Disc harrowing intensity and its impact on soil properties and plant growth of agropastoral systems in the Llanos of Colombia

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Abstract

Oxisols such as those of the Colombian Eastern Plains (Llanos) are susceptible to physical, chemical and biological degradation once brought into cultivation, especially under intensive use of machinery. The main objective of this study was to determine the impact of intensive disc harrowing (2, 4 or 8 disc harrow passes per year over 3 years) on soil physical and chemical properties, soil phosphorus dynamics, plant growth and nutrient acquisition of contrasting agropastoral systems on an Oxisol. The three main systems tested after 2 years of upland rice cultivation were grass alone pasture (*Brachiaria dictyoneura*), green manure (*Crotalaria juncea*), and maize (*Zea mays*). Native savanna treatment was used as a control. Intensive disc harrowing improved macroporosity values of 0-5 cm soil layer up to 59 % for grass alone pasture system compared to native savanna. Disc harrowing significantly reduced bulk densities for pasture and green manure systems compared to the native savanna in the 0-5 cm soil layer. Intensive disc harrowing significantly improved volumetric moisture content of green manure and maize systems at 5-10 cm soil depth. The distribution of biologically, moderately and sparingly available P, organic P and total P varied under green manure, maize and grass alone pasture systems. Two passes of disc harrow per year were sufficient for grass alone pasture while maize showed greater aboveground production and nutrient acquisition at 8 passes of disc harrow per year. The maize and green manure cropping systems were better than the grass alone pasture system at separating the effect of increased number of disc harrow passes on soil physical and chemical characteristics.

Key words: Disc harrowing intensity; Oxisols; Crop-pasture systems; Soil porosity; Phosphorus pools; Nutrient acquisition; Tropical savannas

1. Introduction

Oxisols cover a major proportion of the land in the tropical savannas of Latin America that comprise 243 million hectares (Mha). These extensive savannas comprise the second largest biome of South America and one of the world’s most rapidly expanding agricultural frontiers

(Thomas and Ayarza, 1999). Production on these soils is expected to increase considerably in the near future. The sustainable management of these soils is therefore of high ecological and socioeconomic significance. Production systems in the most intensified areas of the savanna are characterized by continuous monocropping and continuous tillage with heavy machinery. While these systems are economically profitable, they result in soil erosion, compaction, reduced microbiological activity, declining quality of organic matter and deterioration of other soil physical properties (Thomas and Ayarza, 1999). These soils are more susceptible to degradation than most soils, often degrading within 5 years of being opened up for agricultural production.

The tropical savanna covers an area of 20 Mha in the 'Llanos' of Colombia. Soils in the 'Llanos' are characterized as highly acidic and infertile Oxisols and Ultisols, whose mineralogy is dominated by kaolinite and the oxides and hydrous oxides of iron and aluminum. Oxisols have a stable microstructure caused by strong aggregation of negatively charged kaolinite and positively charged gibbsite and goethite (Bartoli et al., 1992). However, these soils are susceptible to physical, chemical, and biological degradation once brought into cultivation (Amézquita, 1998).

Tillage practices with heavy machinery physically break macroaggregates into smaller units, leading to new surfaces. These changes in soil structure act on the pore-size distribution and thus influence drainage or plant-available water content. Pore-size distribution is one sensitive soil physical property that can be used to evaluate the influence of tillage on the physical condition of the soil because it regulates the rate of water entry into the soil. It also influences soil water fluxes, which affect plant nutrient availability and plant growth. Three important phenomena related to plant nutrition, which are negatively affected by reduction in macropores are: root growth, nutrient interception by roots, and soil drainage and aeration (Preciado et al., 1998). Soil porosity of below 10 % will generally limit crop and pasture production. Reduced water infiltration encourages surface water run-off and, consequently, soil and plant nutrient losses brought about by soil erosion (Goedert, 1983).

Phosphorus (P), which has a low mobility, particularly in Oxisols, is likely to be greatly affected by tillage practice. Soil disturbance during tillage operations may increase the degree of contact between fertilizer-derived P and soil particles, thereby, promoting the formation of stable insoluble P compounds (Shear and Moschler, 1969; Muzilli, 1983). Oxisols of the 'Llanos' are characterized by low total and available P contents, and a relatively high P retention capacity (Friesen et al., 1997). Phosphorus deficiency often limits crop and pasture productivity in these soils and is caused mainly by strong sorption of inorganic P (P_i) to Al and Fe oxyhydroxides. The bioavailability of these secondary Al and Fe phosphates is considered to be low because of specific adsorption caused by ligand exchange (Goldberg and Sposito, 1985). Knowledge on phosphorus cycling in these soils is limited. In the past, only readily available P was determined which may not effectively reflect plant-available P. This is because organic P (P_o) fractions are believed to contribute proportionately more with increasing P deficiency (Stewart and Tiessen, 1987; Beck and Sánchez, 1994).

Soil compaction also hinders extensive root growth and reduces the soil volume from which plants can obtain P. Continuous cropping of a native soil also disrupts the peds ($\varnothing > 2$ mm), leading to loss of organic carbon and associated nutrients such as P (Tisdall and Oades, 1982). This implies that land preparation practices should be planned by taking into account the drastic reduction in soil aggregate size brought about by excessive use of machinery and it's resultant negative effect on physical, chemical and biological properties of the soil. A highly successful strategy for intensifying agricultural production sustainably and reversing problems of degradation involves the integration of crop/livestock systems, generally known as agropastoral systems (Thomas et al., 1995).

In 1995 a field experiment was established in the 'Llanos' of Colombia to develop adequate soil tillage practices that could enhance the performance of agropastoral systems by improving plant growth, nutrient acquisition and nutrient cycling while minimizing the risk of soil degradation. The main objective of the present study was to determine the impact of intensive disc harrowing on: (i) soil physical and chemical properties; (ii) soil phosphorus dynamics; and (iii) plant growth and nutrient acquisition by contrasting agropastoral systems.

2. Materials and methods

2.1. Site description and experimental design

The experiment was carried out at Matazul farm (4º 9′ 4.9″ N, 72º 38′ 23″ W and 260 m.a.s.l.) located in the Eastern Plains (Llanos) near Puerto Lopez, Colombia. The area has two distinct climatic seasons, a wet season from the beginning of March to December and a dry season from December to the first week of March and has an annual average temperature of 26.2 ºC. The area has mean annual rainfall of 2719 mm, potential evapotranspiration of 1623 mm and relative humidity of 81 % (data from the nearby Santa Rosa weather station, located at the Piedmont of the Llanos of Colombia). Prior to treatment application, the area was under a native savanna pasture consisting of native grasses. The land is generally flat (slope < 5 %), the soil is deep, well structured and has a textural distribution in the first 10 cm of about 40 % clay, 30 % silt and 30 % sand (loam texture) (Gijsman et al., 1997). The bulk density in the native savanna is 1.30 g cm^{-3} in the top 0-5 cm soil layer, followed by lower values of 1.27 and 1.23 g cm^{-3} at the 5-10 and 10-20 cm soil layers, respectively (Amézquita et al., 1998). The soil has low fertility and the availability of P in the soil is low because of the soil's high P fixation capacity. The soil is classified as Isohyperthermic Kaolinitic Typic Haplustox in the USDA soil classification system (Soil Survey Staff, 1998).

The native savanna pasture (unimproved grassland) was opened in the third week of April 1995 and upland rice (cv. Oryzica Sabana-6) was planted with different intensities of tillage (2, 4 or 8 disc harrow passes) to a depth of 8 to 10 cm. Each tillage treatment had a plot size of 54 x 20 m. These treatments continued for 2 years with upland rice cultivation. At the beginning of the third year (third week of April 1997), each tillage main plot was used to introduce the following 3 cropping systems: (i) Grass alone pasture (*Brachiaria dictyoneura* CIAT 6133 cv. Llanero), (ii) Green manure (*Crotalaria juncea* cv. Common), and (ii) Maize (*Zea mays* cv. Sikuani 110). Native savanna was also included as a control to study changes in the soil conditions without tillage.

The treatments were arranged in a split-plot design (tillage intensity as main plots and cropping systems as sub-plots) and replicated four times. The size of each main plot was 42 x 10 m and sub-plot was 10 x 10 m leaving a border of 6 m between plots. Dolomitic lime (28% Ca and 10% Mg) was applied (Mg ha^{-1}) 1.0 for maize, 0.5 for Crotalaria and 0.5 for grass-alone pasture. Maize received (kg ha^{-1}) 80 N as urea; 50 P as TSP; 100 K as KCl; 8 Zn as $ZnSO_4$; 4 S as $ZnSO_4$; and 9 B as borax. Crotalaria received 22.5 N; 40P and 50 K. Grass-alone pasture received 20 P, 45 K and 4 Zn. Native savanna treatment received no fertilizer application as commonly practiced by farmers in the region.

2.2. Soil and plant sampling and analytical procedures

In the last week of June 1997 (2 months after establishment of agropastoral systems), soil samples from different agropastoral systems including native savanna were collected. The pore-size distribution was determined from the moisture characteristic curves (Amézquita, 1981). Undisturbed soil cores (50 x 25 mm) in four replicates per depth in each treatment were taken from: 0-5, 5-10 and 10-20 cm soil layers. Saturated soil cores were weighed and then subjected to different suctions (5, 10, 100, 300 and 1500 KPa). Pore-size distribution was calculated using Kelvin Equation (Greenland, 1979). Pores were divided into macropores (> 50 μm; drained at a suction of less than or equal to 6 KPa), mesopores (50 to 0.2 μm; water retained between 6 – 1500 KPa), and micropores (< 0.2 μm; water retained over 1500 KPa) (Roth et al., 1988). A composite soil sample, consisting of 50 cores, was also collected in a grid pattern from the whole plot. These samples were air-dried, and then visible plant roots were removed before they were gently crushed to pass through a 2-mm sieve. The < 2-mm fraction was used for subsequent chemical analysis. Other measurements that were made included: bulk density (Amézquita, 1998), soil nutrient availability (Salinas and Garcia, 1985), shoot biomass, plant nutrient composition, and shoot nutrient uptake (Rao et al., 1996).

2.3. Phosphorus fractionation and analysis

A shortened and modified sequential P fractionation procedure of Tiessen and Moir (1993) was used on 0.5-g sieved (< 2-mm) soil sample. In brief, a sequence of extractants with increasing strength was applied to subdivide the total soil-P into inorganic (P_i) and organic (P_o) fractions (Oberson et al., 1999; Phiri et al., 2001). The following fractions were determined. (1) resin P_i, anion exchange resin membranes (in bicarbonate form) were used to extract freely exchangeable P_i. The remaining P_o in the H_2O of the resin extraction step was digested with potassium persulfate ($K_2S_2O_8$). (2) Sodium bicarbonate (0.5 *M* $NaHCO_3$, pH = 8.5) was then used to remove labile P_i and P_o sorbed to the soil surface, plus a small amount of microbial P. (3) Sodium hydroxide (0.1 *M* NaOH) was next used to remove P_i, which is more strongly bound to Fe and Al compounds and associated with humic compounds. (4) The residue containing insoluble P_i and more stable P_o forms (‘residual P’) was digested with perchloric acid ($HClO_4$). To determine total P in the $NaHCO_3$ and NaOH extracts, an aliquot of the extracts was digested with $K_2S_2O_8$ in H_2SO_4 at >150 °C to oxidize organic matter. Organic P was calculated as the difference between total-P and P_i in the $NaHCO_3$ and NaOH extracts, respectively. Inorganic P concentrations in all the digests and extracts were measured calorimetrically by the molybdate-ascorbic acid method (Murphy and Riley, 1962). All laboratory analyses were conducted in duplicate determinations and the results are expressed on an oven-dry weight basis.

2.4. Statistical analysis

Analyses of variances were conducted (SAS/STAT, 1990) to determine the significance of the effects of the planted fallows and the crop rotation system on soil parameters. Planned F ratio was calculated as TMS/EMS, where TMS is the treatment mean square and EMS is the error mean square (Mead et al., 1993). Where significant F-values (at the 5 % level) occurred, mean separation was performed. Unless otherwise stated, mention of statistical significance refers to $P < 0.05$.

3. Results

3.1. Soil properties

Changes in total porosity and macroporosity as influenced by the intensity of disc harrowing are shown in Fig. 1. Intensive disc harrowing improved macroporosity values of 0-5 cm soil layer up to 59 % for grass alone pasture system compared to native savanna. In general, disc harrowing improved macroporosity values of different agropastoral systems compared to native savanna. Intensive disc harrowing (8 passes per year) increased macroporosity values of 0-5 and 10-20 cm soil depth layers of the maize system. In the 0-5 cm soil layer, macroporosity was significantly affected by disc harrowing for green manure system while those were not affected for grass alone pasture system. Similar results were observed for 5-10 cm soil depth. At 10-20 cm soil depth, while total porosity was not affected by the intensity of disc harrowing for each system, macroporosity significantly increased for pasture system. Mesoporosity and microporosity values were not much affected by the intensity of disc harrowing for different agropastoral systems (results not shown).

Results on the influence of the number of disc harrow passes on soil bulk density are shown in Table 1. One important aspect to note with regards to bulk density in native savanna is the presence of a high value (1.26 $g.cm^{-3}$) in the 0-5 cm soil layer. Disc harrowing at 2, 4, and 8 passes per year significantly reduced bulk densities for pasture compared to the native savanna in the 0-5 cm soil layer (Table 1). Bulk density values were relatively unaffected by disc harrowing intensity for the green manure and maize systems. For 5 to 10 cm soil depth, disc harrowing resulted in a small decrease of bulk density for pasture system. Intensive disc harrowing (8 passes per year) significantly increased bulk density values of the green manure system at 5-10 cm soil depth. Volumetric moisture content values of the native savanna system were greater than those of the other systems at 0-5 cm soil depth (Table 1). Intensive disc harrowing (8 passes per year) significantly improved volumetric moisture content of green manure and maize systems at 5-10 cm soil depth compared with 2 passes per year. Grass alone pasture system showed no marked changes in volumetric moisture content across soil layers.

Soil chemical characteristics at different soil depth layers as influenced by the intensity of disc harrowing and agropastoral systems are shown in Table 2. Native savanna system without tillage and fertilizer application has shown low values of soil pH, available P and exgangeable K, Ca and Mg. The amount of available P (Bray II) decreased sharply below the 5-10 cm soil layer under all the systems tested. The amount of P was largest under the green manure and this was followed by the maize treatment (Table 2). At the 0-5 and 5-10 cm soil layers under the green manure and the maize cropping systems, the amount of P increased as the number of disc harrow passes per year were increased. However, for the maize treatment this increase was significant only at the 5-10 cm soil layer (Table 2). The grass alone pasture had the least amount of P and was, on average, 56 % lower at the 0-5 cm soil layer than the green manure treatment, which had the largest amount. The largest amount of exchangeable K was observed under the maize treatment and the second largest amount was observed under the green manure treatment. Most of K was found at the 0.5 cm soil layer in all the cropping systems and decreased rapidly after this soil layer, especially in the grass alone pasture system. Under the maize and grass alone pasture systems, the amount of K tended to decrease as the number of disc harrow passes were increased from 2, 4 to 8 per year (Table 2). The amounts of exchangeable Ca and Mg were largest in the maize treatment followed by the green manure cropping system. The number of disc harrow passes did not significantly affect the amount of Ca or Mg at all soil layers under the grass alone pasture and the green manure cropping systems. The amount of exchangeable Al was larger under the grass alone pasture compared to the green manure or the maize cropping system and it was not significantly affected by the number of disc harrow passes.

3.2. Soil P pools

The amount of extractable biologically available P was generally concentrated in the 0-5 and 5-10 cm soil layers and differed with the cropping system used (Fig. 2). The largest amount of this fraction was obtained under the green manure followed by maize and then grass alone pasture cropping system, which, on average, represented respectively 19 %, 13 %

and 12 % of the total P at the 0-5 cm soil layer. However, this fraction showed decreasing trend with increasing soil depth under all three systems at 2, 4, and 8 disc harrow passes per year (Fig. 2). Eight disc harrow passes per year resulted in the highest amount of biologically available P under green manure and maize at the 0-5 and 5-10 cm soil layers. The high amount of available P at 8 disc harrow passes per year resulted in high P uptake of maize under this treatment (Table 3). Under grass alone pasture the biologically available P was less affected by tillage practices than under the green manure and maize cropping systems. The biologically available P under the grass alone pasture treatment was affected significantly by number of disc harrow passes only at the 0-5 cm soil layer, where 2 disc harrow passes per year had the largest amount. The number of disc harrow passes had little effect on the biologically available P at the 20-40 cm soil layer (Fig. 2), and the amount was the same under all three cropping systems.

Similar to the biologically available P, moderately available P also showed different trends under green manure, maize and grass alone pasture and decreased with increasing soil depth. This fraction accounted for 37, 34 and 30 % of the total P for green manure, maize and grass pasture, respectively. Thirty-three, 45 and 49 % of the extracted NaOH-P_t was in the organic fraction (NaOH-P_o) for green manure, maize and grass pasture, respectively, at the 0-5 cm soil layer (results not shown). The number of disc harrow passes resulted in larger differences of moderately available P at the 0-5, 5-10 and 10-20 cm soil layers under the green manure followed by the maize cropping system. Under the grass alone pasture treatment, the number of disc harrow passes had little effect on moderately available P for all soil layers (Fig. 2). Under the green manure the largest amount of the moderately available P was obtained when 8 disc harrow passes per year were used followed by 2 disc harrow passes per year at the 0-5 cm soil layer. Under maize, on average, the largest amount of moderately available P was obtained with 8 disc harrow passes per year (Fig. 2).

The largest amount of P was obtained in sparingly available P fraction and, on average, accounted for 46 %, 51 % and 57 % of the total P for the green manure, maize and grass alone pasture cropping systems, respectively, for all soil layers. The largest amount of the sparingly available P was extracted at 8 disc harrow passes per year (Fig. 2). However, this fraction was highly variable under the green manure treatment and was not significantly affected by disc harrowing. Treatment effects were better separated under maize than under the grass alone pasture system (Fig. 2).

The sum of organic P (Sum-P_o) was quite stable through out the profile with a small decrease in the amount with increasing soil depth (Fig. 2). The amount of H_2O-P_o, $NaHCO_3$-

P_o and NaOH-P_o were uniform throughout the soil profile and under all cropping systems and were 3-5, 17-23, and 73-78 % of the Sum-P_o, respectively. Treatment effects on Sum-P_o were more pronounced at the 0-5 and 5-10 cm soil layers. Under green manure the largest amount of Sum-P_o was obtained at 2 disc harrow passes per year under green manure and at 4 disc harrow passes per year under maize at the 0-5 cm soil layer. The Sum-P_o profile distribution was uniform under grass alone pasture with no significant differences among the intensity of disc harrow treatments.

3.3. Plant growth and nutrient acquisition

The effects of the intensity of disc harrowing on leaf biomass, stem biomass and total shoot biomass production and nutrient uptake of different agropastoral systems are shown in Table 3. Two passes of disc harrow per year (6 passes in 3 years) are sufficient for best performance of grass alone pasture in terms of both biomass production and nutrient acquisition. Additional disc harrowing resulted in a decreased leaf biomass production and reduced nutrient uptake (Table 3). Maize showed greater leaf biomass production and nutrient acquisition with 8 passes of disc harrow per year (Table 3). The green manure cropping system had greater leaf biomass production and nutrient acquisition, particularly Ca, with 4 disc harrow passes per year.

4. Discussion

Land preparation by machinery leads to a constant breakdown and reduction in soil aggregate size. The action of rainfall and gravity results in a re-packing of these aggregates and, consequently, the total soil porosity and pore-sizes are reduced. The resulting changes in macroporosity affect water flow, which in turn affects nutrient availability and thus impact negatively on the productive capacity of the soil (Preciado et al., 1998). Our results on macroporosity are in contrast to the results of Roth et al. (1988) who detected reduced macroporosity with conventional tillage compared to no-tillage to an Oxisol in southern Brazil. The difference between the two studies could be due to the fact that the native savanna was never subjected to tillage whereas the no-tillage treatment used by Roth et al. (1988) was applied to previously conventionally tilled plots. Considering the low pore space at plant-available matrix potentials in Oxisols (Bartoli et al., 1992), the low amount of mesopores could make the soil prone to drought during dry spells in the rainy season. But we found no marked changes in mesopores of different agropastoral systems.

Neufeldt et al. (1999) found that microporosity was unaffected by tillage practices. Curmi et al. (1994) found that compaction had no effect on intra-aggregate pores of <1 µm diameter because their number is determined only by soil mineralogy (Bui et al., 1989). Our results are consistent with these observations. Results on total porosity suggest that the real rooting depth promoted by tillage was limited only down to 10 cm soil depth. Results on porosity also indicate that tillage of savanna soils could increase the volume of desired pore sizes (macropores) especially in the 0-10 cm soil depth. Good tillage practices that stimulate root growth could also contribute to better soil conditions (Amézquita et al., 1999).

Bulk density values of the native savanna soils suggest that the surface layer, which regulates the entry of water and the flux of air into the profile, exhibits less total porosity than the other layers. Therefore, for crop and pasture production, this constraint at topsoil depth must be alleviated by adequate tillage practices that maintain lower values of bulk density and reduce the risk of soil compaction. Disc harrowing significantly reduced bulk density values of the pasture system compared to the native savanna. Below 10 cm of soil depth, disc harrowing had relatively small effects on different agropastoral systems. This implies that disc harrowing reduced bulk density in the vicinity of the action of discs. Improvement in volumetric moisture content in the 5-10 cm soil layer with intensive disc harrowing observed with green manure and maize systems might have contributed to superior leaf growth and nutrient acquisition.

Although separating total P into seven fractions helps to elucidate the differences in size of various P fractions, the P fractions are of greater practical value when divided into fewer functional pools of similar availability with management implications. These pools can then be used to improve soil P management and serve as decision-making tools (Yost et al., 1992). In this study the P fractions are divided into three groups using a criterion similar to that described before (Bowman and Cole, 1978; Tiessen et al., 1984; Phiri et al., 2001). The three groups were: (1) biologically available P; (2) moderately available P; and (3) sparingly available P.

The biologically available P pool (H_2O-P_o, resin-P_i, and $NaHCO_3$-P_i and -P_o) is the first to be removed by plant roots and mycorrhizal fungi from the soil and is considered to be available to plants in a short time (from days to a few weeks) (Cross and Schlesinger, 1995). The resin P_i is 'readily available' for plant uptake. The bicarbonate-P_i is highly related to P uptake by plants. The H_2O-P_o and bicarbonate-P_o are considered 'readily mineralizable' and highly related to P uptake by plants. A close relationship between resin P_i and P_o on weathered soils was observed by Tiessen et al. (1984). The major component of labile P_o is a diester PO_4 (Tiessen et al., 1984), which prevents it from binding strongly to soil minerals and makes it susceptible to rapid mineralization.

The amount of biologically available P was markedly greater with the green manure treatment followed by maize and grass alone pasture system. Eight disc harrow passes per year resulted in the highest amount of biologically available P under green manure and maize that could contribute to high uptake of P by maize. Under grass alone pasture the biologically available P was less affected by tillage practices than under the green manure and maize systems. This could be explained by the fact that only the soil within the vicinity of the disc harrow action (0-20 cm) was disturbed.

Moderately available P pool consists of NaOH extractable Pi and P_o, which is assumed to be plant available for the medium term, i.e., from months to a few years (Tiessen et al., 1984; Wager et al., 1986; Beck and Sánchez, 1994). This fraction denotes the soil P reserve that is plant available when converted to readily available P through biological and physico-chemical transformations (Cross and Schlesinger, 1995). This fraction is thought to be associated with humic compounds, and with amorphous and some crystalline Al and Fe phosphates (Bowman and Cole, 1978). The sodium hydroxide (0.1 *M*, pH = 8.5) used to extract moderately available P is known to completely solubilize the synthetic iron and aluminium phosphate and labile-P_o. Similar to the biologically available P, moderately available P also showed different trends under green manure, maize and grass alone pasture and decreased with increasing soil depth. Since the moderately available P is plant available in the medium term as outlined above, the high amount of this fraction at 8 disc harrow passes per year also could have contributed to the high P uptake of maize.

Sparingly available P as used in this study is different from the residual P as defined by Hedley et al. (1982), because it includes the HCl and the hot concentrated HCl fractions. The sparingly available P contains insoluble P_i and more stable P_o forms and is not available on a short time scale such as one or more crop cycles. However, a small fraction of this pool may become available during long-term soil P transformations. The largest amount of the sparingly available P was extracted at 8 disc harrow passes per year and treatment effects were better separated under maize than under the grass alone pasture system.

Since P loss from systems occurs mainly through processes in the soil, minimizing P interaction with soil is an important management tool for increasing P cycling (Friesen et al., 1997). Phosphorus maintained in organic pools may be better protected from loss through fixation than P flowing through inorganic pools in soil. Orthophosphate monoesters fractions dominate the P_o fraction and are less easily hydrolyzable, and thus less plant available, than the orthophosphate diester fraction (Condron et al., 1990; Forster and Zech, 1993). Systems that retain more of P_o are expected to cycle P better. We found that the sum of organic P (Sum-P_o) was quite stable through out the profile with a small decrease in the amount with increasing soil depth. This shows that 24 % of the total soil organic P (Sum-P_o) is in the 'easily mineralisable' form and can contribute to plant available P (Bowman and Cole, 1978), and the remaining 76 % is in more stable forms of P_o that are involved in the long term transformation of P.

Two passes of disc harrow per year (6 passes in 3 years) were found to be sufficient for best performance of grass alone pasture. Additional disc harrowing resulted in a decreased shoot biomass production and reduced nutrient uptake. A high number of disc harrow passes is likely to create a marked reduction in soil pore volume (Amézquita et al., 1998) and affect nutrient uptake by plants. In a greenhouse experiment, Meléndez et al. (1998) found that *Brachiaria* grass growth and N uptake were greatly influenced by the size of soil aggregates. They found that N uptake from soil was a function of aggregate size, indicating that any excess preparation of soil could negatively affect the uptake of this nutrient. It is possible that excessive tillage might have reduced moisture content in the upper soil layer that could decrease the ability to acquire nutrients by the introduced pasture grass.

Soil organic matter is an important component of Oxisols because it carries the majority of exchange sites and also participates in the formation of stable microaggregates and controls the degree of clay dispersion (Neufeldt, 1999). More than two disc harrow passes per year for the grass alone pasture treatment could decrease the amount of soil organic matter. This is because of the physical breakdown of aggregates during ploughing and the subsequent higher organic carbon mineralization, which may have resulted in N and P losses through leaching and fixation by soil, respectively. This could have resulted in reduced nutrient uptake, particularly N, and thereby growth of the pasture.

Maize showed greater aboveground production and nutrient acquisition with 8 passes of disc harrow per year. This result, especially for maize, is unexpected considering the negative attributes of reduced soil moisture content and soil compaction resulting from increased disc harrowing, as mentioned earlier. The better performance of maize under intensive cultivation (8 disc harrow passes) could be attributed to improved rooting ability that contributed to greater acquisition of nutrients. The improved amounts of biologically and moderately available P obtained from 8 disc harrow passes could have contributed to the good performance of maize. Previous research showed that maize is a very shallow rooted crop compared to native and introduced pasture species (Friesen et al., 1997). Since the mobility of P in soil is low, high levels of biologically available P can benefit shallow-rooted crops. In contrast to the maize system, the green manure cropping system had higher yields with 2 disc harrow passes per year that resulted in greater nutrient (N, P, Ca and Mg) acquisition.

5. Conclusions

The results of this study showed that disc harrowing could reduce bulk density and improve total porosity and macroporosity, volumetric moisture content, and soil P availability in the topsoil layer of P-fixing Oxisols. However the impact of intensive disc harrowing (4 or 8 passes per year) on soil physical and chemical properties was dependent on the agropastoral system used. The maize and green manure cropping systems were better than the grass alone pasture system at separating the effect of increased number of disc harrow passes on soil physical and chemical characteristics.

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Figure captions

Fig. 1. Changes in total porosity and macroporosity at different soil depth layers as affected by the intensity of disc harrowing and agropastoral systems. LSD values at 0.05 probability level. NS = not significant. The 0 number of paases represent the native savanna system.

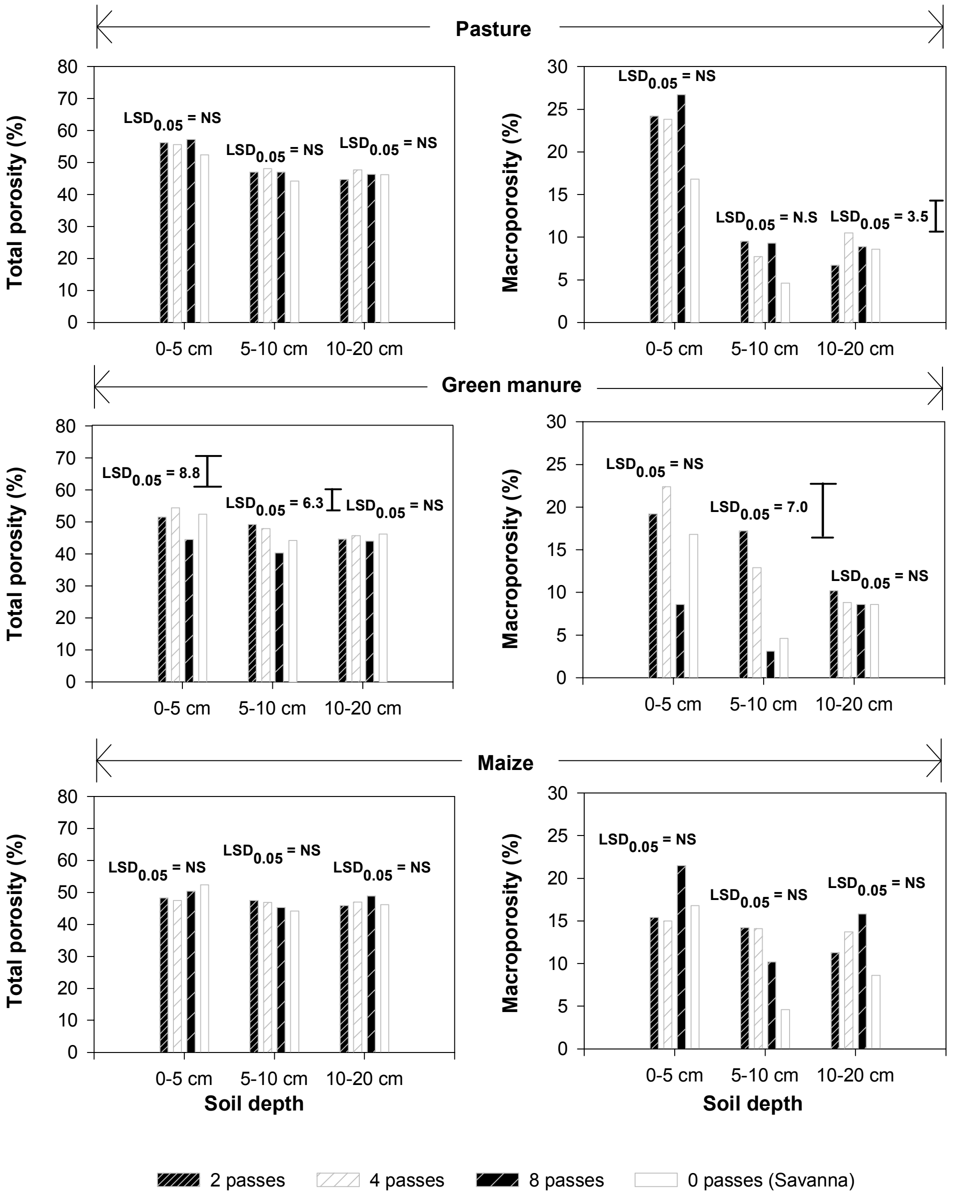

Fig. 2. Soil profile distribution of the P fractions as affected by intensity of disc harrowing under the grass alone pasure, green manure and maize cropping systems.

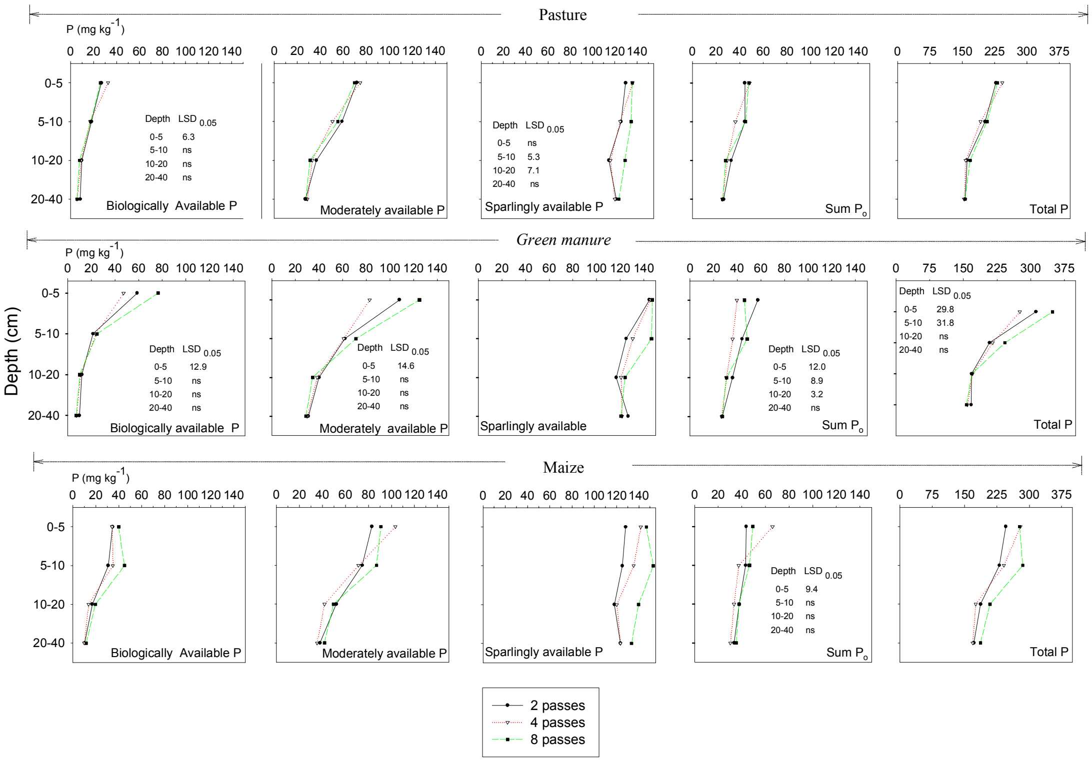

Table 1
Changes in bulk density (g cm $^{-3}$) and volumetric moisture content (%) at different soil depths as influenced by the intensity of disc harrowing and agropastoral systems. LSD values are at the 0.05 probability level. NS = not significant

Soil depth (cm)	Number of disc harrow passes per year	Native savanna	Agropastoral system			$LSD_{0.05}$
			Pasture	Green manure	Maize	
			Bulk density (g cm^{-3})			
0-5	0	1.26				
	2		1.16	1.28	1.37	NS
	4		1.17	1.20	1.39	0.19
	8		1.13	1.47	1.31	0.12
	$LSD_{0.05}$		NS	0.23	NS	
5-10	0	1.48				
	2		1.40	1.34	1.39	NS
	4		1.37	1.37	1.41	NS
	8		1.40	1.58	1.44	0.16
	$LSD_{0.05}$		NS	0.16	NS	
10-20	0	1.42				
	2		1.46	1.46	1.43	NS
	4		1.38	1.43	1.40	NS
	8		1.42	1.48	1.35	0.11
	$LSD_{0.05}$		NS	NS	NS	
			Volumetric moisture content (%)			
0-5	0	35.6				
	2		31.9	32.2	32.8	NS
	4		31.7	32.0	32.0	NS
	8		30.5	35.8	30.5	NS
	$LSD_{0.05}$		NS	NS	NS	
5-10	0	39.5				
	2		37.5	32.0	33.3	3.0
	4		40.3	35.0	32.7	5.9
	8		37.7	38.2	35.2	1.5
	$LSD_{0.05}$		NS	2.5	1.3	
10-20	0	37.5				
	2		38.3	34.3	34.5	1.7
	4		37.1	36.9	33.2	2.4
	8		37.4	35.3	33.9	2.7
	$LSD_{0.05}$		NS	2.1	NS	

Table 2
Soil chemical characteristics at different soil depth layers as influenced by the intensity of disc harrowing and agropastoral systems

Soil depth (cm)	Disc harrow passes per year	Soil parameter						
		pH	C	P	K	Ca	Mg	Al
			(%)	(mg kg^{-1})	(cmol kg^{-1} soil)			
				Native savanna				
0-5	0	4.8	1.1	3.2	0.1	0.2	0.2	2.6
5-10	0	5.0	1.3	4.6	0.1	0.4	0.3	2.0
10-20	0	4.9	1.2	1.2	0.04	0.1	0.2	2.2
20-40	0	4.4	1.1	1.3	0.02	0.2	0.2	1.8
				Pasture				
0-5	2	4.9	2.6a	12.0ab	0.15a	0.72	0.46	1.7
	4	4.9	2.0b	15.8a	0.13ab	0.72	0.42	1.7
	8	4.7	2.0b	9.5c	0.10c	0.53	0.36	1.9
5-10	2	4.7ab	2.1	6.0	0.10a	0.48	0.21	1.9
	4	4.8a	1.9	4.6	0.08b	0.55	0.20	2.0
	8	4.6b	1.9	4.3	0.08b	0.57	0.20	2.0
10-20	2	4.6	1.7	1.8	0.06a	0.25	0.13	2.1
	4	4.6	1.5	1.3	0.06a	0.18	0.13	2.1
	8	4.6	1.4	1.3	0.04b	0.25	0.15	2.2
20-40	2	4.7	1.2	1.1	0.06a	0.15	0.12	1.6
	4	4.6	1.1	1.4	0.04b	0.12	0.11	1.7
	8	4.6	1.1	1.0	0.04b	0.13	0.12	1.6
				Green manure				
0-5	2	5.0	2.5a	36.7b	0.16	1.22	0.50	1.3
	4	5.0	1.8b	38.4b	0.15	1.00	0.48	1.4
	8	4.8	1.9b	56.8a	0.12	0.98	0.37	1.7
5-10	2	4.7b	2.0a	6.6b	0.13	0.44	0.30	2.1
	4	4.9a	1.6b	9.3ab	0.09	0.65	0.30	1.9
	8	4.7b	2.0a	10.7a	0.10	0.67	0.31	2.0
10-20	2	4.6b	1.7	2.1a	0.12a	0.23	0.14	2.1
	4	4.8a	1.5	2.1a	0.07b	0.26	0.17	1.9
	8	4.6b	1.5	1.4b	0.07b	0.19	0.15	1.9
20-40	2	4.7	1.3	1.5	0.07a	0.16	0.12	1.8
	4	4.7	0.9	1.0	0.04b	0.16	0.14	1.7
	8	4.6	1.3	1.1	0.05ab	0.15	0.13	1.7
				Maize				
0-5	2	4.8	2.1	20.5	0.26a	0.96	0.45ab	1.1ab
	4	5.1	1.9	21.0	0.22b	1.29	0.56a	0.9b
	8	4.9	1.8	27.0	0.22b	1.01	0.42b	1.5a
5-10	2	4.8	1.9	18.5b	0.15a	0.64	0.30	1.7
	4	4.9	2.0	17.1b	0.11b	0.87	0.37	1.5
	8	4.9	1.8	24.2a	0.15a	0.79	0.35	1.8
10-20	2	4.7	1.8	7.0	0.13a	0.41a	0.22b	2.0ab
	4	4.7	1.3	4.6	0.08b	0.30b	0.20b	1.7b
	8	4.7	1.5	6.4	0.11a	0.43a	0.26a	2.3a
20-40	2	4.6	1.6	2.2ab	0.09a	0.26	0.14	2.1
	4	4.6	1.4	1.3b	0.06b	0.21	0.16	1.8

Table 3
Total shoot biomass production and nutrient uptake by grass alone pasture, *Crotalaria* and maize as influenced by the intensity of disc harrowing

Cropping system	Disk harrow passes per year	Leaves biomass (kg ha^{-1})	Steam biomass (kg ha^{-1})	Total shoot biomass (kg ha^{-1})	Nutrient uptake (kg ha^{-1}) N	P	K	Ca	Mg
Pasture	2 passes	726	1030	1756	19 a	4.7 a	34 ab	3.6	6.0 a
	4 passes	506	1107	1613	17 a	4.8 a	43 a	2.4	4.8 a
	8 passes	415	1079	1494	12 b	2.5 b	28 b	2.0	3.7 b
Green manure	2 passes	5076	1257	6333 b	185 b	18 ab	81	90 b	21 b
	4 passes	6154	1679	7833 a	227 a	20 a	88	135 a	35 a
	8 passes	4923	1091	6014 b	192 b	14 b	70	82 b	22 b
Maize	2 passes	4472 b	1855 b	6327 c	40 b	10 b	65 b	12 b	9 b
	4 passes	5417 b	2049 b	7466 b	54 b	8 b	94 b	18 ab	12 ab
	8 passes	8803 a	3316 a	12119 a	99 a	16 a	141 a	23 a	14 a

Means followed by different letters within a column and within a cropping system are significantly different ($P < 0.05$)
using Duncan's Multiple Range Test.