Root growth, soil water content and yield of barley under different tillage systems on two soils in semiarid conditions

Abstract

An experiment was conducted on two soils in a semiarid area in the Spain´s Ebro valley. Soil A was a Fluventic Xerochrept of 120 cm depth and Soil B was a Lithic Xeric Torriorthent of 30 cm depth. Three tillage systems were compared in Soil A: subsoiler tillage, minimum tillage and no-tillage, and two (minimum tillage and no-tillage) in Soil B. The experiment was repeated five years on Soil A and three on Soil B. Root length density, volumetric water content and dry matter were measured at important developmental stages. Yield was determined at harvest. In Soil A, root length density and volumetric water content were significantly greater for no-tillage than for subsoiler or minimum tillage (up to 1.4 cm cm^{-3} and 5% respectively), mainly in the upper part of the soil profile. At lower depths, differences as long as 0.8 cm cm^{-3} and 6% were also found. Mean yield (four years) was similar between no-tillage (3608 kg ha^{-1}) and minimum tillage (3508 kg ha^{-1}), and significantly smaller for subsoiler tillage (3371 kg ha^{-1}). In Soil B, no differences were observed between tillage systems for volumetric water content. Significant interactions between tillage and year were found for root length density, dry matter and yield. Mean yield (three years) was no significantly different for minimum tillage (1806 kg ha^{-1}) and no-tillage (1867 kg ha^{-1}). The results in Soil A showed that surface conditions are of major importance in the water content of the soil and determined the differences among tillage systems. **N**o-tillage favoured greater and deeper water accumulation in the soil profile and greater root growth. This makes this system potentially better for years of low rainfall. In Soil B no tillage system proved to be better because of the low water-holding capacity of this soil (56 mm).

Keywords: Root length density, soil water, conservation tillage, barley, semiarid.

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Introduction

In the semiarid area of the Ebro Valley (north-eastern Spain) water availability to crops is the factor most limiting rainfed agriculture. Annual rainfall is highly variable, ranging between 250 and 500 mm, as well as monthly distribution. Under such climatic conditions, water stored in the soil is of great importance to increase and stabilise yields. Adequate selection of tillage systems can increase the water availability for crops by increasing infiltration, reducing evaporation, eliminating weed competition, and allowing a better development of root systems. In our study area, La Segarra, tillage systems have evolved during the last 30 years from the traditional inversion system (mouldboard plough + cultivator) to a vertical system (subsoiler + cultivator) more suited to the high stone content in the surface soil, to reduce costs, and to loosen lower layers to increase infiltration. In some cases, tillage is restricted to two passes of a field cultivator before sowing. Recent interest in a no-tillage system increased primarily as a way to reduce time spent in crop operations. However few studies have been reported in our area about the performance of this systems (Hernanz and Girón, 1988; Pelegrín *et al.*, 1990; López and Arrúe, 1997).

Extensive reviews of the effects of tillage systems on soil physical, chemical and biological characteristics, and on crop growth and yield in various soil and climatic conditions have been made by McCalla and Army (1961), Unger and McCalla (1980), Unger and Stewart (1983), Lal (1989), Godwin (1990), Blevins and Frye (1993), and Cannel and Hawes (1994). The general conclusion is that no single tillage system is appropriate for all situations. Conservation tillage systems (including no-tillage), which leave more than 30% of the surface covered by mulch, nearly always increase stored soil water by increasing infiltration and reducing evaporation. This leads, depending on soil and climate conditions, to greater, equal or even smaller yields than with conventional tillage systems. As a general rule, conservation tillage performs best in well to moderately well-drained soils in arid and semiarid climates, and worst in poorly drained soils in sub-humid and humid regions were traditional inversion systems are more suitable. In soils that are prone to severe compaction and crusting and which have low water infiltration capacity, some form of tillage (as by field cultivator) is necessary to conserve soil and water and facilitate root and crop growth (Lal, 1989). In addition, during extended dry weather a soil mulch (shallow layer of soil loosened by tillage that breaks pore continuity) suppresses evaporation better than surface crop residues (Godwin, 1990). On soils with hardpans sufficiently compacted to seriously interfere with root development, subsoiling can increase crop yield by improving infiltration and water storage (Unger and Stewart, 1983; McDonald and Fischer, 1987), and by increasing the root depth and subsequent water and nutrient uptake (Reicosky, 1983). These soil-loosening treatments, however, are not required every year (Lal, 1989).

According to Godwin (1990) the effect of tillage on root development and function are by far the most important role of tillage in crop development. The root system serves as a bridge between the impacts of agricultural practices on soil and changes in shoot function and harvested yield (Klepper, 1990). One function of the root system is to absorb water stored in the soil. To achieve this objective roots must grow into moist soil before they can access the water. Tillage modifies these two processes, root growth and water uptake, by its effect on soil physical, chemical and biological properties. A good tillage system should increase the water available to the crop by facilitating root growth in zones of the soil profile from which water is lost by evaporation (shallow layers) or remains towards crop physiological maturity (deep layers) (Taylor, 1983). With conservation tillage systems roots tend to concentrate in the surface layer (McCalla and Army, 1961; Unger and McCalla, 1980; Lal, 1989; Cannell and Hawes, 1994) where water can be lost by evaporation. Deep tillage (subsoiling) increases rooting depth and thus the amount of water available to the crop (Reicosky, 1983).

Each tillage system has both advantages and drawbacks that can change with soil and climate. The objective of this work was to determine, under different tillage systems, if the pattern of root growth varies due to different soil water profiles and if these differences are reflected in dry matter and grain yield for two soils of contrasting depths.

Materials and methods

Two experimental fields were established in El Canós, a small village of the Segarra region in Catalonia, Spain. This is a semiarid region of the Ebro Valley with a mean annual precipitation of 440 mm. Following Papadakis (1966), the climate is Temperate Continental Mediterranean. The soils of the region differ greatly in depth according to geomorphologic position. In the more elevated structural platforms of the landscape, shallow soils have developed while in the lower areas, between the structural platforms, the soils are much deeper. We conducted our study in both deep and shallow soils. The deep soil (Soil A) was a loamy fine, mixed, mesic Fluventic Xerochrept, (Villar, 1989) of 120 cm depth, with a water-holding capacity of 266 mm. The shallow soil (Soil B) was a loamy, mixed, calcareous, mesic, shallow Lithic Xeric Torriorthent of 30 cm depth, with a water-holding capacity of 56 mm. Both soils have a high stone content, mainly in the surface (≈15%).

In each of the soils the experiment was established in farmer's field as a randomised complete block with four replications. The plots were 10 by 6 m. The experiment was repeated for five years in Soil A and for three years in Soil B. Three tillage treatments were applied to Soil A (subsoil tillage, minimum tillage, and no-tillage) and two to Soil B (minimum tillage and no-tillage), always over the same plots. Subsoil Tillage (ST) consisted of a subsoiler tilling at 40 cm depth in August followed by a field cultivator to 15 cm depth in October, before sowing. Minimum Tillage (MT) consisted of a field cultivator that worked the soil to a depth of 15 cm in September, after the first rains, and then in October, before sowing. No-Tillage (NT) consisted of direct-drill sowing after spraying with herbicide

(2 l 36% glyphosate [N-(phosphonomethyl) glycine] ha^{-1}).

Before sowing, fertiliser was broadcast at a rate of 50 kg P (18% superphosphate) ha^{-1} and 50 kg K (60% potassium chloride) ha^{-1}. Nitrogen fertilisation was done in February at a rate of 50 kg N (33.5% ammonium nitrate) ha^{-1}.

On Soil A, barley (*Hordeum vulgare* L.) cv. Dobla was sown in late October or early November in 1992, 1993, 1995 and 1996. In 1994 heavy rainfall in September and October waterlogged the experimental field so sowing was delayed until the beginning of February with another barley cv. Garbo. In 1996 heavy winter rainfall waterlogged the field, the crop failed, and was resowing in February with cv. Trait d'Union. Dry spring conditions, however, prevented good establishment and the crop was never harvested. On Soil B, cv. Dobla was sown in late October or early November in 1994, 1995 and 1996. For 1992 and 1993 a no-till disc drill was used but sowing depth was uneven due to the surface stones. Subsequently, for 1994, 1995 and 1996 a no-till tine drill was used to improve sowing. The sowing rate was 160 kg ha^{-1} (≈450 seeds m^{-2}) in rows spaced 17 cm apart.

After emergence, herbicide was applied as 25 g of 75% tribenuron-methyl [Methyl 2-1 ((((n-3-(4-methoxi-6-methyl-1,3,5-triazin-2-il) methylamino) carbonyl) amino) sulfonyl) benzoate] ha^{-1} to control broadleaf weeds and 2.5 l 50% chlortoluron [N-(3-chloro-4-methylphenyl)-N-N-dimethylurea] ha^{-1} to control *Lolium rigidum* L. In some years, an application of 2.5 l 30% imazametabenz-methyl [2-(4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl)-4(and 5)-methylbenzoic acid (3:2)] ha^{-1} was necessary to control *Avena sterilis* L. in Soil A, and an application of 2% lindane [Gamma 1,2,3,4,5,6-hexachlorociclohexane] to control *Zabrus tenebrioides* L. in Soil B. The harvest was performed with a microcombine. After the harvest, cut straw was removed from all plots.

Rainfall and temperature were monitored at a weather station situated 250 m from the experimental field.

Root length density and water content profiles were obtained from soil cores extracted between rows with Edelman or Riverside augers (EIJKELKAMP®) at important developmental stages of the barley: tillering, stem elongation, anthesis, physiological maturity and harvest. Additional samples were taken at sowing and, in some years, during winter to determine soil water content. In each plot of Soil A, soil cores were taken from 0-25, 25-50, 50-75 and 75-100 cm depth. In the shallow Soil B, soil cores sampled the profile from 0 to 10 and 10 to 30 cm. Roots in each core were washed by elutriation (Pearcy *et al.*, 1989) and stained following the procedure of Ward *et al.* (1978) and length determined by the line intersection method (Newman, 1966). Soil volumetric water content was determined by the gravimetric method (Campbell and Mulla, 1990). Water use was calculated as rainfall plus the difference in water content between maturity and sowing.

Above ground biomass was measured by removing plants from 2 randomly selected half-meter long sections of each plot at various stages of development and determining total dry weight. Development stage was determined according to the BBCH scale (Lancashire *et* *al.*, 1991). Grain yield was obtained by harvesting the entire plot, and corrected to 10% water content to allow comparisons.

Statistical analysis were accomplished using SAS® software. When necessary, original data were transformed to meet the assumptions of the ANOVA model. Data were analysed as repeated measures over time and space (Steel and Torrie, 1980; Gómez and Gómez, 1984). Experimental design was a split-split-split plot (Littell *et al.*, 1991) with year (YEAR) as a main plot and tillage (TILL), stage of development (BBCH) and depth (DEPTH) as a successive sub-plots. Mean separations were done for significant effects with the LSD test at P = 0.05 (Montgomery, 1991).

Results

1. Year and Rainfall Pattern

The years in which experiments were conducted can be divided in two groups according to rainfall amount and pattern. In the first three years (1992-93, 1993-94 and 1994-95), total rainfall from July to June was slightly less than the mean (441 mm) with 413, 388 and 430 mm, respectively. The rainfall distribution over these years was typically mediterranean with two rainfall periods, one in September-October and the other in April-May (Fig. 1-A). In the last two years (1995-96 and 1996-97), rainfall was much greater than the mean (551 and 603 mm, respectively) with a drier than normal October and wetter than normal November, December, January and June (Fig. 1-B). Low rainfall in October 1995 and 1996 resulted in low soil water content at sowing.

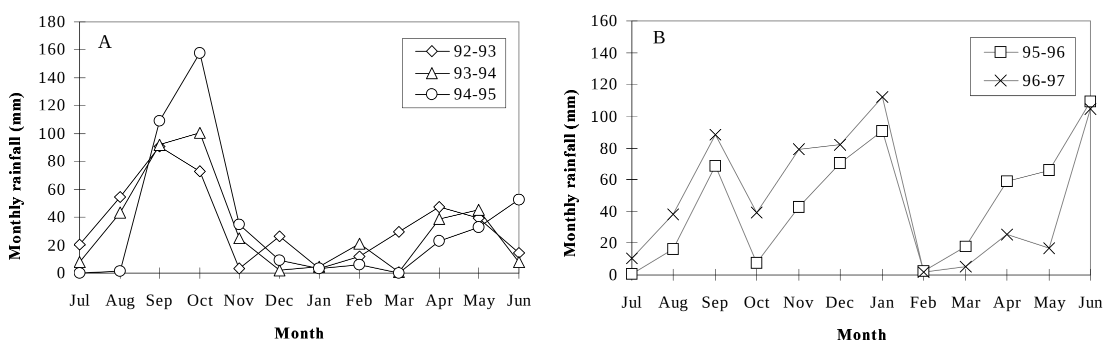

Fig. 1. Monthly rainfall distribution for each growing season.

2. Soil A

As expected by the variable annual rainfall distribution, the effect of year was highly significant in all variables studied ($P<0.0001$, Table 1). The trend of Volumetric Water Content (VWC) of the soil accorded with the rainfall and the growth of the crop (Fig. 2). Years 1992-93 and 1993-94, with low total precipitation, had low VWC reaching the lowest levels at harvest. Years with high rainfall, 1994-95, 1995-96 and 1996-97, in general reached the highest VWC. In 1995-96 and 1996-97 however, sowing was done in dry soil conditions due to delay of the autumn rains. Root length density (LV) was greatest in 1992-93 and 1993-94 (Fig. 3), the years with lowest rainfall. Water Use (WU) ranged from 425 mm in 1995-96 to 200 mm in 1994-95 (Fig. 4), and was well correlated with yield (r = 0.86). Greatest Dry Matter (DM) and yields were obtained in the years of more evenly distributed rainfall and greater WU: 1992-93 and 1995-96 (Fig. 5).

Tillage system significantly influenced soil water content (P<0.0003, Table 1). Under NT, mean VWC was greater than under ST or MT, especially after important rain events (October 1993, October 1994 and June 1996, Fig. 2). The VWC profile was also different for NT system (significant TILLxDEPTH interaction, Table 1). As shown in Fig. 6, greater VWC was found for NT than for ST or MT in the upper part of the soil profile at tillering and stem elongation 1992-93, tillering 1993-94, sowing 1994-95 and maturity 1995-96. The lower profile showed the same response at showing in 1993-94 and 1996-97 (data not shown). Small or no differences were found between MT and ST.

Table 1
Probability values from ANOVA for Volumetric Water Content (VWC), Root Length Density (LV), Dry Matter (DM), Water Use (WU) and yield (YIELD). Soil A.

Source of Variation	D.F.	VWC (%)	LV (cm cm^{-3})	DM (g m^{-2})	WU (mm)	YIELD (kg ha^{-1})
YEAR	4	0.0001	0.0001	0.0001	0.0001	0.0001
TILL	2	0.0003	0.02	NS	0.02	0.0003
TILLxYEAR	8	NS	0.07	NS	0.04	0.002
BBCH(YEAR)	20, 12, 17†	0.0001	0.0001	0.0001	-	-
TILLxBBCH(YEAR)	40, 24, 34	NS	NS	NS	-	-
DEPTH	3	0.0001	0.0001	-	-	-
YEARxDEPTH	12	0.0001	0.0001	-	-	-
TILLxDEPTH	6	0.01	NS	-	-	-
TILLxYEARxDEPTH	24	NS	NS	-	-	-
BBCH(YEAR)xDEPTH	60, 34	0.0001	0.0001	-	-	-
TILLxBBCH(YEAR)xDEPTH	120, 68	NS	NS	-	-	-
Model Pr > F		0.0001	0.0001	0.0001	0.0001	0.0001
R-Square		0.85	0.82	0.98	0.98	0.98
C.V.		5.5	11.0	6.9	5.0	0.7
Transformation		SQRT(VWC)	1/SQRT(LV+1)	$DM^{0.3}$	Unnecessary	LOG10(YIELD)

YEAR Growing season.
TILL Tillage system.
BBCH Development stage.
DEPTH Depth of soil profile.
D.F. Degrees of Freedom.
NS Non-significant at the 0.1 probability level.
C.V. Coefficient of Variation.
† D.F. for VWC, LV and DM, respectively.

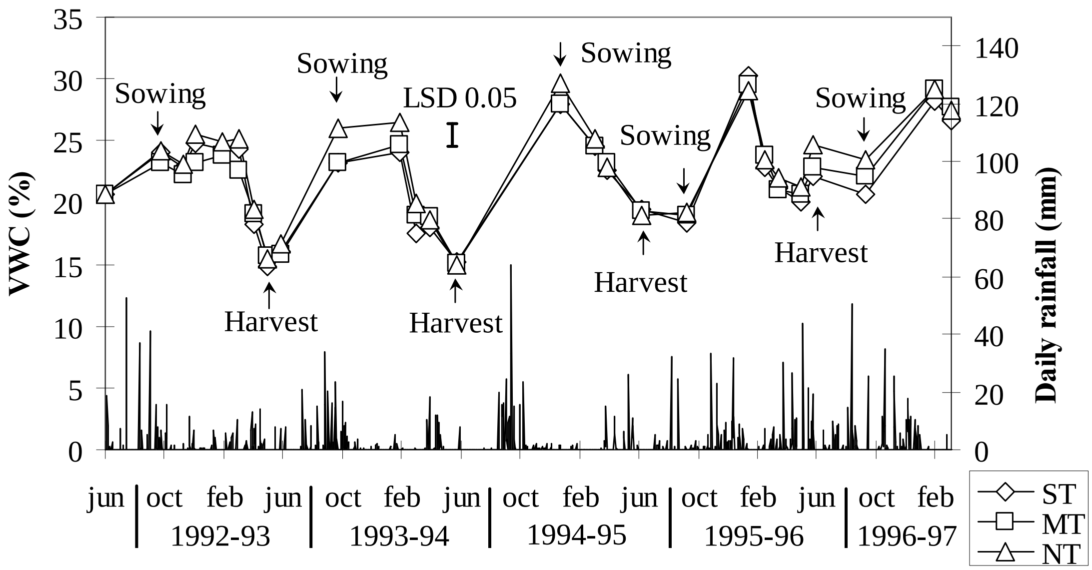

Fig. 2. Volumetric Water Content (VWC) trends over the years for the three tillage systems: Subsoil Tillage (ST), Minimum Tillage (MT) and No-Tillage (NT), and Daily Rainfall. Soil A.

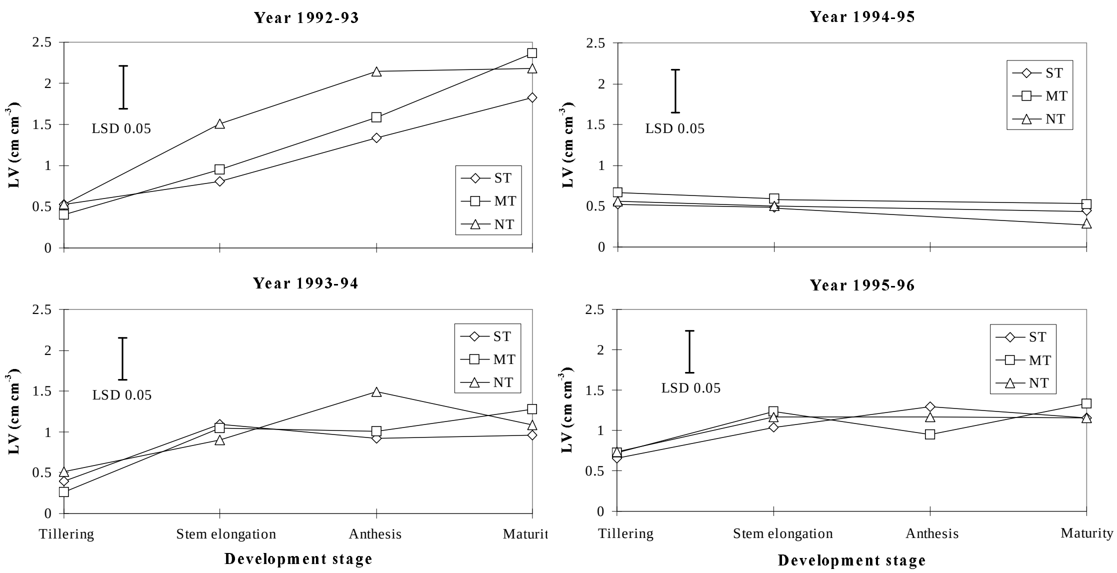

Fig. 3. Mean Root Length Density (LV) trends in each year for the three tillage systems: Subsoil Tillage (ST), Minimum Tillage (MT) and No-Tillage (NT). Soil A.

LV was significantly influenced by tillage (P<0.02, Table 1). LV was greatest under NT at stem elongation and anthesis of 1992-93 and anthesis of 1993-94 (Fig. 3). Even though TILLxDEPTH interaction was not significant, LV tended to be greatest under NT in the upper soil layers at stem elongation and anthesis 1992-93 and tillering and anthesis 1993-94 (Fig. 7), reaching 4.2 cm cm^{-3}. Greater root growth was also observed deep in the soil profile during the stem elongation and anthesis stages in 1992-93.

WU was significantly greater ($P<0.02$, Table 1) for NT than for ST and MT in the first three years, and significantly lower in 1995-96 (Fig. 4).

Though tillage did not affect DM, it had a significant effect on yield ($P<0.0003$ for TILL and $P<0.002$ for TILLxYEAR, Table 1). In general, greater yields were obtained for MT and NT (means 3508 and 3608 kg ha^{-1} over four years), exceeding ST by 20% and 10% in 1993-94 and 1995-96, respectively (Fig. 5).

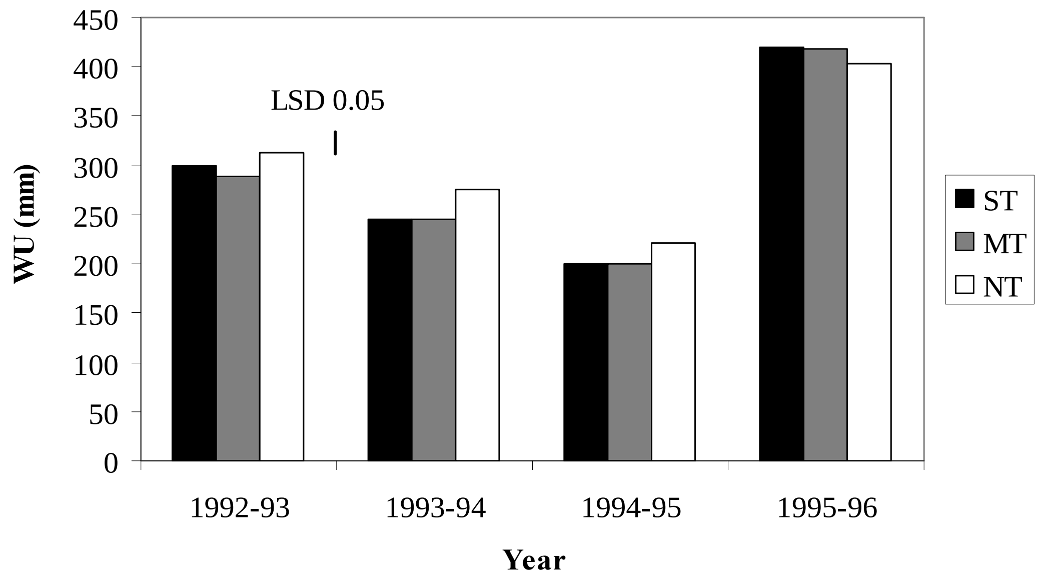

Fig. 4. Water Use (WU) in each year for the three tillage systems: Subsoil Tillage (ST), Minimum Tillage (MT) and No-Tillage (NT). Soil A.

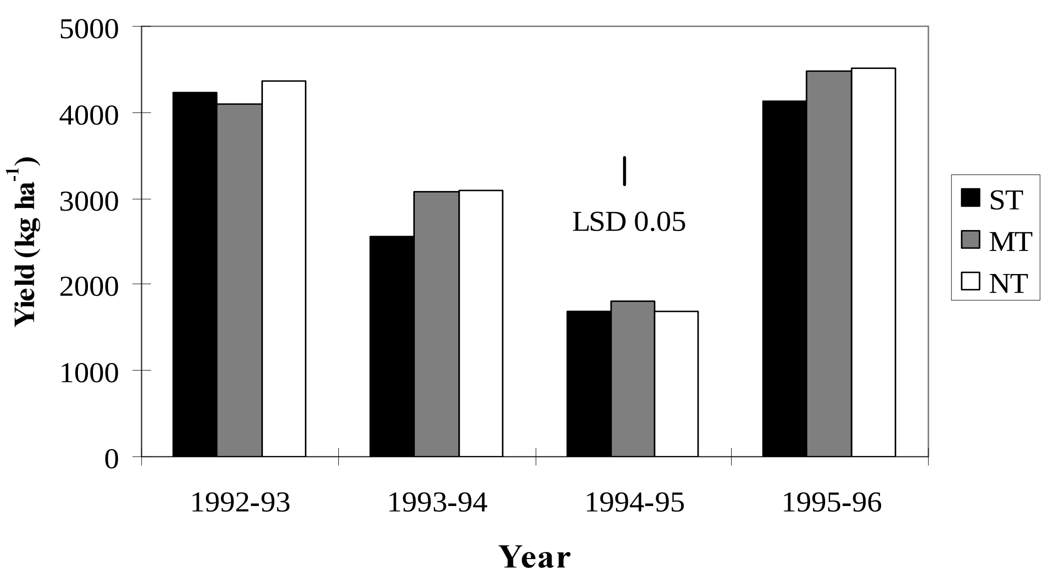

Fig. 5. Yield for each tillage system throughout the experiment: Subsoil Tillage (ST), Minimum Tillage (MT) and No-Tillage (NT). Soil A.

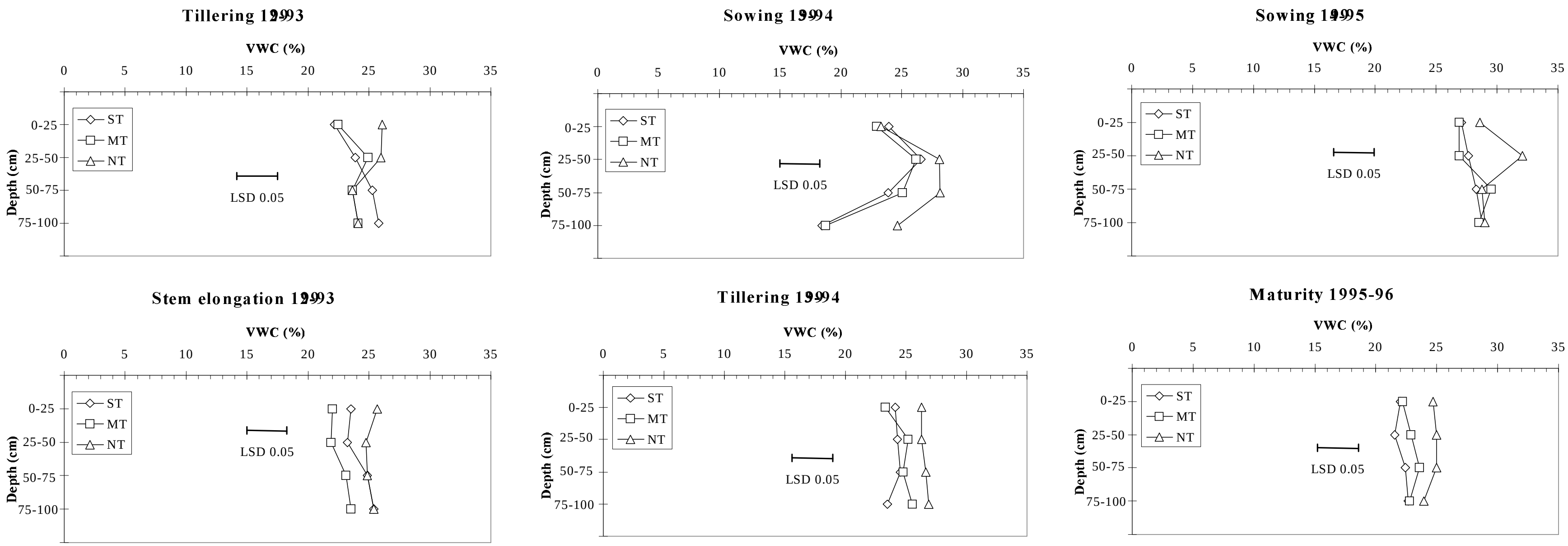

Fig. 6. Volumetric Water Content (VWC) profiles at various development stages in each year for the different tillage systems: Subsoil Tillage (ST), Minimum Tillage (MT) and No-Tillage (NT). Soil A.

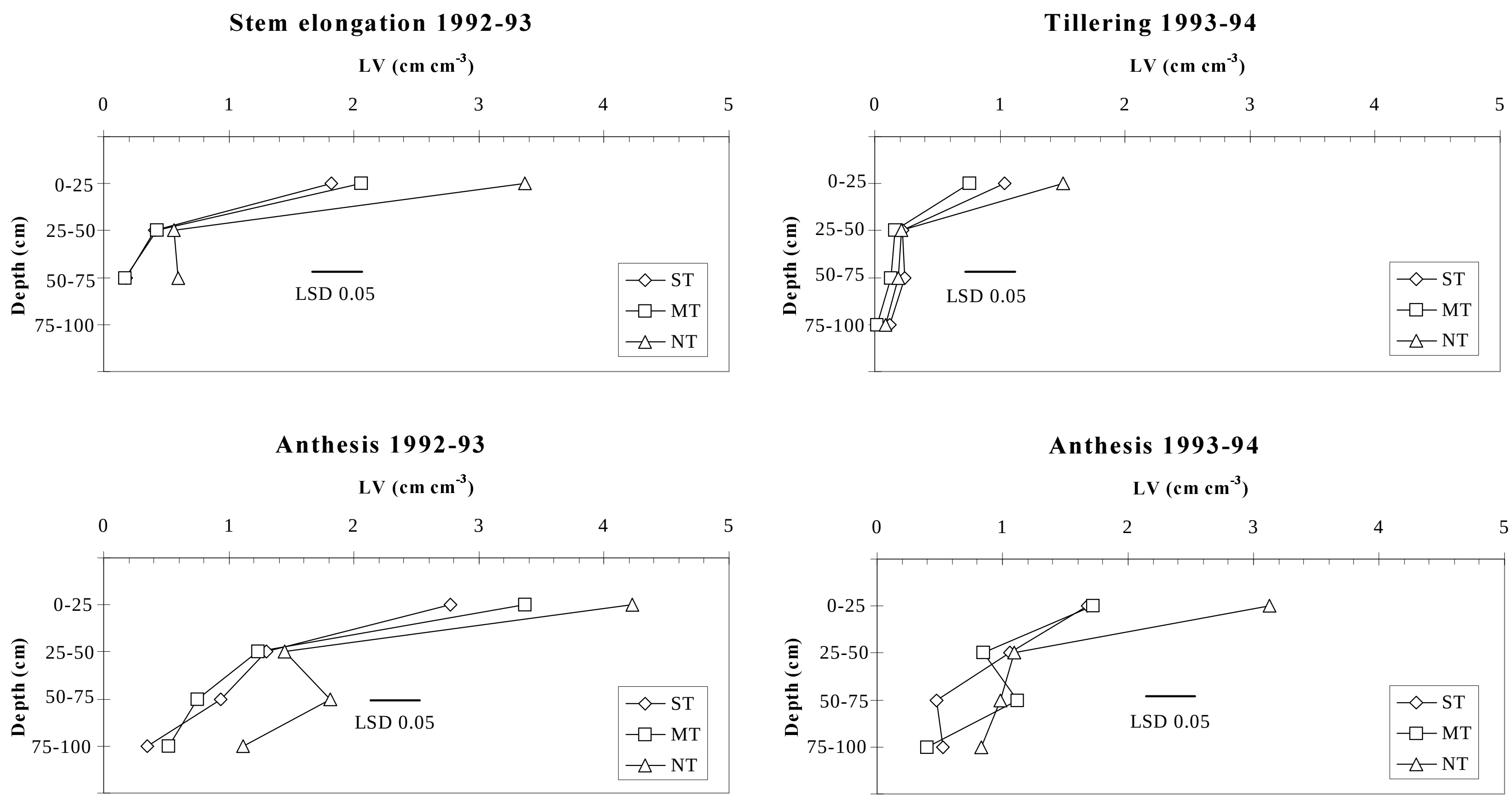

Fig. 7. Root Length Density (LV) profiles at various development stages in each year for the different tillage systems: Subsoil Tillage (ST), Minimum Tillage (MT) and No-Tillage (NT). Soil A.

3. Soil B

Like in Soil A, year had a significant effect in all the variables studied (Table 2).

The trend of VWC (Fig. 8) shows that year 1995-96 had greater water content because rainfall was well distributed over the year. In 1994-95, rains were scarce during the growing season, resulting in lower VWC. Curiously in 1996-97, the year of greatest rainfall, VWC reached values as low as in 1994-95 because of low rainfall during spring. In 1995-96 and 1996-97, unusual high rains in May and June increased VWC at the end of the cycle. LV was largest in 1995-96, reaching the greatest values between stem elongation and anthesis (Fig. 9). For years 1995-96 and 1996-97, DM at harvest and yield where near double those in 1994-95 (Fig. 10 and Fig. 11), and WU was more than double.

Over the 3 years studied, tillage system (TILL), did not have a significant effect on VWC, LV, DM, WU and yield as main effects (Table 2). However, TILLxYEAR interaction was significant for LV, DM, WU and yield. In 1995-96, LV, DM, WU and yield were greater for MT than for NT (Fig. 9, 10 and 11). In contrast greatest values were reached under NT in 1996-97 for those variables, though the difference was only significant for yield.

Table 2

Probability values from ANOVA for Volumetric Water Content (VWC), Root Length Density (LV), Dry Matter (DM), Water Use (WU) and yield (YIELD). Soil B.

Source of Variation	D.F.	VWC (%)	LV (cm cm^{-3})	DM (g m^{-2})	WU (mm)	YIELD (kg ha^{-1})
YEAR	2	0.0005	0.004	0.0001	0.0001	0.0002
TILL	1	NS	NS	NS	NS	NS
TILLxYEAR	2	NS	0.004	0.0009	0.02	0.04
BBCH(YEAR)	13, 8, 12†	0.0001	0.0001	0.0001	-	-
TILLxBBCH(YEAR)	13, 8, 12	NS	NS	NS	-	-
DEPTH	1	0.0001	0.0001	-	-	-
YEARxDEPTH	2	0.004	0.005	-	-	-
TILLxDEPTH	1	NS	NS	-	-	-
TILLxYEARxDEPTH	2	NS	NS	-	-	-
BBCH(YEAR)xDEPTH	13, 8	0.0001	0.08	-	-	-
TILLxBBCH(YEAR) xDEPTH	13, 8	NS	NS	-	-	-
Model Pr > F		0.0001	0.0001	0.0001	0.0001	0.0001
R-Square		0.96	0.81	0.92	0.99	0.92
C.V.		9.5	19.2	9.3	0.2	2.5
Transformation		Unnecessary	SQRT(LV)	DM$^{0.3}$	LOG_{10}(WU)	LOG_{10}(YIELD)

YEAR Growing season.
TILL Tillage system.
BBCH Development stage.
DEPTH Depth of soil profile.
D.F. Degrees of Freedom.
NS Non-significant at the 0.1 probability level.
C.V. Coefficient of Variation.
† D.F. for VWC, LV and DM, respectively.

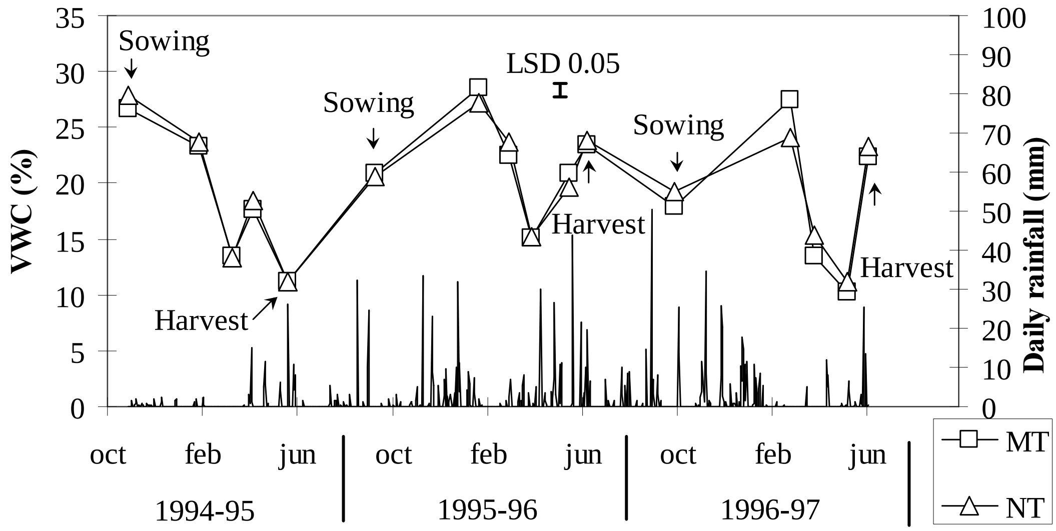

Fig. 8. Volumetric Water Content (VWC) trends over the years for each tillage system: Minimum Tillage (MT) and No-Tillage (NT), and daily rainfall. Soil B.

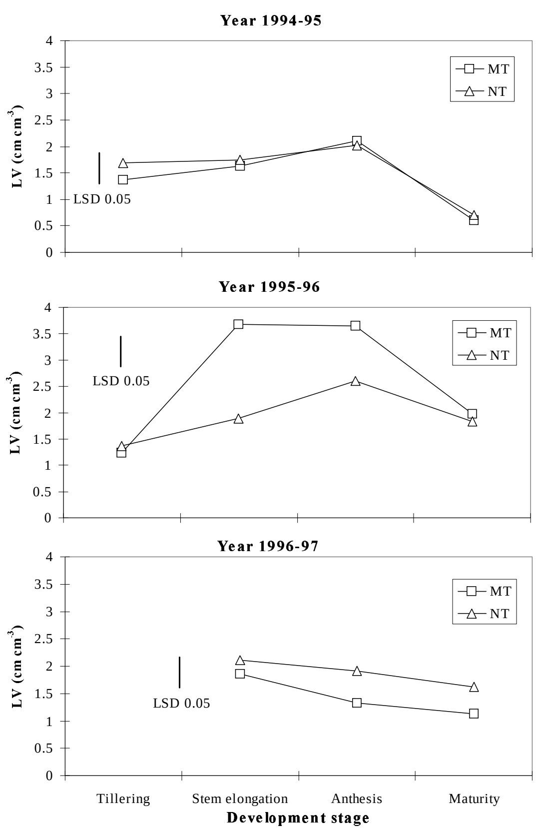

Fig. 9. Mean Root Length Density (LV) year trends for each tillage system: Minimum Tillage (MT) and No-Tillage (NT). Soil B.

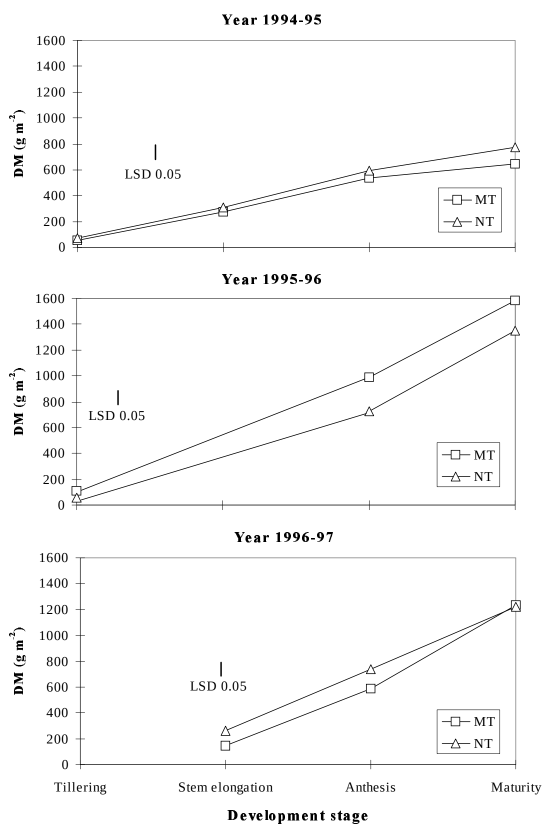

Fig. 10. Dry Matter (DM) year trends for each tillage system: Minimum Tillage (MT) and No-Tillage (NT). Soil B.

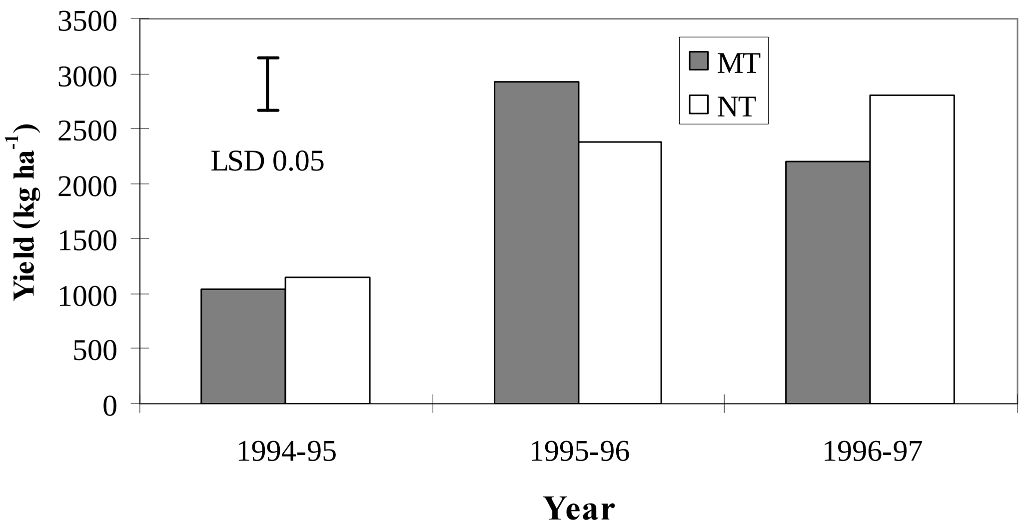

Fig. 11. Grain yield in three different growing season under two tillage systems: Minimum Tillage (MT) and No-Tillage (NT). Soil B.

Discussion

In general, differences between tillage systems were greater in Soil A than in Soil B. In Soil A, effect of tillage was reflected in greater soil water content of NT in the years of lower total precipitation (1992-93 and 1993-94, Fig. 2). In these years, NT had greater VWC in the upper layers of the soil (Fig. 6) after rainy periods (Fig. 2). It seems therefore, that the most important effect of NT, compared with the other tillage systems, is to increase infiltration.

NT maintains the soil surface, conserving natural soil structure and biopores (from earthworms and dead roots) thereby increasing infiltration. This pattern of water conservation in NT systems has frequently been observed when there are no long drought periods (McCalla and Army, 1961; Unger and McCalla, 1980; Unger and Stewart, 1983; Lal, 1989; Godwin, 1990; Blevins and Frye, 1993).

On the other hand, small differences were found between MT and ST probably because they developed the same surface conditions: soil loosened by the field cultivator and without plant residues.ST did not improve water infiltration deep in the soil. This suggest that subsoiling is not necessary unless a restricting infiltration layer exists deep in the soil profile (McDonald and Fischer, 1987).

In addition, NT showed, in some situations, greater VWC deep in the soil profile (Fig. 6). It is likely that good soil structure, biological channels and cracks, that develop under this tillage system, promote water accumulation at depth. Probably, if residues were not removed after harvest, more differences could be found in favour of NT system.

Several authors (McCalla and Army, 1961; Unger and McCalla, 1980; Lal, 1989;

Cannell and Hawes, 1994) report greater root growth in the surface layer in conservation tillage systems. This is attributed in some cases to increased moisture conditions (McCalla and Army, 1961) and in others to greater soil strength that reduces elongation of root main axes and stimulates branching (Cannell and Hawes, 1994).

Lal (1989) proposed a generalised root profile model with more roots in the soil surface under NT compared with the ploughed soil, and less roots in deeper layers. In Soil A, we obtained contrasting results. NT treatment showed greater root development not only in the upper layer but also in the lower ones (Fig. 7) during stem elongation and anthesis 1992-93. This was also reported by Merrill *et al.* (1996) working with spring wheat under drought.

Root growth is a function of soil resistance to penetration and water content (Klepper, 1990). Resistance to penetration depends on soil compaction and also on soil water content. Soil compaction, measured as bulk density of the first 14 cm of soil, was greater under NT than under ST or MT in Soil A (1.35 g cm^{-3} vs. 1.27 for MT or 1.25 for ST, Lampurlanés and Cantero-Martínez, 1996). Also resistance to penetration was higher for NT. It seems that in this soils water content determines root growth more than soil strength. Natural soil structure, vertical cracks and biological channels, preserved under NT, could also facilitate root penetration.

The relationship between water content and LV, studied in 1992-93 (Lampurlanés, 1994), changed during the crop life. During the vegetative period (until anthesis) roots are growing, and growth is greater where water content is larger (positive regression coefficient between VWC and LV). Contrarily, during the grain-filling period there is less water where there are more roots because the root system is extracting water (negative regression coefficient VWC vs. LV).

High root density in the surface layer is a favourable characteristic of crops in semiarid areas to allow ready absorption of water after rain and to minimise evaporation. Root growth deep in the profile allows the crop to explore a greater volume of soil and, consequently, to access more water and nutrients as demonstrated by the positive and high correlation coefficient (0.95) found between mean LV and WU during the first three years (1992-93, 1993-94 and 1994-95). According to this, root systems developed under NT in years of low rainfall seem to be more appropriate to greater yields.

For the deep Soil A, it is important to emphasise that yield in NT was never less than in other tillage systems (Fig. 5). Although MT and NT were similar in yield, NT promoted better water and root distribution in the soil. Yields were smaller under ST compared with MT and NT systems for the driest year (1993-94) and also in 1995-96, when the soil was extremely dry at sowing.

Therefore, for semiarid areas with deep and naturally well structured soils, NT seems to be more appropriate, especially in years of low rainfall, and ST is not an appropriate tillage system.

There was no clear effect of tillage on VWC and yield in Soil B (Table 2) probably because primary effect of tillage is on soil water accumulation. The small water-holding capacity of this soil (56 mm) prevented differences because under both tillage systems the soil reached its maximum capacity. This was also observed in a stony soil by Agenbag and Maree (1991).

Yields in Soil B were greater in 1995-96 and 1996-97, the years of high rainfall during the end of the crop cycle. This demonstrates that in soils of low water-holding capacity, water accumulated in the profile is insufficient to ensure yield. Yield depends more on favourable rainfall distribution during the growing season, specially during the grain-filling period, than on tillage system.

Conclusions

Surface conditions are of major importance to water infiltration into soil and determine the differences observed between tillage systems in deep soils. No-tillage is potentially better for semiarid regions because it maintains greater water content in the soil and promotes root growth in the surface soil and, in some cases, deep in the soil profile also, especially in years of low rainfall.

In shallow soils, differences between tillage systems in soil water content are masked by its small water-holding capacity. In these soils, yield is not advantaged by water accumulated in the profile but depends on favourable rainfall distribution throughout the growing season, including the grain filling period.

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