Effects of different soil tillage systems on sunflower yields and soil physical characteristics

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Abstract
Soil tillage represent a useful management tool to reduce agricultural inputs, preserve soil degradation, save money and increase crop production. The effects of different tillage systems on sunflower yields and physical characteristics of the soil were studied in a long-term experiment carried out in Tuscany on a clay soil. Deep ploughing (45-50 cm deep - DP), shallow ploughing (25-30 cm deep - SP), chisel ploughing (35-40 cm deep - CP) and disk harrowing (10-15 cm deep - MT) were tested from 1987 to 1990 on the same plots where a sunflower-durum wheat rotation was established. When climatic conditions were favourable (1988) grain yields under MT were always lower than under DP, SP and CP while no significant differences among tillage systems were observed in 1989 and 1990 when water storage in winter was lower than the average and strong water stress occurred in the early summer. Dry bulk density and soil cone resistance values under MT indicate a worsening of such soil physical characteristics that may imperil sunflower rooting towards the deeper soil layer. In any case, differences among DP, SP and CP were never observed. The use of alternative tillage systems such as SP or CP for sunflower seems agronomically and economically sustainable in the central Italy.
Key words: Sunflower, soil tillage, soil moisture, bulk density, cone resistance.

Introduction
Intensive agricultural systems, which have become widespread in industrial nations through the last thirty years has led to a decrease in physical, chemical and microbiological soil fertility in many areas (Lal, 1991; Reganold et al., 1993). Special attention must be given to soil management and, particularly, tillage techniques in this context. Inappropriate mechanisation may imperil soil structure, accelerate mineralisation and have adverse effects on soil biota. As a consequence, soil water holding capacity and drainage ability as well as soil organic content may decline while risk of severe erosion may increase (Cook and Lee, 1993). Conservation tillage techniques have been proving particularly adapted for reducing the impact of agricultural practices on the environment and cultivation costs in many areas without reducing significantly crop yields (Unger, 1990; MacRae et al., 1990; Allmaras et al., 1991; Tebrugge et al., 1991). This is particulary important in Italy where the ploughing depth is usually quite high: about 40-55 cm for summer crops and 25-35 cm for winter cereals. In central Italy, where sunflower is widely cultivated on clay soil and often in low-step hilly areas, tillage systems for sunflower are based upon summer deep ploughing (45-50 cm deep), carried out after wheat harvest and followed by secondary tillage (disk and/or rotary harrowing). Even if, this kind of tillage system allows stable yields and good weed control, it may provoke unfavourable changes in physical and chemical characteristics of the soil in the long run.

In addition, using deep ploughing, mechanical costs are very high and may strongly endanger farmer's gross margin when adverse climatic conditions reduce sunflower grain yields. Some experiments carried out in Italy (Bonari, 1992) suggested the possibilty to reduce ploughing depth and sometimes substitute ploughing with other tillage systems (as chisel ploughing and minimum tillage) without yield decrease. These data came from experience carried out in the inner areas of central Italy while results from the coastal plains are still lacking.

Materials and methods

The experiment was set up in 1987 on an alluvial clay soil (Tipic Xerofluvent) of a coastal plain of central Italy (tab.1). The effects of different tillage systems - deep ploughing (45-50 cm deep - DP), shallow ploughing (25-30 cm deep - SP), chisel ploughing (35-40 cm deep - CP) and disk harrowing (10-15 cm deep - MT) - on sunflower yields and physical characteristichs of the soil were studied in a long-term field experiment using a randomized complete block design with three replications. Two experimental sites (site W and site E) were used to establish a sunflower-durum wheat two-year rotation. All phases of the rotation were present each year. At each sites twelve plots (25x200 m) were tilled in 1987 after wheat harvest to grow sunflower in the following year. In 1988, after sunflower harvest the following rotations were carried out: site E, durum wheat (1989) - sunflower (1990); site W, sunflower (1989) - durum wheat (1990). Sunflower was replaced by grain sorghum in 1991 which is presently grown in the same experimental fields. During the winter, before sunflower sowing, soil samples were collected from 0 to 90 cm of depth, in steps of 15 cm to evaluate water storage at site E in 1990 and from 0 to 60 cm of depth in steps of 10 cm at site W in 1989. At each site, during the sunflower biological cycle, the soil was sampled from 0 to 60 cm of depth in steps of 10 cm to measure soil moisture and dry bulk density using the gravimetric method and the "small cylinder" method respectively. Cone resistance was also recorded by means of a penetrograph equipped with a 1 cm^2 surface cone area at the beginning of sunflower cycle. Grain yield, total biomass production and 1000 grain weigth were recorded at harvest on a 30 m^2 test area for each field. The most important agronomic aspects are shown in table 2.

Results, discussion and conclusion

The winter rainfall amount (from October to February) was greater than the average (1981-1990) in 1988 (660 mm vs 473 mm) and lower in 1989 and 1990 (311 and 273 mm respectively). The spring-summer rainfall amount (calculated from the last decade of May to the first decade of July) were 122, 113 and 60 mm in 1988, 1989 and 1990 respectively. As a consequence, in the same period, the water stress (calculated as difference between rainfall and potential evapotranspiration) was greater in 1990 (-197 mm) than 1989 and 1988 (-130 and -110 mm respectively) (tab.3). Sunflower yields seemed to be affected by tillage systems when climatic condition were favourable. In fact, grain yields and biomass production were significantly affected by tillage systems in 1988 contrarily to 1989 and 1990. In 1988, at each site, disk harrowing (MT) gave the worse productions while any significant difference was observed among DP, SP and CP (tab.4). The abscence of differences in sunflower grain yields using SP or CP in comparison with DP for any climatic conditions, may suggest a wider spread of these alternative tillage techniques in Italy thus reducing cultivation costs. Sunflower grain yield under MT may be similar to those obtained with DP, SP or CP when water stress conditions occur. In particular, the absence of appreciable water storage during winter coupled with poor rainfall or strong evapotranspirative demand in the early summer during sunflower flowering may make this tillage system useful to conserve soil moisture and to prevent crop failure. In fact, even though DP allowed a better water storage when rainfall were adequate in winter (fig.1: 07.03.89, 19.02.90), this advantage may be rapidly thwarted by the subsequent climatic patterns. Moreover the greater soil moisture content under DP or under SP seemed to be restricted to the tilled layer and decreased suddenly in the layers below the lower limit of cultivation. When the evapotranspirative processes prevail over the infiltration ones, the moisture stored in the tilled layer may exhaust out before sunflower is able to use it. As a consequence water availability became very similar among tillage systems during the stages when sunflower is more sensitive to water stress (fig.1: 20.05.89, 29.07.89, 21.06.90 and 19.07.90). In these conditions, MT and CP were able to preserve soil moisture more effectively than DP or SP. The water depletion rates, expressed as daily water loss from each of the sampled soil layer during the period between the 4th sunflower leaf and the end of flowering (in 1989) and between the 6th sunflower leaf and the full flowering (in 1990), were generally lower with MT and CP in both years (fig.2). Besides soil moisture, other physical characteristics could have influenced sunflower grain yield and water behaviour into the soil. Soil dry bulk density under MT was significantly higher in the 10-20 cm soil layer (corresponding to the lower limit of cultivation for the disk harrow) while below this layer the difference among MT, SP and CP were negligible. DP showed the lowest dry bulk density values especially in the deeper soil layers (30-50 cm) (fig.3). These findings, coupled with soil resistance results, indicate the presence of denser soil layers along the profile that can reduce both water infiltration in the deeper layers and rooting capacity. This is particularly dangerous for sunflower whose root deepening is very poor when soil density is not omogeneous (Maertens and Bosc, 1981). The possibility to spread out an alternative tillage system depends on its technical and economic feasibility. In comparison with DP, the other tillage systems that we have tested, showed a relevant varying costs reduction as average of the three-year period (-10%, -12% and -21% for SP, CP and MT respectively). Thank to this, sunflower gross incomes resulted higher for all the alternative tillage systems (+10%, +12% and +7% for SP, CP and MT respectively). According to the obtained results, the use of alternative tillage systems such as SP or CP for sunflower seems agronomically and economically sustainable in the central Italy. The use of MT system seems to be particularly useful for the environments of the inner hilly areas of Tuscany where water stress may occur more often.

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Table 1 - Soil characteristics as determined at the beginnig of the experience

Soil layers (cm)		0-7.5	7.5-15	15-30
Clay (i.s.s.s. method)	(%)	38	38	38
Silt	(%)	38	38	38
Sand	(%)	24	24	24
Wilting point	(g/g)	19.3	19.3	19.3
Field capacity	(g/g)	32.1	32.1	32.1
pH		8.4	8.3	8.3
Organic matter (met.Walkey-Black)	(%)	1.9	2.0	2.1
Total N (met. Kjeldhal)	(%)	0.11	0.11	0.12
P assimilable (met. Olsen)	(ppm)	26.9	23.3	23.8
K exchangeable (met.International)	(ppm)	122	126	138
$CaCO_3$	(%)	2.3	2.7	2.0

Table 2 - Agronomic aspects.

	Site E and W 1988	Site W 1989	Site E 1990
Pre-sowing fertiliz. N kg·ha^{-1}	40	40	40
P_2O_5 kg·ha^{-1}	120	120	120
K_2O kg·ha^{-1}	120	120	120
Top-dress fertiliz. N kg·ha^{-1}	100	100	100
Variety	Stromboli	Stromboli	Stromboli
Sowing time	28 March	1 April	22 March
Weed control	chemical (1)	chemical (1)	chemical (1)

(1) pre-emergence prometrin + metobromuron

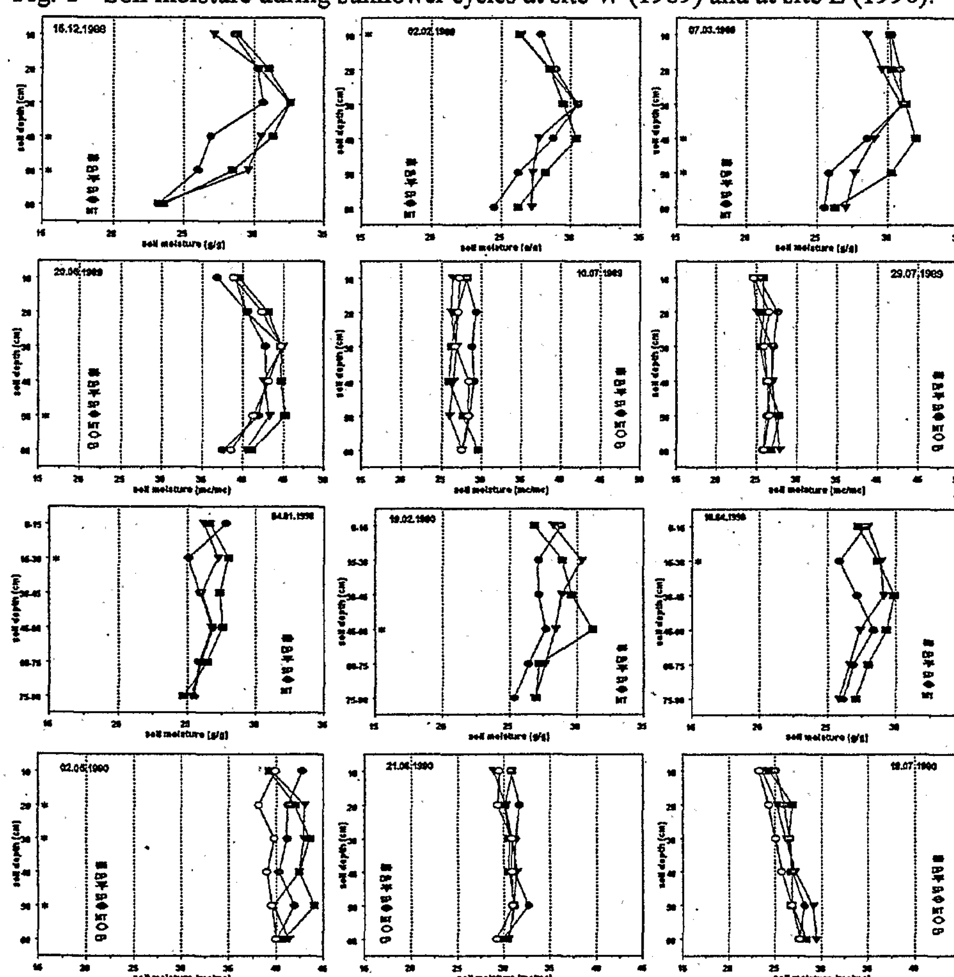
Table 3 - Climatic conditions.

Years	Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
1987	Rainfall	114	93	13	53	43	45	37	63	3	283	183	49
1988	(mm)	80	64	39	108	124	97	11	60	61	128	73	29
1989		21	25	35	183	10	58	52	59	147	40	93	42
1990		45	53	38	188	19	32	13	43	83	223	181	138
1987	Water	101	72	-38	-17	-48	-77	-102	-56	-94	241	160	37
1988	stress	64	35	-9	45	40	-10	-129	-70	-1	83	52	29
1989	(mm)	10	-11	-20	123	-96	-67	-69	-59	69	40	93	42
1990		26	24	-8	122	-104	-86	-126	-78	2	172	156	126

Table 4 - Grain and biomass production, harvest index and 1000 seeds weight of sunflower

		SITE W					SITE E			
Year		Grain yield (t·ha⁻¹)	Bio-mass (t·ha⁻¹)	Harv. index (%)	1000 seeds (g)	Year	Grain yield (t·ha⁻¹)	Bio-mass (t·ha⁻¹)	Harv. index (%)	1000 seeds (g)
1988	DP	2.93 a	7.80 a	37.6 ns	53.5 ns	1988	2.89 a	7.59 a	38.1 ns	55.6 ns
	SP	2.93 a	7.64 a	38.3 ns	52.0 ns		2.97 a	7.65 a	38.9 ns	52.0 ns
	CP	3.02 a	7.82 a	38.6 ns	49.8 ns		2.91 a	7.56 a	38.5 ns	53.3 ns
	MT	2.16 b	5.60 b	38.7 ns	53.9 ns		2.45 b	6.33 b	38.7 ns	54.6 ns
1989	DP	2.55 ns	6.52 ns	39.1 ns	46.9 ns	1990	2.24 ns	5.67 ns	39.8 ns	52.2 ns
	SP	2.39 ns	5.59 ns	42.7 ns	41.7 ns		2.08 ns	5.23 ns	39.8 ns	48.9 ns
	CP	2.31 ns	5.59 ns	41.5 ns	45.8 ns		2.09 ns	5.53 ns	38.2 ns	52.3 ns
	MT	2.12 ns	5.49 ns	39.4 ns	45.6 ns		1.90 ns	4.85 ns	40.0 ns	52.9 ns

Fig. 1 - Soil moisture during sunflower cycles at site W (1989) and at site E (1990).



(*) soil layers where differences among means are statistically different at the 0.05 level

Fig. 2 - Soil water depletion rate at site W (1989) and site E (1990).

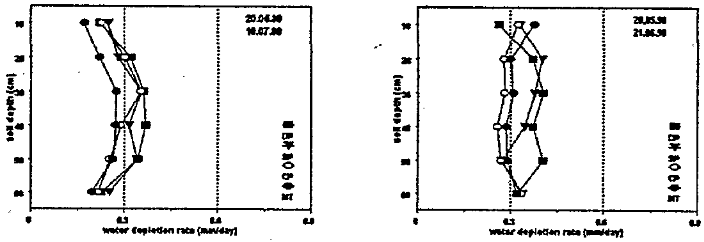
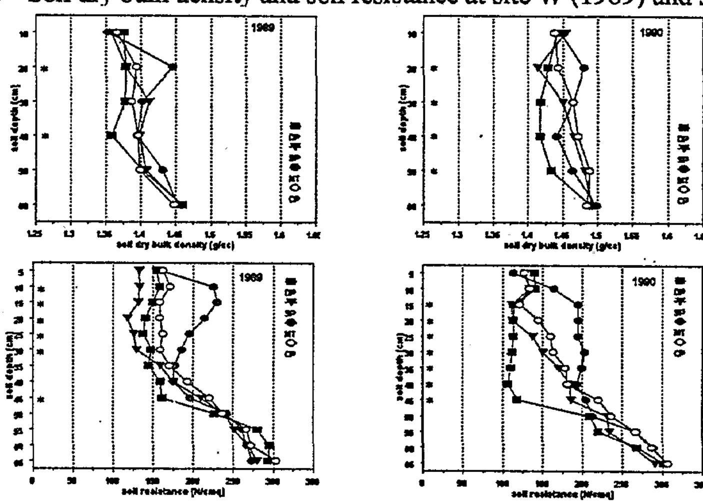


Fig. 3 - Soil dry bulk density and soil resistance at site W (1989) and site



(*) soil layers where differences among means are statistically different at the 0.05 level