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Tillage systems and soil properties in Latin America

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ABSTRACT

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A review of tillage systems in Latin America revealed that considerable research on this topic has been done and much is currently in progress. Results of most of this tillage research, however, have not been published in international refereed journals, thus making it difficult to assess the current state of the art on this topic. A high percentage of tillage research results has not been published at all. In general, conservation tillage practices, that is, those commonly referred to as no-till and minimum till, had higher bulk densities in the surface soil, but lower macroporosities, infiltration rates and crop yields as compared with conventional tillage, which was typically disk plowing. Chisel plowing and subsoiling, deep tillage practices whose action extends below the usual depth of disk plowing, usually decreased mechanical impedance, improved root penetration and increased crop yields. Soil loss from cropped land was usually greatest under conventional tillage unless mulch was applied to the soil surface. We believe that some form of tillage practice that mixes the surface soil layer will have to be incorporated from time to time into any tillage system to maintain soil conditions adequate for sustained continuous cropping.

INTRODUCTION

Growing urban populations along with other complex factors have caused a number of developing countries in Latin America, which were initially net exporters of staple foodstuffs, to become net importers. There exists an urgent necessity to increase productivity of staple foodstuffs at both the small and large landholder levels. This would allow the country a higher degree of self-sufficiency as well as provide exports. To attain this goal it will be necessary either to increase the total area of cultivated land, thus requiring the clearing of more forests, or to improve crop yields per unit land area through more or higher quality inputs and better management. In many situations it may be necessary to increase the energy input for operations such as tillage, weed control and harvesting. In developing countries, a significant amount of this increased energy input may be derived from hand labor as opposed to draught

animals, or engine power. Various energy alternatives for developing countries are discussed by Crossley and Kilgour (1983).

Tillage is performed primarily to prepare a seed bed or to control weeds. Negative aspects associated with some tillage practices are that they often destroy soil structure, promote decomposition of organic matter, promote germination of previously buried weed seeds by positioning them near the soil surface, and leave the soil bare thus promoting soil erosion. Throughout the world, there are many choices of tools and power machinery for tillage and many kinds of chemicals available for weed control. Limited capital in developing countries severely limits the choice of inputs, especially at the small land-holder level. For this reason, it is especially important that an understanding of potentially usable tillage systems and their effects on soil properties be developed prior to investing large sums of capital for the purchase of tillage implements. It is essential to understand the effects of an individual tillage operation on the soil and more importantly, the effect of tillage systems utilizing a combination of tillage operations. In addition, one must understand the effects of these tillage operations on the particular soils of concern. Only then can tillage systems be selected to give the appropriate balance among sustainable yields, minimizing costs and soil deterioration, and optimizing energy use.

The objective of this paper is to summarize state of the art information about tillage systems in Latin America and when possible, to include their effects on soil properties. Most Latin American research on this topic has not been published in widely circulated journals, but often is published in reports having limited circulation and is not easily available to the scientific community.

We acknowledge that only a very small percentage of the research done on this topic is included in this review, but difficulty in collecting and assimilating the information has severely limited its scope. Finally, the information on tillage systems is presented by country for both our and the reader's convenience.

LAND CLEARING

Land clearing is the first step in establishing continuous cultivation. Clearing with heavy machinery is rapid and results in a variable substrate for root growth. The soil is often compacted as in the case of Yurimaguas soil (fine-loamy, siliceous, isohyperthermic Typic Paleudult) in Peru (Alegre et al., 1986a) where bulldozer clearing with straight blade and shear blades increased bulk density in the 0–0.15 and 0.15–0.25 m depths (Table 1). Compaction to a depth of 0.7 m and deeper was reported for mechanical clearing operations, especially windrowing, on a Typic Haplorox in Suriname (Janssen and Wienk, 1990). Bulk density at the 0.15 m depth approached 1.8 Mg

TABLE 1

Mean bulk density and standard deviation (in parentheses) (Mg m^{-3}) of Yurimaguas soil prior to and 14 weeks after land clearing, but before planting the first crop

Time	Clearing method	Depth (m)	
		0–0.15	0.15–0.25
Before clearing		1.16 (0.09)[b]	1.39 (0.08)[b]
14 weeks after clearing	Slash	1.27 (0.07)[a]	1.37 (0.10)[b]
	Straight blade	1.42 (0.12)[a]	1.49 (0.12)[a]
	Shear blade	1.28 (0.25)[a]	1.50 (0.15)[a]

Source: Alegre et al. (1986a).

TABLE 2

Volume fraction of macropores, mesopores, and micropores for a sandy loam of Coebite under forest (F) and after machine clearing (MC)

Depth (m)	Macropores		Mesopores		Micropores	
	F	MC	F	MC	F	MC
0.05	0.12	0	0.17	0.08	0.20	0.32
0.15	0.07	0	0.18	0.08	0.21	0.24
0.25	0.06	0.03	0.17	0.11	0.22	0.23
0.35	0.05	0.03	0.16	0.13	0.22	0.23
0.45	0.11	0.04	0.13	0.12	0.20	0.23
0.55	0.15	0.10	0.12	0.10	0.21	0.22
0.65	0.07	0.12	0.12	0.09	0.22	0.21
0.75	0.07	0.13	0.12	0.08	0.23	0.22

Source: Van der Weert and Maheeh (1972).

m^{-3}. In comparison, manual clearing only slightly increased bulk density at the 0.2–0.3 m depth.

A shift in pore size distribution in topsoil as a result of compaction during clearing operations has been reported by van der Weert and Mahesh (1972), van der Weert (1974), and Alegre et al. (1986b) (see Table 2). The volume fraction of macropores, one of several arbitrary pore size classes, from a sandy loam disappeared entirely in the 0–0.15 m soil increment when it was machine cleared (van der Weert, 1974). Likewise, the volume of mesopores decreased. Although the fraction of micropores increased, the net loss in porosity as a result of machine clearing in the upper 0.2 m was about 0.1 m^3 m^{-3}. Similar results were reported by Alegre et al. (1986b) for the 0–0.15 m depth of Yurimaguas soil (Fig. 1). This compaction not only caused root penetration problems, but it severely reduced water infiltration (Fig. 2). Both straight blade and shear blade clearing reduced the infiltration rate by an order of magnitude.

3

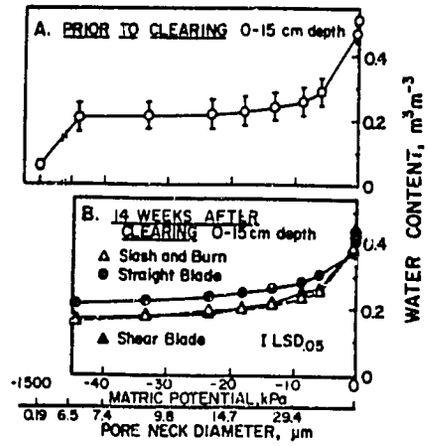

Fig. 1. Soil water characteristics at the 0–0.15 m depth of Yurimaguas soil prior to and 15 weeks after clearing by manual, slash and burn, and mechanical methods (from Alegre et al., 1986b).

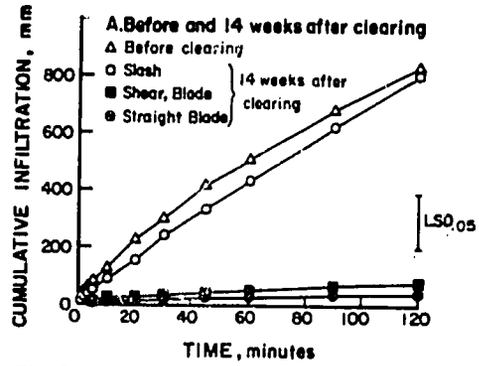

Fig. 2. Cumulative infiltration of Yurimaguas soil before and 14 weeks after clearing for three land clearing methods (from Alegre et al., 1986b).

LAND RECLAMATION

Mechanical land clearing in 1972 of Yurimaguas soil located in the Amazon Basin of Peru, resulted in compacted soil that was abandoned for continuous crop production in 1974. Only chisel plowing and simulated subsoiling alleviated the detrimental effects of the compacted soil below 0.15 m (Alegre et al., 1986a). The infiltration rate at the conclusion of the experiment, i.e. after growing five consecutive crops, was 9 mm h^{-1} for the control treatment compared with 148 mm h^{-1} for the chisel plow treatment. Yield response to eight tillage methods was greatest for chiseling and subsoiling. For example, if we assign a reference value of 100 to the average grain yield for the chisel plow treatment, relative values for the no-tillage treatment were 69, 73 and

20 for upland rice (*Oryza sativa* L.), soybean (*Glycine max* (L.) (Merr) and corn (*Zea mays* L.), respectively.

POST-CLEARING TILLAGE

Peru

A comprehensive study involving various land post-clearing tillage and management practices was conducted in Yurimaguas, Peru from 1980 to 1982 (Alegre et al., 1986b, 1988, 1990a). Treatments included: no-tillage after slash and burn clearing; rototill and chisel plow plus rototill (both treatments following straight blade clearing); rototill and disk followed by rototill (both following shear blade clearing). In addition, the effects of bedding, liming and fertilization were studied in split plots. The infiltration rates of the plots that were disked or chisel plowed were greater than that for the plot that was cleared with a straight blade, but was not chisel plowed. Secondary tillage (disk, chisel plow) disrupted the subsurface compaction imposed by straight blade clearing. Nearly 2 years after clearing, the cumulative effects of those treatments that involved chiseling or disking after clearing were seen in infiltration rates that were at least five times greater than on the plot that was cleared with a straight blade and received only rototiller tillage. Changes in soil physical properties under continuous cropping were minimized when the soil was bedded using a hand hoe. Bedding and liming tended to maintain aggregate stability and organic carbon levels of the newly cleared lands (Alegre and Cassel, 1986). Compaction of both the topsoil and subsoil was less for the bedding system when no mechanization was used for land preparation.

A tillage study in Yurimaguas from 1986 to 1989 examined the effects of three tillage regimes on selected soil properties and corn and soybean production (Alegre and Cassel, 1991). The conventional tillage system employed a

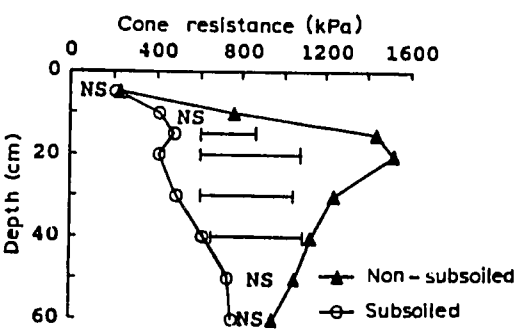

Fig. 3. Penetrometer resistance vs. depth for subsoiled and non-subsoiled Yurimaguas soil (Alegre et al., 1990b).

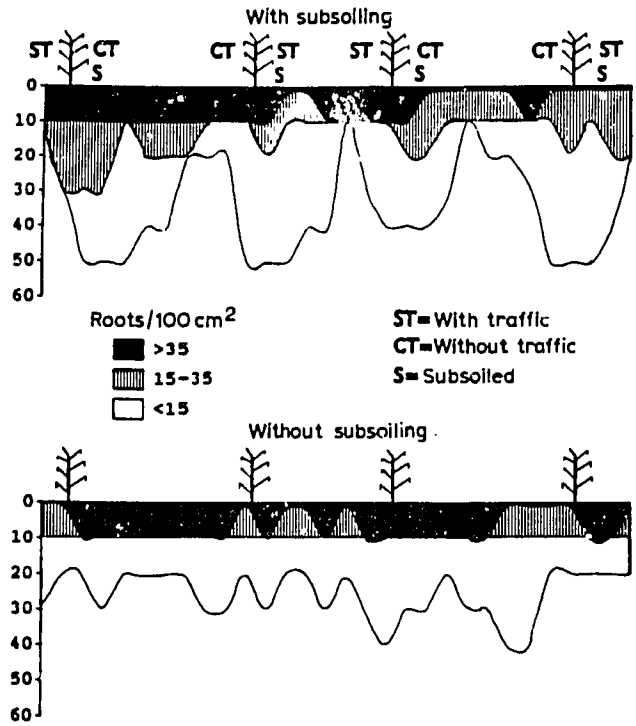

Fig. 4. Root distribution vs. depth and distance perpendicular to the row for corn on Yurimaguas soil (from Alegre et al., 1990b).

TABLE 3

Surface runoff and soil loss from November 1987 to January 1989 for Yurimaguas soil subjected to three tillage systems and planted to two crops (total precipitation was 1757 mm)

Treatment	Runoff (mm)	Soil loss ($t\ ha^{-1}$)
Conventional, subsoil	249	22.4
Minimum, subsoil	120	19.4
No-tillage, subsoil	165	14.9
LSD (0.05)	43	5.5

Source: Alegre and Cassel (1991).

bush hog to chop stalks, weeds and small brush, a disk plow, a field cultivator, a disk bedder, and a bed shaper. Weeds were controlled with herbicides. The minimum tillage system used a bush hog, and after spraying a herbicide on the surface cover, the crop was planted through the surface residue using a two-row no-till planter. Lime and fertilizer were incorporated every 2 years with a disk harrow. The no-till system was similar to the minimum tillage system except that fertilizer and lime were applied on the soil surface. All

6

TABLE 4

Corn and soybean grain yield (Mg ha^{-1}) as affected by tillage in an Ultisol at Yurimaguas, Peru

Tillage	1st corn	2nd soybean	3rd corn	4th soybean	5th corn	$\bar{X}$ corn	$\bar{X}$ soybean
Conventional	1.90	1.80	2.35	0.80	2.91	2.39	1.30
Conventional, subsoil	2.00	1.99	3.39	1.18	2.68	2.69	1.59
Minimum	1.44	1.79	2.66	1.20	2.58	2.23	1.50
Minimum, subsoil	2.20	1.63	2.41	1.40	3.40	2.67	1.52
No-till	1.39	2.18	2.58	0.90	2.90	2.29	1.54
No-till, subsoil	1.90	2.25	2.83	1.25	3.27	2.67	1.75
LSD (0.05)	0.63	0.52	0.96	NS[1]	NS		

Source: Alegre and Cassel (1991).
[1]Not significant.

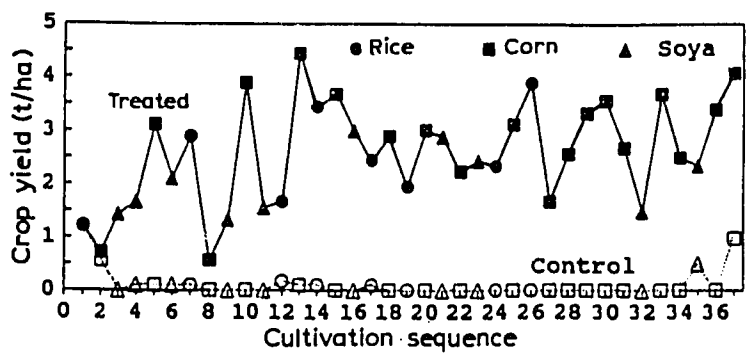

Fig. 5. Successive crop yields for a long-term study in Yurimaguas, Peru (from Alegre et al., 1990b).

three systems were initiated with and without in-row subsoiling (to below the 0.2 m depth). The effect of subsoiling on penetrometer resistance in the row is illustrated in Fig. 3. The subsoiling operation increased rooting depth and root density (Fig. 4). Surface water runoff and soil loss were measured for the three tillage treatments that had been subsoiled. Both runoff and soil loss for the 15 month period November 1987 to January 1989 were greatest for the conventional tillage system, but no difference in soil loss occurred for the minimum tillage and no-till systems (Table 3). The disappointment was that corn and soybean grain yields were not greatly improved over those for conventional tillage without subsoiling (Table 4).

A recent study by Pinna et al. (1991) evaluated the effect of several tillage practices including conventional and minimum tillage on short-term changes in bulk density and infiltration rate of a calcareous Entisol on the coast of Peru. Conventional sugar cane planting involves two disk harrowings, one at the 0.2 m and one at the 0.3 m depth, a heavy grading, two subsoiling opera-

tions, one at the 0.65 m and one at the 0.85 m depth, followed by light grading to shape the land surface and install furrows. Measurements of infiltration rate and bulk density in the A_{p1} and A_{p2} horizons 4 months after planting indicated that conventional tillage (with subsoiling) had no long-term detrimental effects on soil properties.

Finally, a long-term study in Yurimaguas (Alegre et al., 1990b) indicated that tillage involving chisel plowing and disking, along with appropriate liming and fertilization, maintains stable and sustainable production of corn, rice and soybeans (Fig. 5). It is important to understand that sustainability on these nutrient-deficient soils requires the input of plant nutrients from sources external to the land area being farmed.

Brazil

The influence of tillage and cover crops on soil properties, soil erosion and crop yields was studied on a Typic Haplorthox in Paraná from 1977 to 1984 (Derpsch et al., 1986). Tillage systems were conventional (disk plow followed by two diskings), minimum tillage (chisel plow followed by two diskings), and no-tillage. An additional treatment consisted of self-seeding and regrowing permanent cover crops of *Glycine javanica* and Italian rye grass (*Lolium multiflorum*). Turning the soil annually by the disk plow promoted the lowest bulk density in the upper 20 cm (Fig. 6). Chisel plowing loosened the soil annually, but did not create as large a volume of macropores (larger

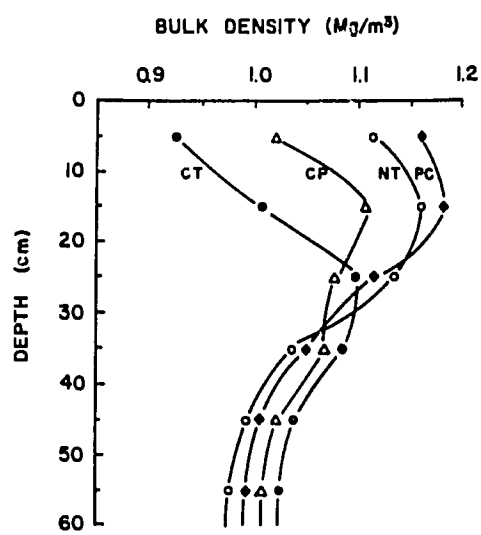

Fig. 6. Bulk density vs. depth of an Oxisol in Brazil as affected by 7 years of conventional tillage (CT), chisel plowing (CP), no-tillage (NT) and permanent soil cover (PC) (from Derpsch et al., 1986).

8

than 50 μm) after a period of 4 years (Table 5). Soil water content monitored throughout 1981 for a wheat crop showed that plant-available water was consistently highest under no-till and least under conventional tillage. This result reflects the higher volume of meso- and micropores under no-tillage (Table 5). The porosity and water content relationships, in turn, affected the soil temperature regime. Maximum daily soil temperature at the 3 cm depth reached 46 °C for conventional tillage, 41 °C for chisel plow and 36 °C for no-tillage. The annual costs associated with no-till, including herbicides, were 56.6% higher than those associated with conventional tillage. Average wheat (*Triticum aestivum* L.) yields over 6 years were 1597 kg ha^{-1}, 1418 kg ha^{-1}, and 1342 kg ha^{-1} for no-till, chisel plow and conventional tillage, respectively. Average soybean yield was greatest for no-tillage (2314 kg ha^{-1}) and least for conventional tillage (1730 kg ha^{-1}).

Other studies conducted at the Instituto Agronomico do Paraná indicated that no-till was the most effective tillage system to control erosion (Mondardo et al., 1979; Sidiras et al., 1982; Roth et al., 1986).

Roth et al. (1986) reported that the degree of soil cover is more important than tillage method in enhancing infiltration and reducing soil erosion. Recognizing that different tillage systems leave different amounts of crop residue (mulch) on the soil surface, they evaluated infiltrability to find the minimum mulch rate necessary to control runoff. Measurements were made 7 years after three tillage treatments had been installed. Various amounts of soybean residue were applied to the soil surface. Infiltrability was determined as the difference between simulated rainfall, applied with a sprinkler, and runoff collected at 2-min intervals from mini-plots. Bulk density at the 0–0.1 m depth was greatest for the no-till treatment (1.06 Mg m^{-3}), and at the 0.2–0.3 m depth was greatest for the conventional treatment (1.22 Mg m^{-3}); this latter value was due to the presence of a plow pan. Nevertheless, bulk densities overall were low, owing to very stable microaggregation, a result of high

TABLE 5

Pore size classes and total porosity at the 0.12–0.20 m depth of an Oxisol in Brazil as affected by 4 years of tillage

Tillage system	Macropores ($m^3 m^{-3}$)	Meso- and micropores ($m^3 m^{-3}$)	Total porosity ($m^3 m^{-3}$)
Conventional	0.271[a]	0.389	0.660[a]
Chisel plow	0.194[b]	0.426	0.620[b]
No-till	0.170[b]	0.433	0.603[b]
Permanent cover	0.171[b]	0.396	0.567[c]

Numbers followed by the same superscript are not significantly different at $P \leq 0.05$.
Source: Derpsch et al. (1986).

iron oxide content. A 100% soil cover led to complete infiltration of a 60 mm simulated rainfall for all three tillage treatments, whereas only 20% of the applied water infiltrated when the soil was bare and the surface sealed.

Hoogmoed and Derpsch (1985) evaluated a number of chisel plow models (different shapes and lengths of shanks and points) with the goal of adopting the chisel plow to till wheat stubble in a wheat–soybean rotation on sloping erosion-susceptible soils in Paraná. The study was done on a clay soil at Londrina and a Dark Red Latosol (43% clay, 51% sand) at Vila Velha. The large amounts of residue and weeds at the soil surface caused clogging of the chisel plows. It is unlikely that the chisel plow will replace the disk plow for tillage wheat stubble prior to planting soybean.

A comparison of the effects of conventional and no-till systems on soil properties of a Latosol Bruno Allic at Guarapuava, Paraná was conducted by Eltz et al. (1989). The long-term use of conventional tillage had allowed soil physical and chemical properties to reach quasi-equilibrium values. The imposition and continued use of no-tillage increased aggregate stability of the surface layer (0–0.02 m) and increased nutrient availability in the upper 0.02 m of soil. Grain production for the no-tillage system was 22% higher than for conventional tillage.

A study on a Planosol in Rio Grande do Sul compared the effects of two surface tillage methods: conventional with flat planting and ridge tillage (Stefani et al., 1990). The crop root systems were more extensive for ridge tillage owing to lower bulk in the A1 horizon compared with conventional tillage (Fig. 7). In a separate study, three tillage methods (conventional, rototill, and no-tillage) were studied on a sandy loam Oxisol with 7% slope in Gualba Rio Grande do Sul (Levien et al., 1990). Runoff and soil loss for a given cropping system were greatly affected by tillage (Table 6). For the corn–soybean–oat (*Avena sativa* L.) cover crop system, soil loss was an order of magnitude greater for conventional tillage than for the no-tillage and rototiller

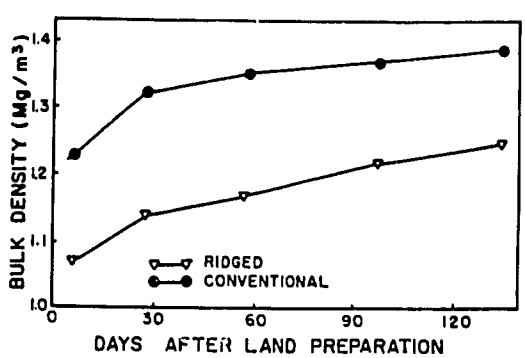

Fig. 7. Bulk density of the A1 horizon of a Planosol in Rio Grande do Sul vs. time after land preparation for two tillage systems (from Stefani et al., 1990).

TABLE 6

Effect of simulated rainfall on soil loss and runoff under different cropping and tillage systems in an Oxisol of Rio Grande do Sul, Brazil

Cropping system	Tillage	Soil loss ($t\ ha^{-1}$)	Runoff (mm)
Corn–beans/ oat–cover	Conventional	42.9	146
	Rototill	3.7	308
	No-till	0.9	40
Corn/wheat	Conventional	41.7	179
	Rototill	2.2	327
	No-till	0.4	79
Bare plot	Conventional	150.9	182
	Conventional	64.1	119

Source: Levien et al. (1990).

TABLE 7

Runoff (as a percentage of total rainfall) and soil loss for different land preparation methods without soil cover and with 60% soil cover in an Oxisol of Rio Grande do Sul, Brazil

Tillage method	No soil cover		With soil cover	
	Runoff (%)	Soil loss ($t\ ha^{-1}$)	Runoff (%)	Soil loss ($t\ ha^{-1}$)
No-till	62	12.8	53	1.4
Subsoiled	43	0.8	17	0.1
Disk plow	51	18.3	28	1.1
Disk	57	18.5	36	1.1
Rotovate+disk	55	3.8	30	1.2
Subsoiled+disk	62	20.3	30	1.7
Disk plow+disk	53	17.9	55	3.0
Two diskings	59	13.2	50	1.0

Source: Bertol et al. (1989).

systems. This same result was found for the corn–wheat rotation. Soil loss was greatest for the bare soil which served as a control. It is surprising that the rototill treatment had nearly two times as much runoff as conventional tillage, yet soil loss was an order of magnitude less.

Studying this same soil, Bertol et al. (1989) found that runoff and soil loss were low regardless of tillage method when the soil had a 60% soil cover of mulch as compared with no soil cover (Table 7). However, subsoiling was the most effective tillage method in reducing runoff and soil loss both in the presence and in the absence of surface cover. Yet another study in this region reported that organic matter in the 0.15 m depth was maintained at 0.034 kg kg^{-1} for no-tillage compared with 0.015 kg kg^{-1} for conventional tillage

(Machado, 1976, cited by Lal, 1986). Bulk density was 1.21 Mg m^{-3} for no-till compared with 1.35 Mg m^{-3} for the conventional system.

Suriname

The effects of various tillage practices on the growth of five crops were reported by Janssen and Wienk (1990). The tillage practices included disk plowing to a depth of 0.25 m followed by harrowing, rotovation to a depth of 0.07 m, and no-till. A summary of yields for 22 cropping cycles for the five crops at Coebiti shows that disk plowing produced the highest yield (Table 8). Yields of crops for rotovation tillage were only slightly larger than yields for no-tillage. The yield difference among treatments for corn was found to increase with time. The relative density of corn roots for the no-till plots was about one-half that of the plowed plots, and most roots were confined to the upper 0.1 m of soil (Fig. 8). Little difference in the total number of roots between plow and rotovation treatments was observed, but the latter had a higher concentration of roots in the upper 0.2 m. Although yield and root development were strongly correlated with tillage depth, no conclusions were drawn as to whether it was differences in chemical or physical soil properties that caused the yield differences. Calcium, magnesium and phosphorus were well distributed throughout the upper 0.2 m depth for the plow and rotova-

TABLE 8

Effect of soil tillage on crop yields in a long-term experiment at Coebiti

Crop	Yield (t ha^{-1})			Relative yield (plow = 100)	
	Plow	Rotovate	No-till	Rotovate	No-till
Corn	2.62	2.08	1.92	79	73
Sorghum	2.45	2.07	1.93	84	79
Cowpea	0.83	0.74	0.60	90	73
Soybean	1.70	1.56	1.43	92	85
Groundnut	1.90	1.90	1.72	99	90

Source: Janssen and Wienk (1990).

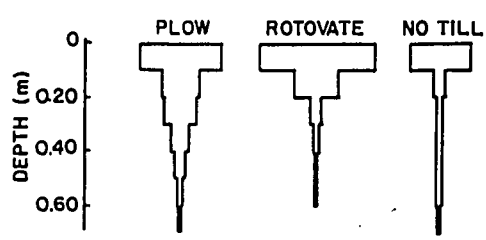

Fig. 8. Relative density of corn roots for three tillage treatments (Janssen and Wienk, 1990).

tion treatments, but they were confined to the upper 0.1 m for no-tillage. Penetrometer resistance in the upper 0.4 m of soil was consistently lowest for the plow treatment.

Caribbean islands

The wet season in the Caribbean can last 6–8 months, making it difficult to traffic soils with impeded drainage. During the dry season the soil is difficult to till to produce an adequate seedbed. The objective of a study by Lindsay et al. (1983) was to assess the effect of three tillage systems on an Inceptisol clay soil with impeded drainage. The zero tillage plots were sprayed with paraquat 3 days before planting. The minimum tillage plots were tilled to the 0.15 m depth with a hand rototiller, and conventional tilled plots were disked to a depth of 0.3 m and rotovated twice. The zero and minimum tillage treatments yielded about 40% less than the conventional tillage treatment (5.64 t ha^{-1} fresh weight of corn ears). The yield reduction due to zero and minimum tillage treatments was only 19% in the second trial because more nitrogen fertilizer (85 kg ha^{-1}) and mulch (6 t ha^{-1}) were used. Further evaluation of these tillage systems was recommended.

Bolivia

Examination of the effects of deep tillage, controlled traffic, and fertilization on soil physical conditions as related to soybean production was initiated in 1985, in eastern tropical Bolivia on an imperfectly drained sandy loam Udic Fluventic Ustochrept with a compact layer at the 0.12–0.35 m depth (Barbosa et al., 1989; Orellana et al., 1990). Tillage treatments were: conventional, two passes of disk operating to the 0.12 m depth followed by two passes of a light disk to the 0.07 m depth; disk plowing to 0.30 m followed by conventional tillage in subsequent years; subsoiling in 1985 to 0.40 m at 0.38 m spacing, followed by conventional tillage in 1985 and subsequent years; subsoiling every year followed by conventional tillage. Penetrometer resistance measurements 2 years later clearly showed that annual subsoiling is necessary to keep the soil below the 0.21 m depth in a looser, more favorable condition for plant growth. During the very wet year of 1987–1988, the annual subsoil treatment provided better drainage, higher plant populations, and higher yields even though there was evidence that root growth rate was still somewhat impeded in the original compacted layer. Four-year average yield increases due to subsoiling in 1985 only, disk plowing in 1985 only, and subsoiling annually ranged from 18 to 29% greater than conventional tillage (Barber and Diaz, 1991).

13

Colombia

In a soil belonging to the Tibaitata Series (Andic Entropept) in Colombia, Herrera et al. (1989) compared the effects of different tillage systems carried out for 6 years, on soil physical properties. Tillage systems were: conventional (one disk plow pass and three disk harrow passes); minimum (two disk harrow passes); no-till and control (old pasture with 15 years of livestock grazing). Contrary to the findings of most studies, mechanical impedance was less for the minimum and no-till than for the tilled and control treatments (Fig. 9).

Argentina

The effects of two tillage systems on bulk density, total and air-filled porosity, moisture retention, soil strength, permeability and gas diffusion after 11 years of cultivation of a Typic Argiudoll were reported by Andriulo and Rosell (1988). Soil strength and bulk density in the 0–0.1 m depth were less for conventional tillage than for direct drilling in a wheat–soybean annual double cropping system. The air-filled porosity was higher for conventional tillage, but the reserve water content was lower. Penetrometer resistance was greatest for direct drilled tillage.

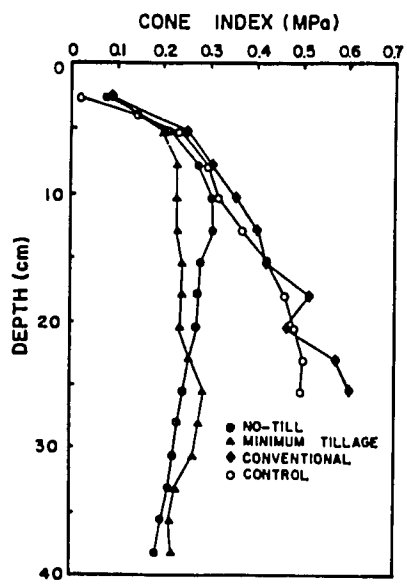

Fig. 9. Cone index vs. depth for three tillage treatments and a grazed pasture for the Tibaitata soil series in Colombia (Herrera et al., 1989).

Venezuela

In a study carried out by Casanova et al. (1989), soil loss under three tillage systems on an Alfisol in Chaguaramas was significantly reduced by minimum tillage (Table 9).

Several tillage systems and their effects on soil physical properties and crop production were evaluated on a fine-textured (70% clay) soil of Guara Monages (Delta del Orinoco) (Amezquita, 1976). Compared with the local control (five disk harrow passes), the deep plow followed by disk plow and subsoil followed by disk treatments reduced bulk density in the 0–0.2 m depth, increased infiltration rate and reduced mechanical resistance (Table 10). In general, corn yields were higher for the disk plow.

TABLE 9

Soil loss for three tillage systems in an Alfisol of Chaguaramas, Venezuela

Treatment	Soil loss (t ha^{-1})
Bare plot	73.8
Conventional	17.3
Minimum tillage	2.1

Source: Casanova et al. (1989).

TABLE 10

Effect of tillage system on bulk density, mechanical resistance, infiltration rate and corn yield on a heavy clay soil of Venezuela

Treatment[1]			Bulk density (Mg m^{-3}) at depths of:			Mechanical resistance (kPa) at depths of:			Infilt. rate (cm h^{-1})	Corn yield (t ha^{-1})
Plow	Harrow	Rotovate	0–10 cm	10–20 cm	20–30 cm	0–10 cm	10–20 cm	20–30 cm		
Before plowing			1.34	1.43	1.45	450	450	450	13.8	–
1	3D		1.20	1.26	1.44	235	346	204	19.5	3.99
1S	2P	1	1.20	1.37	1.50	230	236	263	21.0	4.51
2S	3D		1.22	1.30	1.57	298	396	290	24.7	6.49
2S	2P	1	1.20	1.37	1.50	344	326	271	18.9	4.22
1D	3D		1.18	1.22	1.33	315	375	296	17.1	5.17
1D	2P	1	1.19	1.27	1.32	228	352	336	12.0	5.56
2D	3D		1.20	1.23	1.31	252	354	312	14.7	4.54
2D	2P	1	1.20	1.26	1.41	290	279	300	26.1	4.41
	5D		1.18	1.36	1.44	252	269	330	8.5	4.41

[1]S, subsoiling at 30 cm depth; D, disk; P, cultivator (S tine type).
Source: Amezquita (1976).

15

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17