293.40	153.30	0.89	0.05	35.55
201	5.30	0.09	1.82	31.97	323.50	1857.00	398.40	167.03	0.95	5.05	30.50
202	5.60	0.06	1.68	14.41	344.05	1993.12	472.50	150.42	0.86	0.05	17.12
203	5.58	0.07	1.69	16.05	270.30	1922.10	484.60	149.97	0.91	0.05	20.26
204	5.30	0.10	1.68	27.99	178.15	1858.43	410.80	165.95	0.95	0.05	26.02
205	5.52	0.07	0.61	15.11	242.55	1876.11	480.50	132.29	0.84	0.49	19.40
206	5.13	0.07	1.60	23.00	379.10	1740.80	352.35	152.49	1.20	0.07	37.15
207	5.56	0.07	1.46	12.89	191.15	1781.78	536.50	124.55	0.79	0.19	21.32
208	5.42	0.08	1.49	19.02	213.60	2022.25	481.60	136.47	0.86	0.05	24.87
209	5.82	0.09	1.36	11.72	151.45	2460.46	561.80	113.70	0.86	0.16	17.74
210	5.39	0.07	1.42	22.80	225.80	1921.99	372.70	140.34	0.72	2.19	25.77
301	5.19	0.10	1.77	34.11	286.75	1883.47	381.90	158.39	0.95	1.00	32.95
302	5.53	0.08	1.76	19.97	289.15	2295.62	460.60	148.31	1.00	0.92	20.50
303	5.61	0.08	1.69	20.67	213.20	2010.09	482.50	154.25	0.88	0.38	26.76
304	5.37	0.09	1.48	21.85	129.85	1969.92	450.90	152.54	1.11	0.77	24.73
305	5.50	0.07	1.42	18.55	172.20	2102.37	473.60	144.62	1.05	0.05	20.21
306	4.98	0.09	1.58	42.36	284.20	1820.51	317.90	180.44	0.97	2.01	38.16
307	5.50	0.07	1.55	22.80	199.05	2191.89	561.20	167.88	0.85	0.67	20.93
308	5.03	0.07	1.52	31.52	207.20	1724.76	362.70	176.43	1.04	0.69	36.87
309	5.56	0.07	1.45	13.84	88.20	2240.95	475.90	132.60	0.90	0.65	18.90
310	5.15	0.09	1.47	25.00	339.30	1658.88	388.80	146.00	0.80	0.30	35.00

Appendix 2 Data organic N, Total C, MWD and TTP

Top layer (0-5 cm)

Plot nr	Organic N		C	MWD sieving		Time to
	NO$_3^-$	NH$_4^+$		dry	wet	pond
	mg/kg		(g/kg)	(mm)		(s)
101	6.40	13.40	22.34	3.78	0.96	3.81
102	2.23	6.22	23.79	3.60	1.72	11.37
103	7.93	11.97	23.12	3.86	1.27	5.89
104	2.09	6.22	21.81	4.06	1.08	16.41
105	1.67	15.80	25.59	3.77	1.42	22.32
106	2.36	17.23	25.68	3.80	1.58	22.03
107	2.09	12.45	25.74	3.70	1.48	5.52
108	5.42	11.01	24.76	3.62	1.38	17.00
109	0.68	11.67	26.03	3.60	1.60	9.83
110	2.29	7.90	27.79	4.11	1.81	14.89
201	1.18	4.07	23.16	4.61	1.41	3.81
202	3.96	13.64	25.02	3.98	2.13	8.71
203	3.16	10.89	23.65	4.19	2.00	5.52
204	2.49	5.45	22.14	3.83	0.83	15.39
205	2.64	14.84	23.75	3.76	1.66	18.06
206	2.50	3.83	24.63	3.70	1.65	28.28
207	3.34	16.28	24.97	3.58	1.47	7.20
208	2.09	2.39	25.72	3.11	1.40	24.66
209	1.25	0.96	22.54	3.39	1.01	13.26
210	0.83	0.08	25.31	4.05	1.41	9.18
301	2.50	0.08	24.08	3.92	1.24	3.81
302	1.25	1.44	25.01	3.99	1.74	12.83
303	2.23	6.70	24.27	4.19	1.71	5.15
304	1.25	2.87	22.4	4.29	0.82	37.90
305	2.36	6.22	22.98	4.04	1.63	14.13
306	1.95	4.79	25.65	3.97	1.66	27.41
307	0.45	12.45	26.68	3.86	1.44	5.50
308	2.64	8.38	24.19	3.46	1.40	19.53
309	4.17	9.81	23.02	4.23	1.04	9.04
310	3.20	8.38	25.31	3.86	1.74	11.87

Sub layer (5-20 cm)

Plot nr	NO_3^-	NH_4^+	C
	N		
	(mg/kg)		(g/kg)
101	3.06	4.67	20.08
102	0.01	0.04	19.35
103	2.36	6.94	20.09
104	1.67	2.63	20.23
105	3.06	4.55	18.88
106	1.53	2.63	20.21
107	1.25	3.59	18.88
108	1.67	2.15	18.88
109	0.70	1.68	19.55
110	2.09	5.03	19.57
201	1.11	0.04	19.43
202	0.01	0.04	17.84
203	0.56	0.04	17.97
204	3.06	3.83	21.02
205	2.94	1.56	19.07
206	0.01	0.04	20.02
207	1.81	1.44	18.45
208	0.42	0.04	18.93
209	3.34	5.27	18.33
210	1.39	0.96	18.75
301	2.23	6.70	19.32
302	0.83	4.79	17.76
303	0.28	1.44	17.98
304	1.95	3.35	20.73
305	0.01	1.44	18.55
306	0.28	0.96	19.91
307	0.28	0.04	18.98
308	0.01	0.04	18.98
309	0.01	0.04	17.79
310	0.01	0.48	18.98