The Impact of Tillage Systems and Machinary Traffic on Some Soil Properties and Crop Yield in a Calcic Luvisol of Central Spain

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Abstract: Long-term field experiments were carried out on a Calcic Luvisol in a semiarid environment of central Spain. Objetives of this research were to evaluate the effects of tillage practices (no-tillage and conventional tillage) and machinary traffic, on plant development and soil physico-chemical properties after a 7 years period.

Nutrient stratification was evident for no-tillage method while the mouldboard plowing had the most uniform soil test levels within the 300-mm management zone. No-tillage favoured the surface accumulation of soil organic C, total N as well as of available P, K, Ca and Mg. Traffic-induced compaction decreased soil pH in plots under conventional tillage. The amount of dry matter and concentrations of N, P and K in barley plants during the growing season, were significantly lower in no-tillage system. The crop yield decreased as a result of traffic-induced compaction in no-tillage plots.

Differences in the vertical distribution of soil water were found. The moisture below the plough layer remained high under no-tillage whereas, with conventional tillage, the water content was greatest in the surface. The values for soil bulk density showed significant tendency to be lower in conventional tillage than in no-tillage; the effect of machinary traffic being more marked in the former case. The above differences were much more noticeable when reflected by the cone index.

Keywords: barley, crop rotation, semi-arid soils, soil compaction, soil chemical characteristics, tillage

1 Introduction

One of the most important problems in dryland Mediterranean soils subjected to conventional tillage consists of the enhancement of the organic matter mineralization, leading to progressive degradation of soil structure and physico-chemical and biological soil characteristics. Such unfavourable effects may came from compaction of the soil due to traffic of vehicles, as well as from the progressive disruption of its structure. (Quiroga *et al*., 1999). On the other hand, the alternative agricultural practices based on reduced tillage have greatly been encouraged in semiarid agrosystems exposed to severe risks of erosion and desertification (Agenbag and Maree, 1991). Long-term no-tillage or reduced tillage systems have shown to increase residue return, less mixing and soil disturbance, higher soil moisture content, reduced surface soil temperature, and increased proliferation of root growth and biological activity (Lal, 1989; Blevins and Frye, 1993). Nevertheless such practices may also lead to increased bulk density and soil hardsetting (Hamblin and Tennant, 1979; López-Fando *et al*., 1995) with a probable bearing on the decreased crop growing rates (Chan *et al*., 1987; Lopez-Fando and Almendros 1995). It is known that in addition to the rapid soil compaction derived from the application of external loadings (e.g., agricultural traffic), progressive hardsetting of a cultivated soil can originate from an internal dynamics of the soil, frequently connected to low amounts of organic matter and the presence of 2∶1 or 1∶1 clay minerals (Mullins *et al*., 1990; Raghavan *et al*., 1990). The objectives of this research were to evaluate the effects of tillage practices and machinary traffic on plant development and soil physico-chemical properties after a 7 years period.

2 Material and methods

This study was part of a long-term (iniated in 1992) project designed to determine the interactive effects of tillage methods and wheel-traffic (compaction) on crop yields and soil properties in the cereal-producing area of central Spain. The soil formation is a Calcic Luvisol, (bulk density=1.3 $g \bullet cm^{-3}$, pH=5.8, soil organic carbon (SOC)=7.0 $mg \bullet g^{-1}$, cation exchange capacity=17.4 $cmol_c \bullet kg^{-1}$). The experimental site is characterized by a semiarid continental climate (minimum and maximum average annual temperatures are 6^{o}C in the winter and 23^{o}C in the summer, with 400 mm of average annual rainfall).

The experiment was arranged in a split-plot design with the rotation as the main plot (9 m × 72 m) and tillage as the split-plot (9 m × 36 m). All treatments were replicated three times (three blocks). The crop rotation variable consisted of: (1) barley (*Hordeum vu*lgare L.)–vetch (*Vicia sativa* L.) B→V in a 2-year rotation, (2) barley–sunflower (*Heliantus annus* L.) B →S in a 2-year rotation, and (3) barley monoculture B→B . The tillage variable consisted of no-tillage (NT) and conventional tillage (CT). Sufficient number of plots were established so that each different phase of the crop rotation was present every year. To study the effect of tractor traffic on soil compaction, a fixed string was placed so that the tractor should always pass through the centre of the plot, making a clear division between the areas subjected to wheel traffic (wt) or not (nt).

Barley biomass was determined at 2-week from sowing to ripening. Plant samples of each barley plot collected at tillering, stem extension, heading and ripening were analyzed for total N, P, K content. After harvesting soil samples from 0 mm—300 mm layer at 75 mm intervals were collected in order to asses soil fertility Soil pH, available P, K, Ca and Mg, SOC and total N were evaluated. After plowing, sowing and hardvesting soil samples were taken between 0 mm—450 mm depth at 75 mm intervals and the following determinations were made: the changes in the water profile, resistance to penetration and bulk density. The samples were subjected to analysis of variance (ANOVA). The least significant difference test was used to compare treatments at the $P<0.05$ level.

3 Results and discussion

The soil moisture in the upper 150 mm of the NT plots was lower than in CT plots whereas in the underlying horizons, water content was higher in the NT plots, especially between 225 mm—300 mm (Table 1). In this situation, the wheel traffic had some positive effects in preventing high evaporative losses. This higher soil water content below 150 mm could be attributed to compacted layers that held the water tightly in small pores. In years where soil moisture is suitable for seeding summer crops, NT may be associated with moisture conservation to support the crop during the dry months.

Table 1 Gravimetric soil water content (SWC) at six depths and two occasions as influenced by tillage system and wheel traffic. NT= no-tillage; CT= conventional tillage; nt= no traffic; wt= with machinary traffic

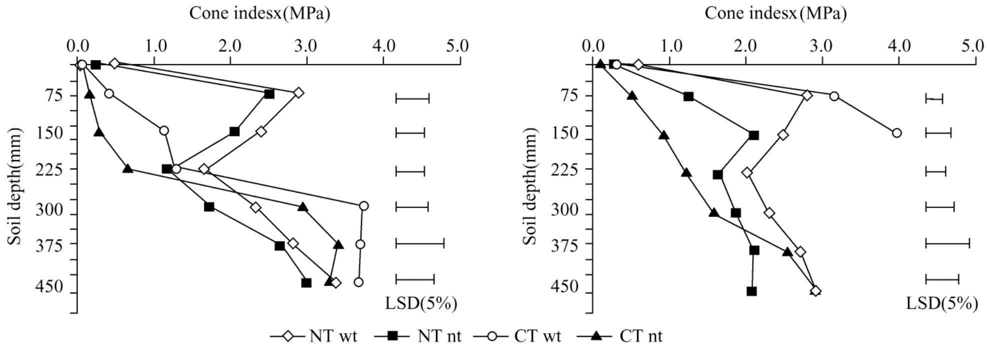
Treatments	0mm—75mm	75mm—150mm	150mm—225mm	225mm—300mm	300mm—375mm	375mm—450mm
At seeding						
NT nt	8.68 b*	8.46 b	14.95 a	16.20 a	17.37 a	17.45 a
NTwt	8.26 b	7.69 b	13.52 a	15.87 a	17.78 a	16.76 a
CT nt	10.85 a	11.90 a	11.68 b	12.51 b	14.56 b	14.23 b
CT wt	9.97 a	11.15 a	10.16 b	12.81 b	13.54 b	12.93 b
At harvest						
NT nt	12.86 b	15.32 ab	17.88 a	18.29 a	20.18 a	21.10 a
NT wt	12.90 b	14.25 b	17.42 a	21.61 a	21.68 a	18.08 a
CT nt	15.13 a	16.03 a	15.55 b	15.53 b	16.83 b	15.04 b
CT wt	14.07 a	15.88 a	15.31 b	13.24 b	13.74 b	14.07 b

* Means within a occasion and depth followed by the same letter are not significantly different by LSD ($P<$ 0.05).

The values for bulk density showed significant tendency to be lower in CT than in NT conditions; the effect of machinery traffic being more marked in the former case (Table 2). The above differences were much more noticiable when reflected by the cone index (penetrometer measurements). In general, the penetration resistance tends to be greater under NT than under CT and the values obtained varied significantly in the course of the year (Fig.1). At sowing, the maximum penetration resistance corresponded to the NT plots and was not greatly affected by the machinery traffic. At harvesting, the highest compaction (*ca.* 4 MPa) was found in points affected by wheel traffic in the CT plots.

Table 2 Soil bulk (g cm^{-3}) density at five dephts, at seeding and harvest of plots subjected to no-tillage (NT) and conventional tillage (CT). nt= no traffic; wt= with machinary traffic

Soil depth	At seeding					At harvest				
	NT		CT		LSD	NT		CT		LSD
	wt	Nt	wt	nt	*P*<0.05	wt	nt	wt	nt	*P*<0.05
0mm–75 mm	1.63	1.60	1.49	1.46	0.029	1.61	1.59	1.56	1.54	0.031
75mm–150 mm	1.57	1.59	1.55	1.51	0.023	1.62	1.59	1.54	1.53	0.034
150mm–225 mm	1.58	1.56	1.60	1.57	0.016	1.54	1.55	1.58	1.60	0.041
225mm–300 mm	1.56	1.58	1.59	1.55	ns	1.57	1.56	1.64	1.63	ns
300mm–375 mm	1.59	1.60	1.56	1.60	ns	1.59	1.61	1.57	1.60	ns



(a) (b)

Fig.1 Soil strength (Mpa) at six depths and two occasions as influenced by tillage system and wheel traffic. a= at seeding, b= at harvest, NT= no-tillage, CT= Conventional tillage, wt= wheel traffic, nt = no traffic

The effect of tillage and wheel traffic on soil pH, SOC, total N, C/N ratio, and available P, K, Ca and Mg is shown in Table 3. Soil pH was higher in the 0mm—75mm and 75mm—150mm layers in CT plots. Traffic-induced compaction decreased soil pH in both NT and CT systems. No significant differences between tillage and wheel traffic were observed in the 150 mm to 300 mm layers. Soil pH showed a marked tendency to increase with depth especially in NT plots.

Among the pronounced effects caused by the different continuous long-term tillage intensities was the accumulation of SOC at the soil surface under NT. The SOC concentrations were approximately 1.4 and 2.4 times greater at the soil surface (0-75 mm) in the NT plots under wheel traffic or no-traffic respectively. The concentration of SOC in the NT plots rapidly decreased with increase in soil depth. The differences in the SOC concentrations in the 0mm to 75 mm soil increment layer between the NT plots and CT plots may due to (1) less soil-residue interaction as a result of NT, (2) a lower rate of biological oxidation and/or (3) less erosion of soil high in organic matter.

Total N concentrations closely followed the pattern observed for SOC. No significant differences were observed among wheel traffic or no-traffic treatments. Higher rates of N fertilizer have generally been required to achieve the same level of yield for NT as for CT during the first years of NT cropping. This was attributed to greater immovilization of N fertilizer by the soil microorganisms during the decomposition of fresh plant residues of high C/N ratio. This effect is diminished in subsequent cropping years. In the present study equal amounts of N were applied to each tillage treatment. The total amount of N in the 0 to 150mm soil profile, however, was significantly ($P<0.05$) greater under NT than were the plots had been plowed.

Table 3 Effect of tillage: conventional tillage (CT) , no-tillage (NT) and wheel traffic: with traffic (wt), no traffic (nt) on soil pH, C/N ratio and concentrations of SOC, total N and available P, K, Ca and Mg in soil profiles

	Soil pH	SOC g • 100g^{-1}	Total N g • 100g^{-1}	C/N	P μg • g^{-1}	K μg • g^{-1}	Ca μg • g^{-1}	Mg μg • g^{-1}
0 mm—75 mm NT nt	5.17 b*	1.39 a	0.11 a	12.63 a	26.95 a	170 a	1065 a	167 a
0 mm—75 mm NT wt	5.17 b	1.15 a	0.10 a	10.50 b	24.00 a	150 ab	1025 a	165 ab
0 mm—75 mm CT nt	5.33 a	0.54 b	0.06 b	9.00 c	15.35 b	100 b	855 a	116 c
0 mm—75 mm CT wt	5.21 ab	0.59 b	0.06 b	9.80 bc	16.75 b	120 ab	1065 a	144 bc
75 mm—150 mm NT nt	5.47 b	0.59 a	0.07 a	8.42 b	19.30 a	160 a	1480 a	234 b
75 mm—150 mm NT wt	5.17 c	0.48 a	0.06 ab	8.00 b	18.40 b	155 a	1600 a	243 a
75 mm—150 mm CT nt	5.68 a	0.50 a	0.05 b	10.00 a	13.45 c	95 b	925 b	118 d
75 mm—150 mm CT wt	5.52 b	0.50 a	0.05 b	10.00 a	13.85 c	91 b	925 b	130 c
150 mm—225 mm NT nt	5.93 a	0.41 c	0.05 a	8.20 b	12.60 a	145 a	2015 a	244 a
150 mm—225 mm NT wt	5.58 a	0.41 c	0.05 a	8.20 b	13.75 a	130 a	1640 a	198 ab
150 mm—225 mm CT nt	5.92 a	0.59 a	0.05 a	11.80 a	15.20 a	130 a	1025 b	145 b
150 mm—225 mm CT wt	5.84 a	0.56 b	0.05 a	11.20 a	14.40 a	105 a	925 b	130 b
225 mm—300 mm NT nt	6.37 a	0.34 c	0.05 a	6.80 b	7.75 a	165 a	2600 a	320 a
225 mm—300 mm NT wt	6.29 a	0.38 bc	0.05 a	7.60 ab	10.10 a	170 a	2380 a	306 a
225 mm—300 mm CT nt	5.97 a	0.49 a	0.06 a	8.17 ab	10.55 a	120 a	1150 b	146 b
225 mm—300 mm CT wt	5.90 a	0.44 ab	0.05 a	8.80 a	9.48 a	135 a	1500 b	205 b

* Means within a occasion and depth followed by the same letter are not significantly different by LSD ($P<$ 0.05)

In the NT plots the C/N ratios decreased as soil depht increased. The highest C/N ratios observed were at the soil surface (0 mm—75 mm). The relatively low C/N ratios indicate that soil organic matter has undergone humification and favours N mineralization. Since large amounts of total N accumulated at the soil surface of the NT plots compared to the CT plots, mineralization may contribute an important part of the available N to plants during the growing season. However, the higher C/N ratios at the surface (0 mm—75 mm) under NT compared to CT also indicate that even though substantial humification had taken place, the organic matter in the NT plots is still less humified and more carbon enriched compared to the plots were tillage has been applied.

Lack of tillage, higher SOC and concentration of crop residues at the soil surface in NT contributed to its higher concentrations of available P and K in the 0 mm—150 mm layer. No significant differences were observed among wheel traffic or no-traffic treatments. In the 150 mm to 300 mm soil layer, the soil P and K were lower in all tillage treatments, which could be explained by lower SOC in this layer and fixation by exchangeable Ca. In general, exchangeable Ca and Mg were significantly greater with NT than with CT. A greater amount of Ca and Mg at 15 cm to 30 cm layers in all tillage treatments might be due to weathering and leaching of lime materials.

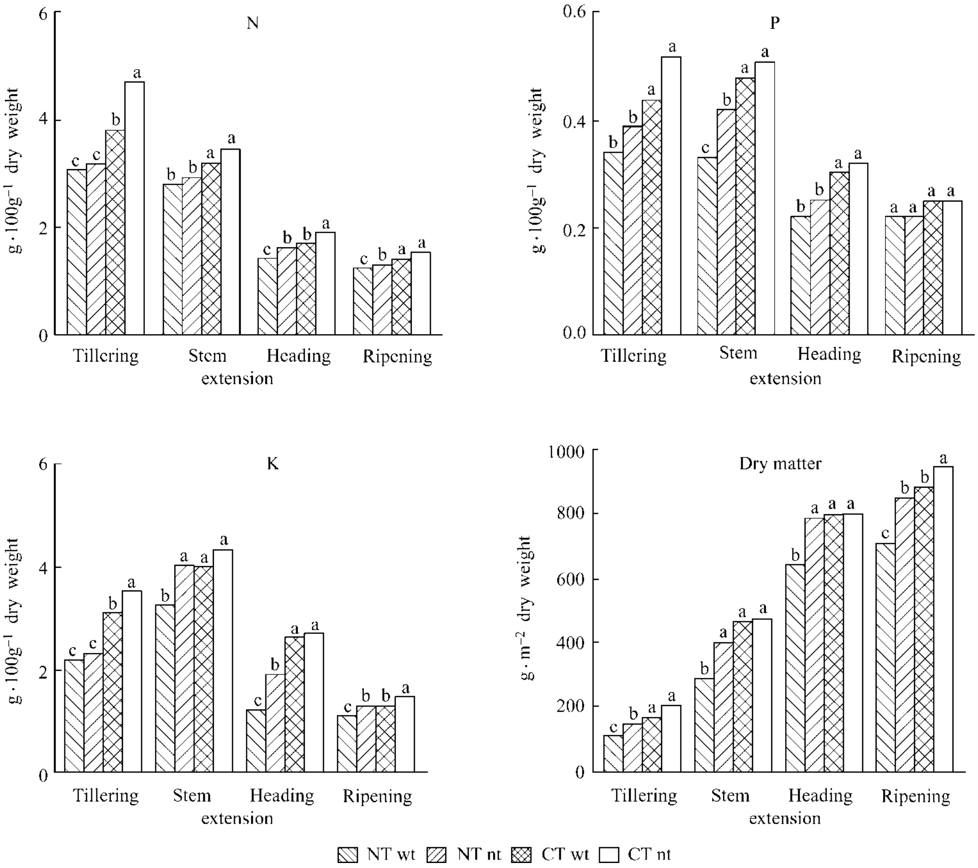


Fig.2 Concentrations of N, P, K (g • 100 g^{-1}) and plant biomass (g • m^{-2}) in barley plant at tillering, stem extension, heading and ripening as influenced by tillage system and wheel traffic. NT = no-tillage, CT= Conventional tillage, wt= wheel traffic, nt = no traffic. Means within a occasion followed by the same letter are not significantly different by LSD ($P < 0.05$)

The high N, P, and K concentrations observed in the soil upper layers (0mm to 150mm) in NT plots, were not reflected in the N, P and K, levels in the barley plants. Fig.2 shows the average concentration of N, P, K and plant biomass during four stages of the growing season: at tillering, stem extension, heading and ripening. The N and K concentrations were significantly lower under NT in all stages. The P concentration at ripening was no significantly different in both tillage systems. As regards traffic induced compaction, the NT plots under traffic showed a less biomass production with significant differences from NT plots under no traffic.

4 Conclusions

In conclusion, it is suggested that a significant limitation for the use of no-tillage in the site studied came from the generalised hardsetting of soil surface layers that, under conventional tillage, was in part compensated by plowing. In the latter case, soil compaction tends to be restricted in the space and time, as correspond to a more direct connection with the effects of tractor wheels.

Aknowledgements

Financial support from the JCCLM to the Project 167/RN-32 is gratefully acknowledged.

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