EVALUATION OF FOUR CONSERVATION TILLAGE METHODS IN THE SUGAR BEET CROP

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ABSTRACT

In Greece there is a need for reducing sugar beet production costs and adopting methods enhancing sustainable agriculture. Minimizing tillage operations by adopting conservation tillage can provide significant energy and cost production savings. Additionally, reduced or no-tillage can offer the opportunity to the farmers to conform to the good management practices imposed by the EU. A three year conservation tillage experiment was carried out in Central Greece in order to evaluate the profits. Tested methods were: reduced tillage with a heavy cultivator (HC), rotary cultivator (RC), disk harrow (DH) and no-tillage (NT) compared with a conventional tillage method (CT) using plough. Reduced tillage methods caused an increase of weeds, of the soil dry bulk density, penetration resistance and shear strength. Soil retained a greater amount of water in the seedbed layer. As a result, crop emergence was facilitated in dry years. Plant growth was better in the methods of CT and HC. Conservation tillage reduced yields compared to CT method, by 1,2-8,9% in the HC by 19,7-34,3% in the RH, by 20,4-31,3% in the DH and by 26,1-46,6% in the NT.

Keywords: Conservation tillage, Reduced tillage, No-tillage, Sugarbeet.

INTRODUCTION

Sugar beet is the fifth most important arable crop in Greece. (National Statistics Bureau, 2000). EU' s CAP reform and the World Trade Agreement resulted in lower prices. Farmers are under pressure to reduce production costs to remain competitive. At the same time EU Agenda 2000 and the directive for good agricultural practices require the adoption of cultivation techniques friendly to the environment. Tillage is a labour and energy intensive field work (Larney, et al., 1988, Hernanz et al., 1995). It can have considerable effects to the crops (Ekeberg and Riley, 1997), the soil (Watts et al., 1996) and the environment (Uri et al, 1998). In Greece farmers are ploughing their fields for spring-sown crops every autumn before the rainy period which starts in November or December. Fields are left undisturbed until seedbed preparation. For sugar beet crop they start seedbed preparation in February to drill the crop by the end of February or March. Seedbed preparation is accomplished by several passes of disk or tooth harrows. In the recent years rotary tillers were imported and used, especially in dry years.

In Greece limited data exist on the use of minimum or no-tillage methods of crop establishment. Gemtos et al. (1998) have presented data of successful wheat establishment with minimum tillage, after cotton crop. In an experiment contacted at

Northern Greece, Doundoulakakis (1992) found that establishment of sugar beet crop planted under no-till with a winter wheat cover crop was one week earlier and stands were 9,4% more than with conventional tillage. Generally speaking the data on conservation tillage are limited for Greek conditions and this is a draw back for any attempt to enhance minimum tillage adaptation by Greek farmers although international data suggest that a lot of benefits can be expected for the farmers and the environment.

A serious problem caused by conventional tillage practices is soil erosion. In Greece 34% of the arable land is in slopes. Mitsios et al. (1995) estimated that about 150-300 million tones of fertile soil are removed annually from the surface with erosion. Conservation tillage is defined as any tillage and planting system that keeps at least 30% of the soil surface covered by residue after planting and includes such practices as no-tillage, ridge tillage, strip tillage, mulch tillage and reduced tillage. Covering the soil surface with crop residue provide significant protection from soil erosion (James and Russell, 1996). The plant residue also impedes evaporation of soil water keeping the upper layer moist (Gantzer and Blake, 1978). Increased soil moisture in the seedling depth advance emergence of the seedlings (Giles et al., 1995, Gemtos and Lellis, 1997).

Another serious problem, which had led to serious soil degradation of the arable Greek lands is the compaction caused by heavy machinery. In conventional tillage there is intensive use of heavy machinery for field operations such as large tractors and harvesters. Cooke and Scott (1993), found in Germany that the intensity of freight movement in the field, for the sugar beet crop is about 300 - 400 t*km/ha for the whole productive period. Up to nine passes might be necessary just for seedbed preparation, application of fertilisers, herbicides and planting. Compaction decreases soil porosity and water capacity and adversely affects crop establishment, plant growth and final yield (Arvidsson and Hakansson, 1996, Gemtos and Lellis, 1997). With reduced tillage however traffic in the field is minimised and compaction is prevented (Chancellor, 1977). In addition soil aggregate stability is increased and strength to compaction is improved (Mahboubi and Lal, 1998).

In the sugar beet crop, about 30% of the plant mass is allocated in the tops and usually return to the field as green manure. In conservation tillage systems the organic matter of the upper layer of the soil is gradually increased due to the decomposition of crop residue (Hao, 2001). Increased organic matter improves soil structure and fertility and prevents compaction (Haiquan et al., 1997, Thomas et al., 1996).

As a result of the improved soil properties, the yield of the crop is increased. According to Koch et al. (1994), sugar beet yields with reduced tillage are similar to that of beets grown in ploughed soil when the N-application is increased. N-fertilization during the first years of adoption of conservation methods of tillage must be increased because the soil micro-organisms that decompose the crop residue compete with the crop for N usage (McConnell et al., 1994).

Miller and Dexter (1983) found that yield of sugar beet in no-tillage is equal to that of conventional tillage if there is sufficient control of weeds. Hao et al. (2001) also found no significant reduction in sugar beet yield when ploughing was substituted by chisel cultivation. According to Dragovic (1982) there is no significant improvement in sugar beet yields by deep tillage. However by reducing tillage depth to 12-18 cm Koowenhoven, (2002) found a reduction in sugar beet yield up to 9% compared with mouldboard ploughing at a depth of 20-30 cm.

In order to investigate the margins for reducing the intensity of tillage in the sugar beet crop by identifying the effects on soil compaction, soil moisture conservation, weed control, crop emergence, growth, yield and product profits, as well as energy consumption, a three-year experiment was established in 1997 at the Farm of University of Thessaly, in Velestino, Central Greece

MATERIALS AND METHODS

The experiment was carried out in two fields, a silty - clay (sand 9.7%, silt 41.1, clay 49.2, O.M. 1.26%) and a clay (sand 20.1%, silt 32.7%, clay 47.1%, O.M. 1.08). The experimental design was split strip blocks with four replications. Main plots had a width of 6 m with twelve rows of sugar beets and a length of 10 m. Five methods of tillage:

1. Conventional tillage (CT) with ploughing at 25-30 cm in autumn and 2-3 passes of a disk harrow at 7-9 cm or a light cultivator at 6-8 cm for seedbed preparation.
2. Reduced tillage (HC) using a heavy cultivator at a depth of 20-25 cm or a subsoiler at 30-35 cm and 2 passes of a disk harrow or a light cultivator for seedbed preparation.
3. Reduced tillage (RC) with one pass of a rotary cultivator at 10-15 cm for primary tillage, and one or two passes of a disk harrow or a light cultivator before planting.
4. Reduced tillage (DH) Primary and secondary tillage with a disk harrow at 6-8 cm. One or two passes in autumn or early in the winter for residue management and weed destruction and one or two passes for seedbed preparation before planting the crop. In the third year a field cultivator was used for secondary tillage
5. No-tillage (NT). Direct planting using a conventional pneumatic planting machine. The weeds were destroyed with *glyphosate* application within one week after planting the crop.

Sub-plots included two local varieties of sugar beet. *RHIZOR* which is considered resistant to rhizomania and *TURBO*, which is an early maturing one. Sugar beet were grown in rotation with other common crops in Greece as shown in Table 1.

A conventional seeder was used for planting. Fifteen seeds/m were placed in rows 50 cm apart and at a depth of 3 cm. Five plants per m were left after thinning. Fertilization for the first year was based on soil analysis and the recommendations of the Hellenic Sugar Industry. In the silty-clay field a basic dressing was applied by incorporating 50, 110 and 350 units of N, P, and K respectively per ha, while in the clay field fertilization applied at 120, 110 and 300 units of N, P and K respectively per ha. For the other two years fertilization was applied according to local conventional practices 140, 70 and 20 units of N, P and K respectively per ha applied in both fields.

In both fields, two to three sprayings with a mixture of low doses of the herbicides: (*phenmedipham, enthofumesate, metamitron* and *paraffinic* oil, each at 500g\ha) were carried out each year to control broad leave weeds. In addition, one or two sprayings were done with *haloxyphop* at about 800g\ha to control cereals. In order to obtain better control during the third year 10 kg/ha *metamitron* were incorporated into the soil before planting. Two manual hoeing were applied in 1997 and 1998 and one in 1999. Each year, about 500 mm of water were applied during the growing period using a drip irrigation system with pipes placed every two beet rows (1 m apart). A prolonged period of draught after planting in 1998 a water application was necessary to enhance crop emergence. In the clay field irrigation was applied one week later than in the silty-clay field. Harvesting was done by hand by extracting plants from two rows of 7,5 m long in each plot. In Table 2 the timetable of the field operations for each year is presented.

Table 1. Rotations of sugar beet crop

	Previous crops (1996)	First year crops (1997)	Second year crops (1998)	Third year crops (1999)
Rotation 1	Cotton	Cotton	Sugarbeet	Corn
Rotation 2	Cotton	Corn	Sugarbeet	Cotton
Rotation 3	Wheat*	Cotton	Corn	Sugarbeet
Rotation 4	Wheat*	Sugarbeet	Cotton	Corn

*Only in the silty-clay field. In they clay field a cotton crop existed

Sub-plots included two local varieties of sugar beet. RHIZOR which is considered resistant to rhizomania and TURBO, which is an early maturing one. Sugar beet were grown in rotation with other common crops in Greece as shown in Table 1.

A conventional seeder was used for planting. Fifteen seeds/m were placed in rows 50 cm apart and at a depth of 4 cm. Five plants per m were left after thinning. Fertilization for the first year was based on soil analysis and the recommendations of the Hellenic Sugar Industry. In the silty-clay field a basic dressing was applied by incorporating 50, 110 and 350 units of N, P, and K respectively per ha, while in the clay field fertilization applied at 120, 110 and 300 units of N, P and K respectively per ha. For the other two years fertilization was applied according to local conventional practices 140, 70 and 20 units of N, P and K respectively per ha applied in both fields.

Table 2. Field operations for the five methods of tillage for each year.

	1997					1998					1999				
	CT	HC	RC	DH	NT	CT	HC	RC	DH	NT	CT	HC	RC	DH	NT
Primary tillage			11/11					26/3					20/1		
Ploughing	+					+					+				
Heavy cultivator		+					+								
Subsoiler												+			
Rotary cultivator			+					+					+		
Disk harrow				++					+					++	
Secondary tillage			17/3					2/4					25/2		
Disk harrow	++	++	++	++		++	+	+	+						
Field cultivator											++	++	+	+	
Glyphosate application					26/3					8/4					5/3
Fertilization			19/3					3/4					3/3		
Metamitron incorporation													3/3		
planting			20/3					6/4					4/3		
Sprinkler irrigation								21/4 (29/4)							
Low doses herbicide application			6/5 & 13/5					27/4 & 4/5					14/4 & 23/4 & 18/6		
Haloxyphop application			9/5					28/4					16/4 & 20/6		
thining			18/5					15/5					28/4		
Manual hoeing			28/5 & 5/7					5/5 & 12/6					28/5		
Harvest			10/10					19/10					30/9		

In both fields, two to three sprayings with a mixture of low doses of the herbicides: (*phenmedipham, enthofumesate, metamitron* and *paraffinic oil*, each at 500g\ha) were carried out each year to control broad leave weeds. In addition, one or two sprayings were done with *haloxyphop* at about 800g\ha to control cereals. In order to obtain better control during the third year 10 kg/ha *metamitron* were incorporated into the soil before planting. Two manual hoeing were applied in 1997 and 1998 and one in 1999. Each year, about 500 mm of water were applied during the growing period using a drip irrigation system with pipes placed every two beet rows (1 m apart). Because a prolonged period of draught prevailed after planting in 1998, sprinkler irrigation was necessary to enhance crop emergence. In the clay field irrigation was applied one week later than in the silty-clay field. Harvesting for yield estimation was done by hand by extracting plants from an area of 7,5 m^2 in each plot. The rest of the area was harvested with a conventional sugar beet harvester after taking the samples. In Table 2 the timetable of the field operations for each year is presented.

Soil physical properties, weed biomass and plant's growth measurements were carried out each year.

Weed dry biomass was estimated by sampling the aerial part of the plants at two random square sampling areas in each plot. Squares had dimensions of 50 cm. The weeds were weighed and samples were oven dried at 72^0C for 48 h. Dry mass per m^2 for each plot was calculated.

Soil dry bulk density and moisture content were measured at the beginning of each period at two depths, 0,5-3 cm and 7,5-10 cm. Sampling for dry bulk density was made by means of metal cores with a diameter of 70 mm and a height of 25 mm. Soil moisture content was estimated into the same samples by oven drying at 104^0C for 48

h. Soil shear strength and penetration resistance was also measured during the period of root development. Shear strength was measured by means of a shear vane at depths of 5, 10, 15, 20 and 25 cm. The vane had a height of 5 cm and a width of 2,5 cm. Three sets of measurements were taken at each plot and a mean for each sampling depth was calculated. Penetration resistance was measured with a Bush soil penetrometer supporting a cone with base diameter 12,83 mm. Measurements were taken at intervals of 1 cm to a final depth of 35 cm. Five measurements were taken on each plot and average values for intervals of 5 cm were calculated.

During emergence of the crop, beet populations were monitored every three to five day intervals. Measurements were carried out at two marked rows, 1 m long, on each plot. During the growing periods, the leaf area was monitored. From each plot plants of a row of 1 m were collected. LAI was estimated by comparing the leaves with templates of known area. In addition, during the second and third year, the length, the max diameter and the angle of development of the sampled plants were monitored. Yield was measured in October of each year, the middle of the harvesting period in Greece. Two rows of a length of 7,5 m were collected by hand from each plot. The tops were removed with knife and the fresh relative weight of roots and tops was measured. Root samples were analysed by the Hellenic Sugar Industry for the sucrose content and the Na and N-impurities.

An instrumented tractor described by Gemtos and Tsiricoglou (1994) and Gemtos et al. (2000) was used for the tillage operations to estimate the energy consumed for the five tillage treatments. The implements measured draft forces, PTO torque and turning velocity as well as travelling speed of the tractor. The data were used to estimate the energy consumed through traction and through PTO i.e. the net energy for tillage. Energy for tractor movement and the other energy spent were not taken into account.

RESULTS

Weeds

Fig 1 shows that when tillage is reduced weed infestation is dramatically increased. In the no-tillage plots, before *glyphosate* application, there was a significant amount of weeds. Although these weeds were destroyed by the *glyphosate* a new infestation appeared few weeks later and the problem persisted throughout the whole growing period. Despite the significant reduction during secondary tillage, in the methods of rotary cultivator and disk harrow there were also a serious weed problem during the first critical period of development of the crop. In the plots of the heavy cultivator the weeds were generally more than conventional tillage. In this method, a lot of weeds persisted in the field after primary tillage and made difficult the seedbed preparation. Also a greater amount of spring weeds competed with the sugar beet crop.

In the first year (1997), in the silty-clay field, sugar beet crop followed a winter wheat crop and so before secondary tillage, winter weeds were predominant. During the second year (1998), two rotations of sugar beet existed and were combined with the five methods of tillage. A significant statistical interaction (P= 0.01) was detected between the two factors for the first two sets of measurements (12/4 and 5/5/98). In the "cotton - sugarbeet" rotation, there was a significant greater amount of weeds in the methods of reduced tillage (Fig 2). In the "corn -sugarbeet" rotation, the corn stalks that were left on the surface shaded the soil and did not allow the weeds to emerge. This phenomenon however was not observed in the conventional tillage where the stalks were incorporated into the soil by the inverting action of the plough. The last set of measurement (15/7) was carried out after manual hoeing when the stalks were removed from the plots along with the weeds and new weeds had emerged. During that period the beets were already shading the soil and no differences were found between the two rotations.

The predominant species of the weeds were: *Sonchus sp, Amaranthus retroflexus, Circium arvensis, Xanthium strumarium, Chenopodium album, Echinochloa crus-gali, Cyperus rotondus, Convolvulus arvensis, Silipum marianna, Euphorbia helioscopia, Veronica hederifolia.*

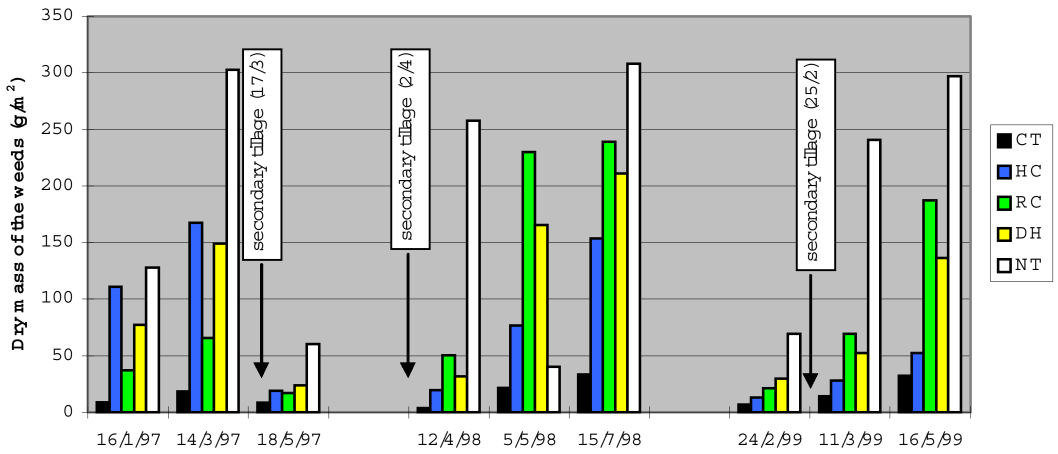

Fig 1. Dry mass of the weeds in both fields for the three years.

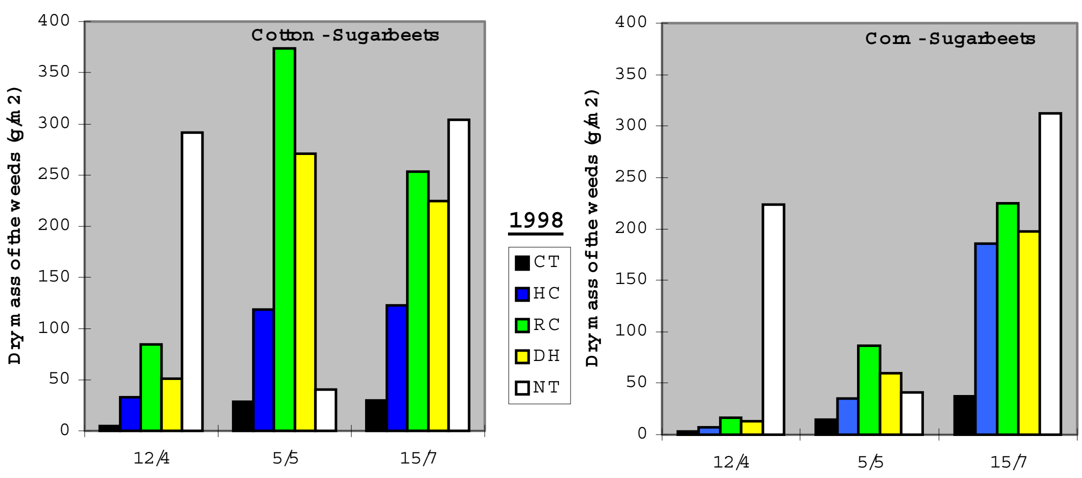

Fig 2. Dry mass of the weeds in both fields for the two rotations in 1998.

Soil properties

Reduced tillage plots presented a higher bulk density (Table 3). Differences were greater at the upper layer of the soil. Greater values were found in no-tillage plots. On the second and third year bulk density was further increased because no soil loosening operations were performed to alleviate the compaction caused by tractor and machinery traffic. As a result, soil porosity was low and at a depth of 7,5-10 cm it was less than 40%. The methods of disk harrow and rotary cultivator presented also higher bulk densities at a depth of 7,5 -10 cm. The most loose soil surface was found in conventional tillage with bulk densities ranging from 1,05 - 1,15 g/cm3. As a result, soil porosity was about 60%.

Table 3. Dry bulk density of the soil

	Dry bulk density (g/cm^3)					
	26/3/97		22/4/98		11/3/99	
	0.5-3 cm	7.5-10 cm	0.5-3 cm	7.5-10 cm	0.5-3 cm	7.5-10 cm
CV (%)	8,44	6,82	9,81	7,80	9,86	6,96
Conventional	1,09	1,27	1,16	1,42	1,09	1,36
Heavy cultivator	1,13	1,27	1,19	1,44	1,10	1,42
Rotary cultivator	1,18	1,37	1,29	1,54	1,21	1,47
Disk harrow	1,16	1,38	1,27	1,56	1,21	1,47
No-tillage	1,31	1,45	1,46	1,60	1,48	1,59
	**	**	**	*	**	**
LSD (P = 95%)	*0,10*	*0,09*	*0,13*	*0,12*	*0,12*	*0,11*
Location X Tillage	ns	ns	ns	ns	ns	ns

Penetration resistance of the soil is a function of tillage depth and soil moisture content. At the upper layer of the soil (0-10 cm) resistance was greater in no-tillage. The methods of disk harrow and rotary cultivator presented a looser surface while the loosest were found in the methods of heavy cultivator and conventional tillage. At a greater depth however, penetration resistance in the methods of disk harrow and rotary cultivator was increased. Especially in the method of disk harrow, a peak can be noticed at a depth of about 10-cm, just beyond the tillage depth. The increased penetration resistance indicates the existence of a compacted layer at that depth caused probably by the tillage implement. Concave side of the disks can cause compaction below the working depth. From the tillage implements used, disk harrow was the only towed which means that all the weight is transferred to the soil by the concave side of the disks. The implement weighed about 1 t and in the method of (DH) it was used both for primary and secondary tillage, operating at about the same depth three to four times repeatedly. The soil beyond the tillage depth in the method of disk harrow was undisturbed and so compaction was concentrated on a thin layer beyond depth of tillage. In the other methods of tillage however, the disk harrow was used only for secondary tillage and the soil was already loosened at a greater depth by the implements of primary tillage. The loose subsoil was subjected to compaction at a greater depth and no compact layer was detected. The loosest soil to a depth of 25 cm was found again in the methods of heavy cultivator and conventional tillage. In Fig 3 the results of two sets of measurements are presented, the first at 20/7/97 and the second at 10/6/98.

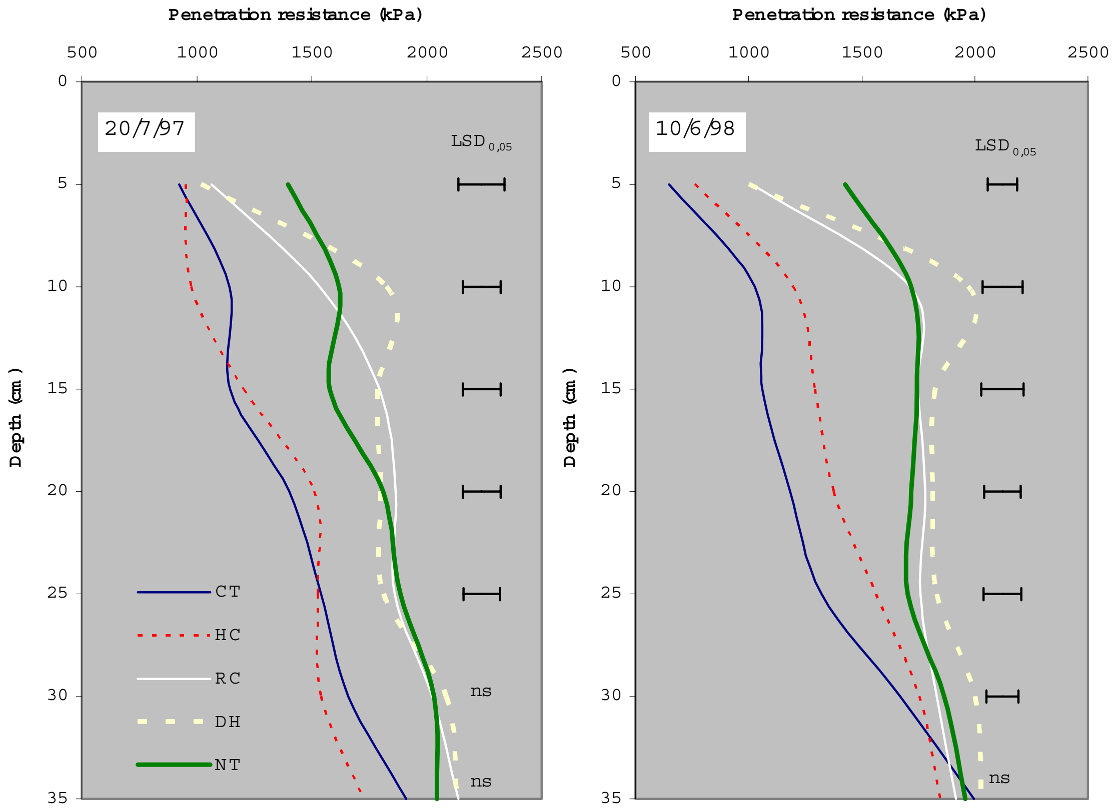

Fig 3. Penetration resistance. Average over the two fields.

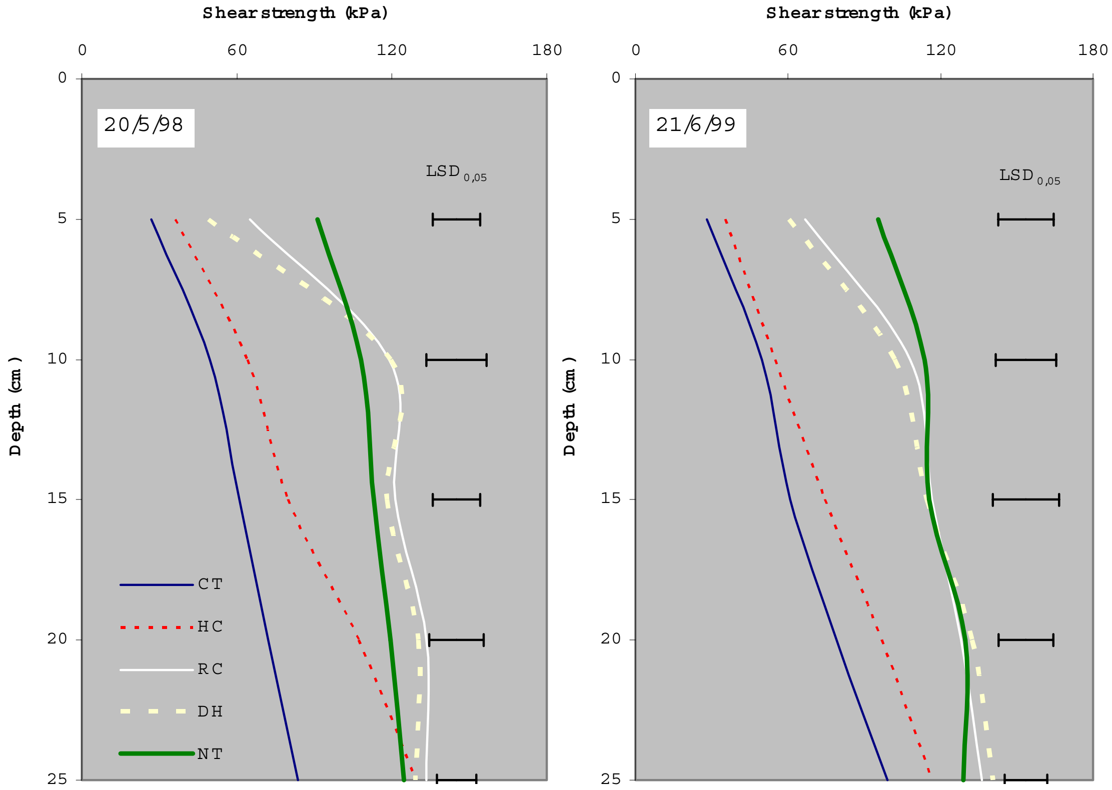

Fig 4. Shear strength of the soil. Average over the two fields

Results of soil shear strength were similar to those of penetration resistance. At a depth of 5 cm the soil of the methods of conventional tillage and heavy cultivator presented lower shear strength as a result of the great shear forces which caused soil loosening during tillage. At the same depth, shear strength in the plots with rotary cultivator and disk harrow was greater while the more compact soil was detected in the method of no-tillage (Fig 4). At a depth of 10 cm the methods of rotary cultivator and disk harrow presented also high shear strength, which sometimes were greater of that of no-tillage. As with penetration resistance, shear strength of the soil is also a function of tillage depth and soil moisture content but also a function of root existence in the soil. At depths where no tillage operation was performed the roots of previous crops impeded the revolution of the shear vane resulting in greater shear stresses. The loosest soil up to a depth of 25 cm was found in the method of conventional tillage followed by the method of heavy cultivator. Mouldboard ploughs apply great stresses during tillage that cause shear planes and results in soil loosening.

Soil moisture content is a function of soil dry bulk density and soil coverage by crop residue and weeds and therefore statistical significant differences were detected among the methods of tillage (Table 4). Differences were greater at the upper layer of the soil where fluctuation was greater. The higher moisture content was found in the no-tillage plots. Next were the methods of disk harrow and rotary cultivator. These methods had a relatively compact soil surface with a higher bulk density. High bulk density results to lower porosity and consequently reduced air circulation and water vapour losses. Soil surface also was covered by crop residue, which impeded solar radiation from reaching the soil and reduced water evaporation. The lower moisture content was found at the method of conventional tillage, which had a loose soil with a total porosity about 60% while the soil surface was completely uncovered.

Table 4. Soil moisture content

	Soil moisture content (% vol)								
	1997			1998			1999		
	26/3	20/4	8/5	21/4	12/5	15/5	11/3	17/4	16/5
CV (%)	6,06	5,58	6,80	5,77	8,07	7,68	6,11	6,08	7,58
0,5 - 3 cm									
Conventional	20,82	18,01	17,36	5,52	23,19	17,73	11,41	15,90	17,79
Heavy cultivator	22,88	19,15	17,88	6,97	25,29	18,90	11,90	15,92	17,07
Rotary cultivator	25,55	20,83	20,42	11,71	27,79	20,87	21,01	20,97	20,47
Disk harrow	24,23	19,86	18,71	9,60	27,60	21,23	21,27	20,30	20,32
No-tillage	24,04	24,32	23,17	11,42	28,78	25,72	27,13	22,73	18,35
	**	**	**	**	**	**	**	**	**
LSD (P = 95%)	1,85	1,42	1,79	0,72	2,71	1,62	1,11	1,63	1,84
7,5-10 cm									
Conventional	29,68	25,09	25,09	15,77	29,94	24,63	22,02	26,03	25,63
Heavy cultivator	30,78	26,18	25,88	16,66	30,40	24,89	23,70	27,25	25,99
Rotary cultivator	34,09	25,86	25,93	20,14	30,86	26,75	26,98	30,26	29,49
Disk harrow	33,32	28,11	26,43	21,67	31,34	27,25	27,07	30,89	29,38
No-tillage	32,69	28,83	28,28	20,75	31,26	27,57	32,54	32,27	27,95
	**	**	**	**	ns	**	**	**	**
LSD (P = 95%)	*1,62*	*1,21*	*1,29*	*0,93*	-	*1,65*	*1,67*	*1,30*	*1,69*
Location X Tillage	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*	*ns*
Depth X Tillage	*ns*	**	*	**	*ns*	**	**	*ns*	*ns*

At 20/4/97 and 8/5/97, 12/5/98 and 15/5/98 and 16/3/99 the soil in the method of no-tillage presented the highest moisture content. During those periods, the weeds in the method were destroyed by the action of the *glyphosate* and had created mulch over the soil surface, which impeded evaporation. At 26/3/97 and 21/4/98, however, the weeds were still alive. Also at 20/4/99 and 8/5/99, about two months after the *glyphosate* application, new weeds had emerged. Although the weeds were covering again the soil and impeded evaporation they also pumped soil water through transpiration. As a result, the soil moisture content was at the levels of rotary cultivator and disk harrow. At 12/5/98 measurements were made a couple of days after a heavy rainfall. Average soil moisture content was high and differences were detected only at the upper layer of the soil.

No significant interactions were found between location and tillage for moisture content. There was however a significant interaction between sampling depth and method of tillage when average soil moisture content was low. In that case, differences between the methods of tillage were much greater at the upper layer of the soil.

Crop emergence

Results of the three years show no consistency. 1997 was a year with normal rainfall during spring. A rain occurred a day after planting and enhanced crop emergence.

However emergence progress was differentiated between the two fields. In the silty-clay field, emergence was delayed and a lower population was obtained with no-tillage (Fig 5a). In the clayey field however, no-tillage, along with disk harrow favoured an earlier crop emergence and a larger final population (Fig 5b).

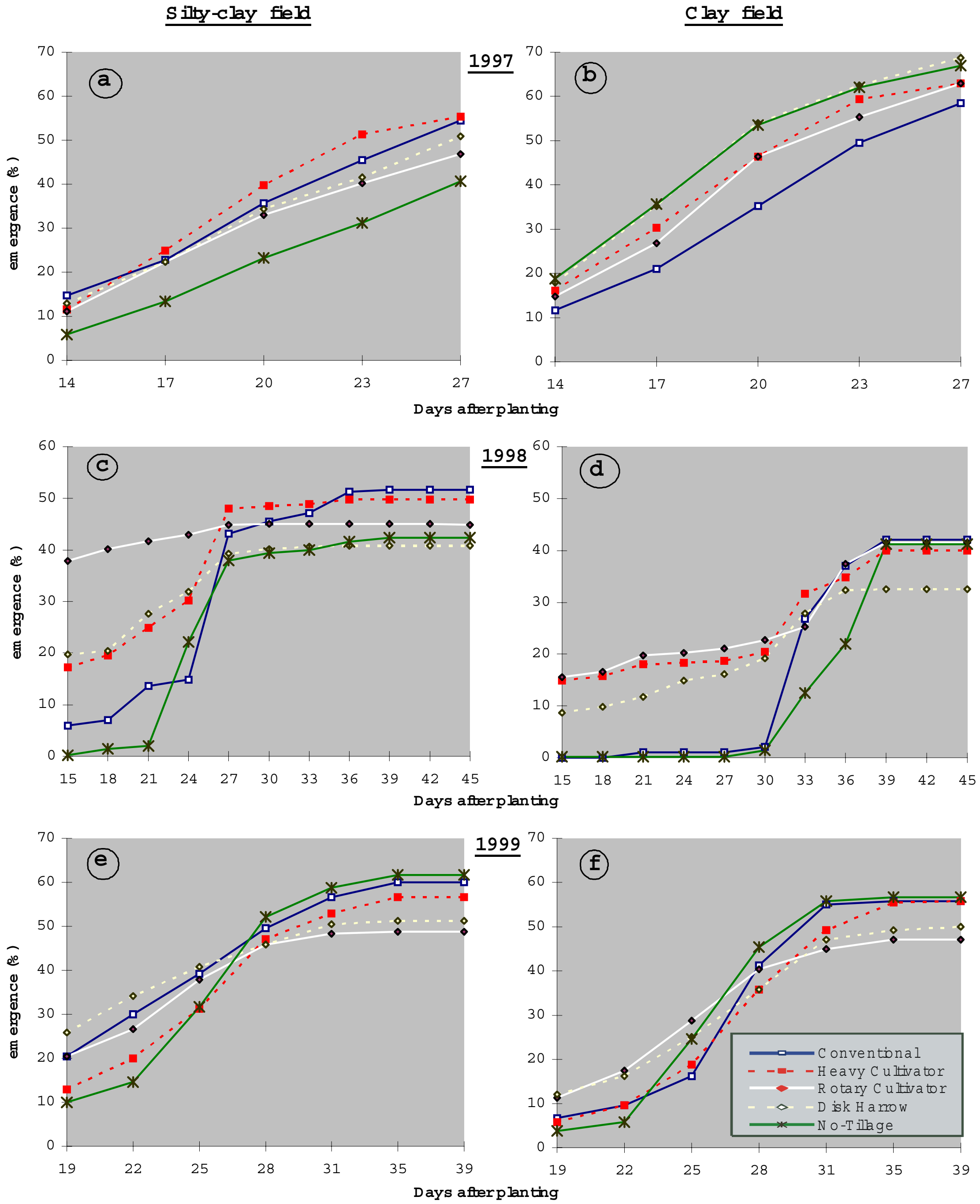

Fig 5. Crop emergence for the five methods of tillage on the two fields and the three years of experimentation.

Differences are attributed to the different rotations in each field during that year. In the silty-clay field sugar beets followed a winter wheat crop while in the clay field, beets followed a cotton crop. In the winter wheat rotation, the excessive mulch impeded the covering mechanisms of the conventional planter to work efficiently when no-tillage was applied and so a greater amount of seed were left uncovered in the slot. Additionally, straw was incorporated into the soil with seed and it is possible to cause toxins production during decomposition. In the cotton rotation however, the woody crop residue was in small quantities and a better coverage of the seed was obtained. Provided an improved seed coverage, the higher soil moisture content retained in the methods of reduced tillage, favoured emergence of the seeds.

1998 was a year with a prolonged period of draught after planting. In conventional tillage, in both fields, emergence started only after irrigation was applied (Fig 5c,d). In the methods of reduced tillage however, emergence was able to start even without irrigation. Especially in the method of rotary cultivator, in the silty-clay field, the emergence progress could have been completed without the addition of any water. It seems, the higher moisture content retained in the soil with reduced tillage is a crucial factor to obtain a satisfactory population in dry years. Such an advantage however wasn't obtained in the method of no-tillage, even though the soil had the highest water content. After the first year of no-tillage, soil surface became more compact and cohesive. Under these conditions, the planter had difficulty to penetrate the soil while no loose soil was found by the covering mechanisms to cover the seed. In addition, crop residue on the soil surface exacerbated the task. As a result, the greater amount of the seed were left uncovered in the slot or buried by a thin soil layer where the moisture content wasn't enough for emergence to proceed. As with conventional tillage, emergence started only after irrigation was applied.

1999 was a year with excessive rainfall after planting. While soil moisture content wasn't a restricting factor emergence started in all methods of tillage at the same time and no advantage was revealed for the reduced methods of tillage (Fig 5e,f). Even though the seed in the method of no tillage was again poorly covered it emerged quite well and a higher population was achieved. The repeated rains after planting kept the surface wet for as long as the emergence was completed. As the seed was placed on a smaller depth it was much easier for it to emerge.

In all three years a satisfactory final population was achieved. Statistical significant differences between the five methods were obtained only for the second and third year (Table 5). Interaction between location and tillage was found only for the first year, which however was attributed to the different rotations. No interaction was obtained between variety and tillage.

Table 5. Final populations of sugar beets for the five methods of tillage.

	plants/m²			
	1997	1998	1999	combined
CV (%)	16,3	17,6	15,4	15,8
Conventional	15,81	13,78	17,38	15,66
Heavy cultivator	16,56	13,19	16,88	15,54
Rotary cultivator	15,38	12,69	14,38	14,15
Disk harrow	16,75	10,78	15,19	14,24
No-tillage	15,06	12,28	17,75	15,03
	ns	**	**	**
LSD (P = 95%)		1,10	1,78	0,60
Year × Tillage				**
Location × Tillage	*	ns	ns	*
Variety × Tillage	ns	ns	ns	ns

Crop development

Measurements of leaf area index revealed a better growth in the method of conventional tillage for all three years (Table 6). Second best growth was detected in the method of heavy cultivator while the beets in the methods of rotary cultivator and disk harrow presented a restricted growth. The worst growth, with a poor canopy was found in the method of no-tillage. For every year, a location X tillage interaction was found. Generally, plants growth was better in the silty-clay field where the differences between the methods of tillage where greater.

Table 6. Leaf area index for the five methods of tillage

	Leaf area index								
	1997			1998			1999		
	22/6	1/7	10/7	22/5	12/6	2/7	19/5	6/6	26/6
CV (%)	23,6	15,9	12,6	33,8	17,4	12,1	24,1	19,5	15,8
Conventional	3,10	3,98	4,33	0,14	1,40	2,49	1,40	2,68	4,16
Heavy cultivator	2,85	3,76	4,24	0,28	1,53	2,42	1,10	1,91	3,93
Rotary cultivator	2,19	3,04	3,64	0,31	1,35	1,89	0,59	1,22	2,49
Disk harrow	1,73	2,79	3,34	0,28	1,34	1,84	0,68	1,24	2,66
No-tillage	1,63	1,97	2,58	0,08	0,95	1,62	0,61	1,32	2,72
	**	**	**	**	**	**	**	**	**
LSD (P = 95%)	0,39	0,35	0,32	0,04	0,11	0,12	0,15	0,23	0,36
Location × Tillage	**	**	**	**	**	ns	*	ns	ns
Variety × Tillage	ns	ns	ns	ns	ns	ns	ns	ns	ns

Measurements of the root growth during the second and third year proved that the differences found for the above ground growth are related with differences of the root development. Regression analysis between leaf area index and root length shown a significant correlation at P<0,01 between the two parameters (r = 0,79 for 1998 and r = 0,71 for 1999). A significant correlation at P<0,01 was also found between leaf area index and root max diameter (r = 0,86 for 1998 and r = 0,72 for 1999).

Table 7 presents the results of the first and the last measurement of root growth for each year. Beets in the methods of deep tillage, i.e. conventional tillage and tillage with heavy cultivator were longer and had a larger diameter except for conventional tillage at 2/6/98. During that year, emergence in the method of conventional tillage was delayed and until the first date of measurement the beets did not achieve the growth of the earlier emerged beets. One month later however, the deeper loosened soil helped the plants to develop a more vigorous root which in turn, favoured above ground growth. In the method of no tillage, on the contrary, where a compact soil layer impeded the root growth, the roots presented a smaller diameter and were developing on a smaller depth.

It is also remarkable to notice that the roots in the methods of rotary cultivator and disk harrow had not a vertical pattern of development but formed an angle at about the depth of tillage (Fig 6). It is obvious that when the tip of the roots reached the lower point of tilled soil it met a hard subsoil in which it had difficulty to penetrate. So, roots preferred a horizontal development on the loose soil layer. Such a phenomenon was not detected in the method of no-tillage where the soil was evenly compact at all depths. When beets did not have a more favourable layer to develop their roots, the plants formed a vertical main root, which however had a smaller length and diameter.

Table 7. Root development for the five methods of tillage

	1998						1999					
	Root length		Root diameter		Root angle		Root length		Root diameter		Root angle	
	2/6	2/7	2/6	2/7	2/6	2/7	19/5	26/6	19/5	26/6	19/5	26/6
CV (%)	18,0	11,5	23,5	13,5	63,4	29,6	21,2	12,4	25,3	12,5	56,6	22,6
Conventional	10,5	20,3	1,4	5,4	18,5	21,1	14,0	29,8	2,1	9,2	4,9	21,6
Heavy cultivator	11,2	20,0	1,9	5,5	19,6	19,5	12,9	27,8	1,7	8,6	7,8	15,8
Rotary cultivator	11,1	17,4	1,9	5,0	33,4	39,6	7,9	18,7	1,3	7,0	33,9	39,9
Disk harrow	11,0	17,0	2,2	4,5	37,4	43,3	9,0	18,7	1,3	7,1	36,2	39,6
No-tillage	8,6	16,3	1,2	4,0	18,1	23,8	7,0	21,0	1,1	5,8	9,9	18,4
	**	**	**	**	**	**	**	**	**	**	**	**
LSD (P = 95%)	*0,9*	*1,0*	*0,2*	*0,3*	*8,0*	*4,3*	*1,5*	*2,0*	*0,3*	*0,7*	*7,5*	*4,4*
Location × Tillage	*	*	**	ns	ns	ns	**	ns	ns	ns	ns	ns
Variety × Tillage	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

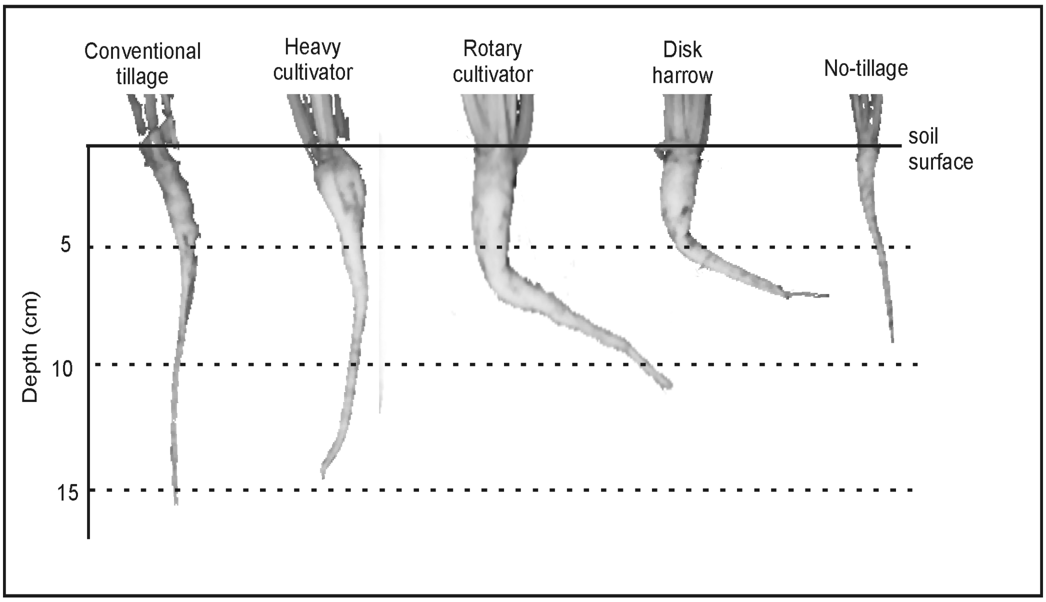

Fig 6. Typical patterns of root growth for the five methods of tillage in 2/6/98. During that period, the roots in the method of conventional tillage were thinner because of the later emergence of the plants.

Crop yield

A significant yield reduction was found for all three years in the methods of reduced tillage (Table 8 & Fig 7). Yield losses were greater in the method of (NT). Every year, (CT) gave a stable yield of about 63-66 t/ha. Compared with the (CT), during the first year, root yield in the method (HC) was 7,3% smaller, in the methods of (RC) and (DH), 19,7% and 20,4% respectively smaller while in the method of (NT) 27,6% smaller. Similar were the results during the second year except for the method of (HC) that gave almost the same yield with (CT) (1,2% smaller) probably because of the earlier emergence. During the third year however a significant greater reduction was marked in the methods of (RC) (34,3%), (DH) (31,3%) and (NT) (46,6%) compared with (CT). The method of (HC) gave 8,9% smaller yield compared with (CT).

Yield losses in the methods of reduced tillage are attributed to the reduced development of the roots. In Table 8, mean weight of the roots was considerable lower in the methods of rotary cultivator, disk harrow and no-tillage. The compact layer of the soil beyond the tillage depth along with the greater competition of the weeds, are two probably factors that led to this yield reduction. From Table 8 also it can be seen that during harvest the plants in the methods of reduced tillage retained a greater amount of their mass on the canopy. This is an indication of crop lateness. Combined analysis for the three years is also shown in Table 8. CT gave the significant higher yields than all the other tillage treatments.

Table 8. Yield parameters of the sugar beets for the five method of tillage.

	Fresh root yield (t/ha)				(%) root weight				Root mean fresh weight (g/root)			
	1997	1998	1999	comb	1997	1998	1999	comb	1997	1998	1999	comb
CV (%)	13,6	21,4	17,0	16,7	2,7	5,2	6,6	7,9	19,2	24,8	19,6	18,1
Conventional	65,6	66,2	63,8	65,2	79,9	80,8	74,6	78,5	673	670	664	669
Heavy cultivator	60,8	65,4	58,1	61,4	79,5	79,4	74,4	77,8	615	688	629	644
Rotary cultivator	52,6	52,3	41,9	48,9	78,0	76,6	70,3	75,0	540	598	454	531
Disk harrow	52,2	51,6	43,8	49,2	79,2	77,2	70,6	75,6	505	604	474	528
No-tillage	47,5	48,9	34,1	43,5	81,4	76,4	68,5	75,4	555	539	380	491
	**	**	**	**	**	**	**	**	**	**	**	**
LSD (P = 95%)	5,4	6,1	5,8	*2,7*	*1,5*	*2,0*	*3,4*	*1,5*	*79*	*76*	72	*42*
Year × Tillage				**				**				**
Location × Tillage	**	ns	ns	*	*	ns	ns	ns	**	**	ns	**
Variety × Tillage	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

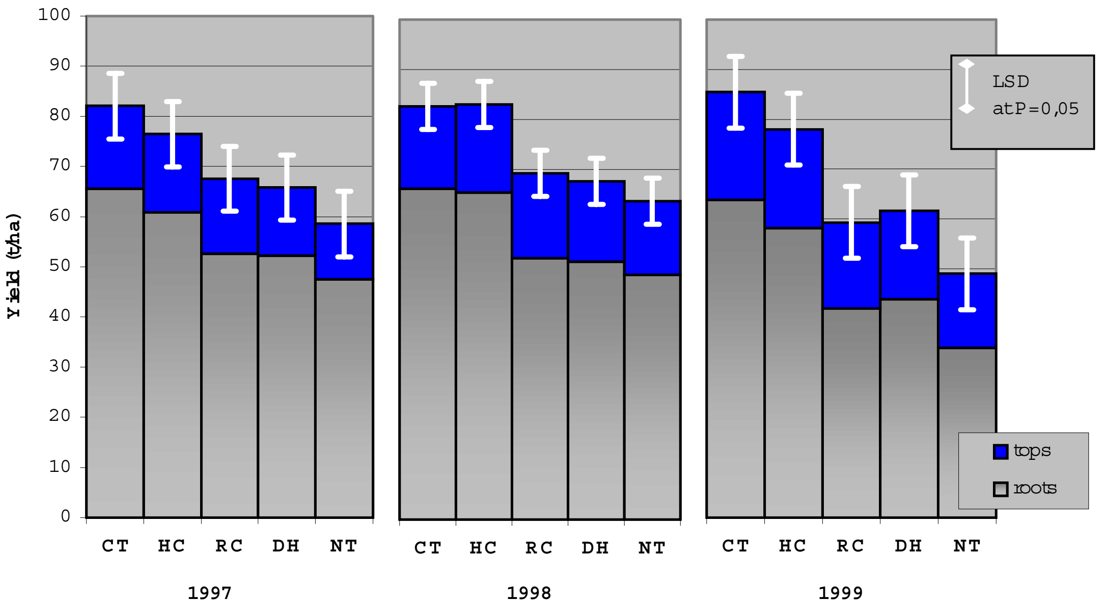

Fig 7. Fresh root and tops yield of the sugar beets for the five methods of tillage in the three years of the experiment.

Table 9. Chemical characteristics of beet harvested roots for the five methods of tillage in the three years of the experiment.

	Sugar content (%)				Na				N - impurities			
	1997	1998	1999	comb	1997	1998	1999	comb	1997	1998	1999	comb
CV (%)	4,5	6,9	8,8	6,4	20,9	24,0	14,3	19,4	14,2	23,5	13,7	13,5
Conventional	14,7	13,45	12,42	13,5	3,33	2,55	3,00	3,0	5,01	2,38	3,29	3,56
Heavy cultivator	14,8	13,74	12,58	13,7	3,42	2,24	2,76	2,8	5,09	2,55	3,24	3,63
Rotary cultivator	14,9	13,69	12,17	13,6	3,58	2,29	3,01	3,0	5,44	2,53	3,21	3,73
Disk harrow	14,8	13,76	12,37	13,6	3,47	2,18	3,05	2,9	4,96	2,51	3,22	3,56
No-tillage	14,8	13,59	13,01	13,8	3,04	2,23	2,92	2,7	4,89	2,52	3,26	3,55
	ns	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**
LSD (P = 95%)	5,4	-	-	-	-	-	-	-	-	-	-	-
Year × Tillage				ns				ns				ns
Location × Tillage	**	ns	ns	ns	*	ns	ns	ns	**	ns	ns	ns
Variety × Tillage	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

No differences were found among the methods of tillage for the sugar content of the roots and neither for the Na and N-impurities contents (Table 9).

Energy consumption

Net energy, absorbed from the tillage implements, was estimated during second and third year. Results are shown on Table 10. For both years, the most energy intensive method was the CT. Compared with the CT, energy conservation with the HC method was 39,6% in 1998, when a heavy cultivator was used and 12,7% in 1999 when a subsoiler was used. The method of RC provided energy savings of 26,4% in 1998 and 34% in 1999. With DH energy conservation was 84,8% in 1998 and 74% in 1999. Energy requirements for *glyphosate* application with the sprayer in the NT method were neglectable.

Table 10. Net energy requirements for the tillage operations.

	Net energy (MJ/ha)									
	"1998"					"1999"				
Methods of tillage:	CT	HC	RC	DH	NT	CT	HC	RC	DH	NT
Ploughing	228,5					302,9				
Heavy cultivator		144,6								
Subsoiler							246,5			
Rotary cultivator			200,8					207,1		
Disk harrow (1st pass)	23,7	20,2		22,0					28,2	
Disk harrow (2nd pass)	20,4			19,5					28,5	
Field cultivator (1st pass)						45,2	51,9	46,8	43,4	
Field cultivator (2nd pass)						36,5	37,1			
Sprayer					0,05					0,05
Total	272,7	164,8	200,8	41,6	0,05	384,5	335,5	253,9	100,1	0,05

Table 11. Estimation of soil specific resistance and intensity of energy use per soil volume during tillage operations. Average values from the last two years.

	Working width (m)	Average working depth (m)	Draft (kN)	Absorbed energy (MJ/ha)	Specific resistance (N/cm^2)	Intensity of energy use for tillage (kJ/m^3)
1 *Mouldboard plough*	1,2	0,27	31,9	265,7	9,93	99,3
2 *Heavy cultivator*	2	0,18	28,9	144,6	8,03	80,3
3 *Subsoiler*	1,8	0,37	44,4	246,5	6,70	67,0
4 *Rotary cultivator*	2,5	0,10	5,7	209,6	-	209,6
5 *Disk harrow*	3	0,08	7,0	23,2	2,90	29,0
6 *Field cultivator*	2,3	0,06	10,0	43,5	7,26	72,6

On Table 11 according to the cutting front (working width X working depth) and the average draft it is calculated the soil specific resistance for each implement except for the rotary cultivator on which power is transmitted through the PTO. It is also estimated the "*intensity of energy use for tillage*" per soil volume unit. From the results shown it is obvious that the energy use per cultivated soil volume is two times greater with the rotary cultivator compared with the mouldboard plough. However from the measurements of soil properties (dry bulk density, penetration resistance and shear strength) and crop development, this additional energy wasn't found to improve soil porosity neither to increase crop yields. The patterns of root development indicated that despite of using it only at the upper layer, the energy should be used to provide soil loosening on a greater depth. On the contrary, with the heavy cultivator and especially the subsoiler, despite the lower energy sequestered into the soil during tillage, compared with ploughing, there were no great differences on soil properties and crop yield.

DISCUSSION

Soil water content and dry bulk density seem to be a function of tillage intensity and depth as found and by other researchers (Tebrügge, and Düring, 1999, Arshad, et al., 1999). Greater soil water content in the soil enhance earlier beet emergence (Gemtos and Lellis, 1997, Guérif, et al., 2001). Differences of the final populations were significant for the two last years but results show no consistency. Differences in the emergence rate between the methods of tillage were small in years with adequate rainfalls. In dry years however, the methods of rotary cultivator and disk harrow that retained greater moisture content in the seedbed layer, favoured an earlier crop emergence. This advantage is very important for Greek farmers as very often in spring prolonged periods of draught lead to poor crop establishment. In most serious cases, replanting may be necessary. This advantage was not obtained for the method of no-tillage, despite the greatest moisture content, because conventional drilling machine used in the experiment was not able to penetrate to the soil, place the seed at the appropriate depth and cover it. During planting a three times denser seed spacing in the row was used, in all the methods of tillage, and so, for the three years, a satisfactory final population was achieved and thinning was applied to regulate the population at about 100.000 pl/ha.

For all three years, crop development was significantly better in (CT) and (HC) with worst (NT). Leaf area index was greater and root development was significant better. Plant development for the (RC) and (DH) methods were similar and at an intermediate stage between (CT) and (NT).

Similar results were obtained for yield. (CT) and (HC) gave the higher yields. Average fresh root yield for the three years were 65,2 t ha^{-1} and 61,4 t ha^{-1} respectively. It should be noted that that (CT) gave more stable yields, which is important for the farmer. (RC) and (DH) gave the second best yield with a three year average of 48,9 t ha^{-1} and 49,2 t ha^{-1} respectively. Every year the (NT) gave the lower yields. The three year average was 43,5 t ha^{-1}. Hao et al. (2001) reported that yield of sugar beets was similar for conventional tillage and reduced tillage with a chisel plough. Koowenhoven et al. (2002) found a 9% yield reduction for sugar beets when deep ploughing at 20-30 cm were substituted with shallow tillage at a depth of 12-18 cm. Miller and Dexter (1983) report higher sugar beet yields under no-tillage if no weed competition is allowed, but in a field with 6% organic matter.

In the present experiment yield reductions are attributed mainly in the firm cohesive soil, which impeded root growth, and to the greater competition of the weeds. According to Gregory (1988) the most of the cultivated plants can exert a maximum root pressure of about 700-2500 kPa to penetrate the soil. In the methods of shallow tillage (RC, DH) and (NT) however, the soil at a depth more than 10 cm exhibited a penetration resistance greater than 1800 kPa. In dry conditions the resistance would be much greater and probably the root development was restrained. This suggestion is further proved by the patterns of root growth. As a result roots harvested in the reduced tillage plots were smaller. Chancellor (1977) refers that Taylor and Bruce, 1968 found that sugar beet root weight is considerably reduced when penetration resistance is increased.

The main reason for yield reduction in the (HC) method was weed competition. According to Scott, et al. (1979) weed competition in the sugar beet crop have to be terminated until the 4-6 leaf stage if yield reduction is to be avoided. Weeds however are another main problem with reduced and no tillage techniques. Deibert et al. (1979) found a root yield decrease of 37,5% caused by competition from weed Kochia. NT plots had most of the weeds. HC plots had a lot of weeds. It is important to note that most of them remained in the field from autumn tillage because heavy cultivators although disturb the soil in the ploughing depth they do not disturb soil surface and leave established weed. This seems to be a disadvantage of the heavy cultivators. Disk harrows and rotary cultivators destroy weeds but the population is relatively high in April due to the emergence of the seeds left on soil surface during tillage. In the third year a better chemical weed control alleviated the problem.

Another probable reason for yield reduction in the method of no-tillage is the negative effect of the crop and weed residue. In this method all the destroyed plant material were left on the soil surface. Richard et al., (1995) found that early growth of sugar beets when sown in crop residue was slower because of the shading effect of the reside and probably due to nitrogen immobilation from the microorganisms that decompose the plant material However they found no negative effect of the residues on soil temperature.

Despite the improved beet yields, (CT) method was the most energy intensive one. Net energy requirements for tillage operations was 272 MJ ha^{-1} for 1998 and 384 MJ ha^{-1} for 1999. Average energy savings with the (HC) method were 23,9% and average yield reduction 5,8% compared with (CT). With the (RC) method energy savings were 30,8% and with (DH) 78,4%. However these methods resulted also to a significant yield reduction of the order of 24-25% compared with (CT). No energy was required for seedbed preparation in the (NT) method, (discarding the negligible amount required for *glyphosate* application). However average yield reduction of about 33,4% is a discouraging factor for the adoption of the method. By overviewing the profits and penalties resulted from the five methods of tillage tested on the experiment it is obvious that Greek farmers could substitute conventional mouldboard ploughing by using heavy cultivators or subsoilers without significant sugar beet yield reductions but with considerable energy savings and environmental benefits arising from soil and water conservation.

CONCLUSIONS

- Conservation tillage dramatically increased weed infestation. Applied crop rotations had an effect on weeds but they were not sufficient to solve the problem.
- Soil in the methods of conservation tillage presented higher bulk density, shear strength and penetration resistance. It also retained higher moisture content.
- As a result of the greater moisture, emergence of the crop in the reduced tillage was facilitated when dry conditions prevailed after planting.
- Crop development and yields in the methods of reduced tillage were reduced. The reduction was greater in the method of (NT).
- Yield reduction is attributed to weed competition and deterioration of soil physical properties.
- Heavy cultivators or subsoilers use appears to be a viable alternative to conservation tillage due to the small yield reductions but with considerable energy savings.

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