Influence of soil compaction and conservation tillage on sunflower (*Helianthus annuus* L.) below ground system.

Javier David Scheiner [a], Virginie Mirleau-Thebaud [a,b], Jean Dayde [a]
[a] Université de Toulouse / EI. Purpan, UMR 1248 AGIR, 75, voie du T.O.E.C, 31076 Toulouse, FRANCE, javier.scheiner@purpan.fr
[b] CETIOM (Centre technique interprofessionnel des oléagineux et du chanvre), Toulouse, France, mirleau.thebaud.virginie@gmail.com

ABSTRACT

- Soil compaction represents an important issue in the actual context of agricultural system sustainability. The sunflower (*Helianthus annuus* L.) is the second French oilseed crop in oil production (tons of oil). In France, 20 % of the sunflower cropping area is not tilled before sowing and this practice is increasing. The aim of this work is to study the root system modifications caused by minimum tillage practices and soil induced compaction in field.
- Two field experiments were implemented on two type of soil in the south of France: a well-drained Glossaqualf soil; and a Mollic Udifluvent soil. On the Glossaqualf the factor “soil tillage” was studied, characterized by minimum tillage (MT) and triple tillage (TT). On the Mollic Udifluvent the factor “mechanically induced compaction” was studied, characterized by compacted soil (CS), non-compacted soil (NCS). Soil compaction was characterized using a penetrometer, up to 80 cm depth. Root systems were observed on replicated soil trench as well as on consecutive extraction in each replicated plots.
- In both designs, increases of soil resistance to the penetration were observed, characterizing soil compaction. A decrease of soil water content in depth was also reported. Under those constraints deep modifications of sunflower roots architecture, growth and exploration occurred. Decrease of root length, root surface, root volume, and root average diameter were observed. Root system exploration analyzed using geostatistics, was also negatively impacted by soil compaction, by reducing global root system exploration and rooting depth and by increasing lateral growth; at different stages of development.
- Those modifications were the direct and indirect consequences of soil compaction, and suggest a compensatory effect under soil compaction constraints.
- Variation of root system exploration under soil mechanical constraints has been explored for many crops (Maize *Zea mays*, Wheat *Triticum durum*, or Soybean *Glycine max*), but only few researches have been carried out on sunflower, and none involved the soil compaction issue. Root systems are currently studied through soil trench or monolith methods, which is difficult to carry on and replicate. The method used in this study proposed an alternative with accurate statistics, using replicated samples extraction and geostatistics.

Key words: Sunflower, tillage, soil compaction, root system, geostatistics.

INTRODUCTION

Soil compaction is characterized by a loss of porosity, a loss of water and nutrient availability, an increase of soil bulk density, and an increase of soil penetration resistance (SPR) facing root growth (Lipiec and Hatano, 2003). This led to decreases of roots systems growth and root explorations (Andrade *et al.*, 1993; Petcu and Petcu, 2006; Rosolem *et al.*, 2002). Compaction also alter soil water availability (Lipiec and Hatano, 2003; Sadras *et al.*, 2005; Taboada *et al.*, 1998) which can be the cause of root distribution changes (Sharp *et al.*, 1988). Root exploration changes play a major role in loss of water and nutrient capture (Bingham *et al.*, 2010 ; Jackson and Caldwell, 1993). Root system alteration led to an alteration of above ground resources acquisition and efficiency, which also lead to root growth alteration involving the feedback between the both system (Lipiec and Hatano, 2003; Sadras *et al.*, 2005). Superficial or sub-superficial soil compaction due to agricultural traffic has been reported in many areas and on many crops (Lipiec and Stepniewski, 1995; Taboada *et al.*, 1998). Temporary changes in soil compaction attributed to conservation practices have also been reported in the first year of practices, depending of the type of soil (Sasal *et al.*, 2006). In France, conservation practices are applied over 20% of the sunflower cropping area, covering up to 25 % in the Southwestern region.

As many summer crops, sunflower production main limiting factor is water availability. Only a part of the top soil is explored by the root systems during a growing season, and the contact with the soil matrix depends mainly on soil bulk density (Lipiec and Stepniewski, 1995). Sunflower root system can extract more water than many other crops, specifically from deep soil (Scheiner and Lavado, 1999). Root growth dynamics as affected by soil compaction has been reported in many crops (Lecompte *et al.*, 2003; Taboada and Alvarez, 2008). Only a few studies were conducted on sunflower crop (Andrade *et al.*, 1993; Murillo *et al.*, 2004; Sessiz *et al.*, 2008), and none included a fine root system architecture study. A multi-location trial was implemented in 2009 and 2010. The main objective of the study was to quantify the impact of a compacted soil on the growth and development of root system in sunflower, by testing on two complementary hypothesis: the physical modifications due to conservation practices and/or soil compaction lead to, i) an alteration of the root system architecture, ii) a decrease of the root system exploration.

MATERIAL AND METHOD

Two non irrigated field experiments were implemented. These soils were chosen for their contrasting properties (table 1). The field A, was conducted at Lamasquère (Midi Pyrenees, France, 43° 30’ 11.75’’ N; 1° 14’ 54.53’’ E) on a well-drained Glossaqualf soil. Two soil tillage treatments were compared: minimum tillage (zero tillage, cover crop in spring, MT) and triple tillage (cover crop followed by three perpendicular passes of subsoiler at 60 cm depth in spring, TT). Field A soil has low water storage (about 1.4 mm per cm of soil) and was chosen to expose plants to hydric stress. The soil tillage was realized on 05/05/2009 and the crop was sowed on 05/06/2009 (6.5 plants.m^{-2}). The field B was conducted at Auzeville-Tolosane (Midi Pyrenees, France, 43° 32’ 35.1’’ N; 01° 30’ 02.7’’E) on a Mollic Udifluvents soil. The compacted soil modality (CS) was obtained by several wheel passes of a 3.5 tons tractor on the whole soil surface after an autumn tillage (soil moisture at 20%, Lecompte *et al.*, 2003). The non-compacted soil resulted from an autumn tillage (NCS). The soil compaction was applied on 04/14/2010, the sowing on 04/27/2010 (6.5 plants.m^{-2}) and the harvest on 09/20/2010. NK-MELODY (half late, Syngenta Seeds SAS) was the only cultivar used for the two experiments. The design used were adjacent plot design, four replications per plot, plot of 1297 m² in field A and 320 m² in field B)

Field A – 2009

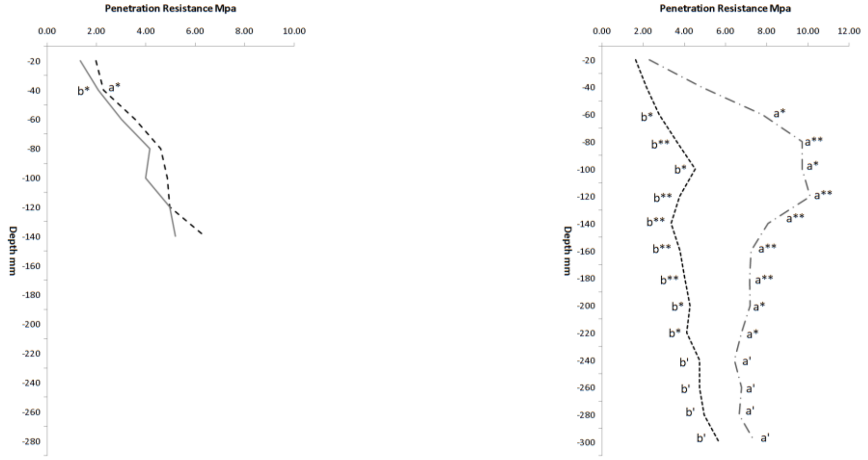
Depth	0-20 cm	20-40cm
Clay g.kg-1	243	250
Silt g.kg-1	451	445
Sand g.kg-1	308	304
pH	6.40	6.15
SOM g.kg-1	33	26.8

Field B - 2010

Depth	0-30 cm	30-60cm	60-90 cm	90-120 cm
Clay g.kg-1	18.6	19.2	28.7	38.9
Silt g.kg-1	41.7	45.4	49.1	48.5
Sand g.kg-1	28.6	24.2	13.8	7.1
pH	8.34	8.35	8.45	8.46
SOM g.kg-1	17.15	12.8	13.8	11.5

Table 1. Soil data of fields A and B (2009, 2010) each 20 cm depth. Data obtain after analyses of soil samples taken before the sowing (INRA, Arras, FRANCE)., SOM : Soil Organic Matter .

Soil resistance penetration (SPR) was assessed using a dynamic penetrometer (06/16/2009; 08/05/2009; 04/28/2010; 07/27/2010; 09/23/2010) twice in each replicate, and was estimated as Vanags (Vanags *et al.*, 2006). Gravimetric soil water (θ) content was determined by extracting soil cores in each plot every 10 cm depth (06/25/2009; 07/13/2009; 08/18/2009; 06/30/2010; 07/30/2010; 09/21/2010). Soil trenches were scooped to evaluate in situ root systems profiles (in two replicates per soil treatments). Root systems profiles on soil trench were scored on 08/08/2009; 06/28/2010; 09/13/2010. A 1cm² grid was used to assess root length (cm), according to Tennant (Tennant, 1975). Three consecutive root systems were also directly extracted on the row in each plot using an electric auger (Scheiner et al., 2000). Roots were washed and sifted on a 2 mm grid. Measures on extracted root system were obtained from analyzed photography (Winrhizo 2009a, Régent Instruments Canada). The data recorded were root surface (cm²), root length (cm), root volume (cm3), number of forks and root average diameter (mm). Data were analyzed using analysis of variance (ANOVA, Rgui 2.12.0), carried out for each depth of reference (5 cm for root system, 10 cm for θ; 2 cm for SPR). A Student test was carried out when significant differences appeared at $P<0.05$. Soil trench data were also analyzed using semivariograms, and then modelized using a kriggeage (ArcMap.10, 2010; Ferrero *et al*., 2005; Jackson and Caldwell, 1993). In order to examine the roots spatial variance in the soil trench, and to estimate the relative differences between soil treatments, the root intersections points for a given soil treatment by soil trench, were ranked and averaged by plant and replication at the same grid position (440 in 2009, 5306 at stage E2 in 2010, 7142 at harvest in 2010). A semivariogram was carried out, before kriggeage of root interception on the grid for each soil treatment in each trial. The structural variance, characterizing the spatial dependence of variables, was determined as Jackson and Caldwell (1993).



Field A, 05 August 2009, Stage M2 **Field B, 21 September 2010, Harvest**

Figure 1. Dynamic of tillage impact on soil penetration resistance. In 2009, — —: Minimum tillage; - - - : Triple Tillage. In 2010, — ▪ —: Compacted Soil; ▪ ▪ ▪: Non-compacted Soil. $^{a, b}$: homogenous group according to Student test; ‘ Difference Probability at 0.1, * Significant Probability at 0.05, ** Significant Probability at 0.01, *** Significant Probability at 0.001.

RESULTS

In 2009, the soil presented differences for θ in depth at stage E2 in favor of triple tillage (+33% at -60 cm depth, $P<0.05$, 687 degrees.days^{-1}, data not shown). In 2010, a decrease of 16% at 60 cm depth ($P<0.05$, stage M0, data not shown) was observed under NCS. In 2009, at the beginning of the season, TT treatment induced a lower soil SPR at the top soil (-49% at 2 cm depth, $P<0.01$, data not shown) and a strongest at depth (-29% and -41% at 28 cm and 30 cm depth respectively, $P<0.05$) than MT. At stage M2 TT presented a strongest SPR in the top soil (-4 cm depth, $P<0.05$, figure 1). In 2010, NCS presented a lower value of SPR at the beginning and during the crop cycle, both at the surface and at depth (-8 cm depth, $P<0.05$ at stage A2; and from -6 cm to -30 cm depth, from $P<0.01$ to $P<0.1$, at harvest).

In our study, root system architecture and growth were affected by soil tillage treatment at harvest. Global root system morphology presented significant decreases under CS treatments in field B, -67% of root surface ($P<0.001$, data not shown), -42% of root average diameter ($P<0.01$), -55% of root length ($P<0.001$), -71% of root volume ($P<0.001$). No significant differences were observed in field B. The major part of root systems were located in the upper part of soil (94% of root length before -40 cm depth at stage M0 for field A, 96% at harvest for field B). In field A, root were more abundant in surface (-5 cm depth, $P<0.1$, data not shown), and lower in depth (-45 cm depth, $P<0.1$) under MT. In field B, the maximum root depth decreased of 13% under CS ($P<0.1$, data not shown), and roots were more abundant in the upper part of soil and lower in depth under CS ($P<0.05$ at -15 cm depth, $P<0.1$ at -45 cm depth). At harvest, roots intersections on the grid increased under NCS in depth (-60 cm depth, $P<0.05$, data not shown).

The variability of root systems in soil trench between soil treatment and fields were important (table 2). Some anisotropy associated with the depth was observed in each grid. In field A, semivariogram showed no spatial dependence under TT (table 2; no plateau reached, data not shown), and a low spatial dependence under MT. In field B at stage E2, the spatial dependence was relatively high for the both treatment, but lower for CS (c: 95% against 96% for NCS, data not shown).

Table 2. Model parameters for each semivariogram in figure 2. The nugget is the y-intercept on the graph, and the sill is the y value where the line becomes a plateau.

	Field A, Stage M0		**Field B, Stage E2**		**Field B, Stage harvest**	
Treatment	**TT**	**MT**	**CS**	**NCS**	**CS**	**NCS**
Effective	110.00	111.00	2653.00	2653.00	3571.00	3569.00
Mean	$5.90.\ 10^{-3}$	$9.20.\ 10^{-3}$	$5.70.\ 10^{-4}$	$3.04.\ 10^{-5}$	$7.16.\ 10^{-5}$	$1.57.\ 10^{-5}$
Standard error	0.43	0.41	0.14	0.10	0.08	0.11
RMSE	0.44	0.41	0.12	0.11	0.07	0.09
Structural variance c	-	0.67	0.95	0.96	0.92	0.73
Nugget value, C	-	1.21	0.05	0.09	0.07	0.49
Sill, C_0	-	3.64	1.05	1.91	0.95	1.78

Krigged root grid interception showed different soil exploration pattern (figure 2). Under CS, the root system exploration was smaller with the occurrence of an important network of lateral root (45 cm width against 35 cm in NCS at stage E2). The tap root was deeper under NCS than under CS (difference of 10 cm, at stage E2). In the same field at harvest, the spatial dependence was higher under CS (c: 92%) than under NCS (c: 73%). The krigged root exploration showed an evolution from stage E2 to harvest. In both treatments, the tap roots were deeper at harvest. A decrease in root system width was also observed, traducing a decrease in root branching between the both date which was more important in CS than in NCS. Comparable behavior was observed under both treatments between the two stages for the tap root elongation (difference of 10 cm in favor of NCS).

DISCUSSION

Over 2MPa of resistance to penetration value, the soil is strong enough to modify root growth and exploration (Wolfe *et al*., 1995), and strong compaction can affect soil water availability (Sadras *et al.*, 2005), which would have consequences on root system growth. The presence of a higher number of roots in depth, absorbing water could explain the decrease of water content at depth in field A and B. As observed under soil compaction, an increase of penetration resistance and a decrease of plant water availability have been reported (Lipiec *et al.*, 2003a; Sadras *et al*., 2005; Taboada *et al*., 1998). The great instability of field A adding to the important content of silt, and the low content of soil organic matter lead to a quick resilience phenomenon. Under soil compaction, soil water content increased at the surface and decreased in depth (Micucci and Taboada, 2006; Reintam *et al*., 2005) due to macropore reduction (Richard *et al*., 2001). This led to a decrease of plant water availability (Sadras *et al*., 2005), of hydraulic conductivity (Lipiec and Hatano, 2003), of gravimetric water content at high matric potential (Lipiec and Hatano, 2003). In our experimental context we can observe this phenomenon in field B, but not in field A. The authors attributed this difference to the soil texture of both fields.

Under soil compaction, researches on several crops (included sunflower) reported: either i) decreases on root number (Micucci and Taboada, 2006); rooting depth (Lecompte *et al*., 2003); root length (Rosolem *et nal.*, 2002); root growth (Petcu and Petcu, 2006); root biomass (Andrade *et al*., 1993); and water and nutrients uptake (Bingham *et al*., 2010); or ii) increases of lateral root length (over 54% for bean). This is consistent with our experiments. The sunflower root system alteration was greater the Glossaqualf soil under triple tillage than in the Mollic Udifuvent soil under mechanical induce compaction. The spatial dependence of root exploration was confirmed (Tardieu and Manichon, 1988). The response of relative root length, surface, volume, average diameter and number of forks, varied with trials and treatments, because of the two contrasted soils. Field B confirmed a deep modification of the root system architecture and exploration under soil mechanical constraint, as observed in literature. Such modification (increase of branching, and decrease of rooting depth) could be the result of compensation processes under soil constraint as observed by Lipiec et al. (Lipiec *et al*., 2003b). In this case an alteration of root capture efficiency could be induced by the modification of the root system growth and thus functioning (Croser *et al*., 2000).

CONCLUSION

The two types of soil reacted differently due to their properties (texture and water content). The constraint on roots system was greater in the Glossaqualf soil under triple tillage than in the Mollic Udifluvent soil under soil mechanical induced compaction. The compaction observed traduced by an increase of soil penetration resistance and a decrease of water availability; had several direct and indirect consequences on sunflower root system growth. The decrease of root length, surface, volume, and diameter, and the increase of branching in the top soil were observed, traducing deep modifications of root architecture. Alterations of root systems growth and exploration were also observed, suggesting a compensatory behavior under soil mechanical constraint. Those modifications were reported among several times of observation. Since soil conservation practices tend to increase in the French context, such results would have to be taken into consideration, in order to optimize sunflower production.

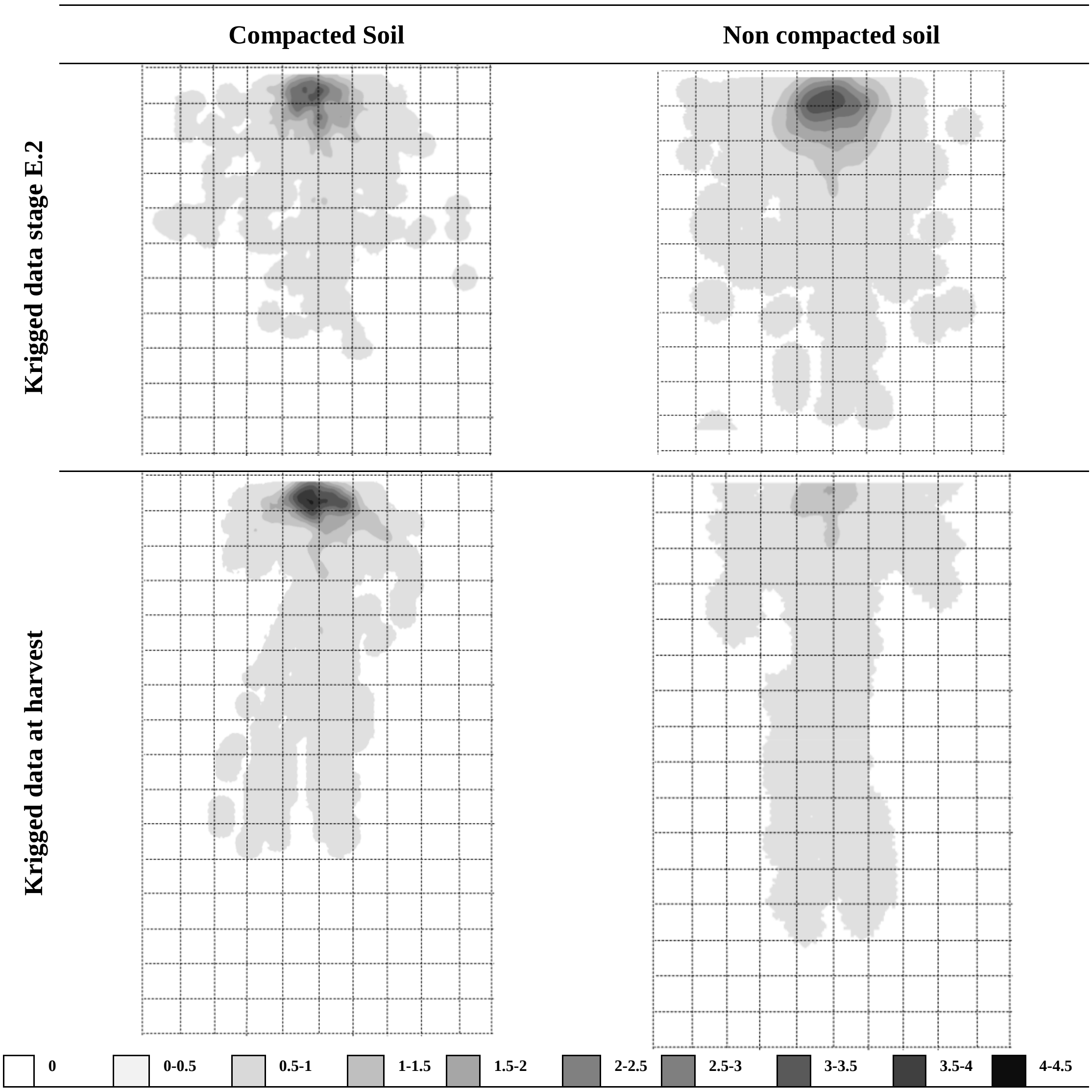


Figure 2. Effect of soil induced compaction on root exploration. Field B, 2010, stage harvest. Grid of 5 cm², X from -25 cm to 25 cm, 0: sunflower stem base; Y, from 0 to 80 cm depth. Data calculated from grid intersection (1cm²) with Tennant method (Tennant 1975). Semivariogramm: Ɣ: semivariance; Distance between points (cm); line: model; cross: average. Kriggeage data: root length cm.

REFERENCES

Andrade A., D.W.Wolfe, E. Fereres. 1993. Leaf expansion, photosynthesis, and water relations of sunflower plants grown in compacted soil. Plant and Soil. 149:175-184.

Bingham I.J., A.G. Bengough, R.M. Rees. 2010. Soil compaction-N interactions in barley: Root growth and tissue composition. Soil & Tillage Research. 106:241-246.

Croser C., A.G. Bengough, J. Pritchard. 2000. The effect of mechanical impedance on root growth in pea (*Pisum sativum*). II. Cell expansion and wall rheology during recovery. Physiologia Plantarum. 109:150-159.

Ferrero A., B. Usowicz, J. Lipiec. 2005. Effects of tractor traffic on spatial variability of soil strength and water content in grass covered and cultivated sloping vineyard. Soil & Tillage Research. 84:127-138.

Jackson R.B., M.M. Caldwell. 1993. Geostatistical patters of soil heterogeneity around individual perennial plants. Journal of Ecology. 81:683-692.

Lecompte F., H. Ozier-Lafontaine, L. Pages. 2003. An analysis of growth rates and directions of growth of primary roots of field-grown banana trees in an andisol at three levels of soil compaction. Agronomie. 23:209-218.

Lipiec J., W. Stepniewski. 1995. Effects of soil compaction and tillage systems on uptake and losses of nutrients. Soil and Tillage Research. 35:37-52.

Lipiec J., R. Hatano. 2003. Quantification of compaction effects on soil physical properties and crop growth. Geoderma. 116:107-136.

Lipiec J., J. Arvidsson, E. Murer. 2003a. Review of modelling crop growth, movement of water and chemicals in relation to topsoil and subsoil compaction. Soil & Tillage Research. 73:15-29.

Lipiec J., V.V. Medvdedev, M. Birkas, E. Dumitru, T.E. Lyndina, T.E. Rousseva, E. Fulajtar. 2003b. Effect of soil compaction on root growth and crop yield in central and Eastern Europe. International Agrophysics. 17:61-69.

Micucci F.G., M.A. Taboada. 2006. Soil physical properties and soybean (Glycine max, Merrill) root abundance in conventionally- and zero-tilled soils in the humid Pampas of Argentina. Soil & Tillage Research. 86:152-162.

Murillo J.M., F. Moreno, I.F. Giron, M.I. Oblitas. 2004. Conservation tillage: long term effect on soil and crop under rainfed conditions in south-west Spain (Western Andalusia). Spanish Journal of Agricultural Research. 1:35-43.

Petcu G., E. Petcu. 2006. Effect of cultural practices and fertilizers on sunflower yield in long term experiments. Helia. 29:135-144.

Reintam E.K., J., E. Nugis, K. Trükmann. 2005. Soil compaction and fertilisation effects on nutrient content and cellular fluid of spring barley (*Hordeum vulgare L*.). Agronomy Research. 3:189-202.

Richard G., I. Cousin, J.F. Sillon, A. Bruand, J. Guerif. 2001. Effect of compaction on the porosity of a silty soil: influence on unsaturated hydraulic properties. European Journal of Soil Science. 52:49-58.

Rosolem C.A., J.S.S. Foloni, C.S. Tiritan. 2002. Root growth and nutrient accumulation in cover crops as affected by soil compaction. Soil & Tillage Research. 65:109-115.

Sadras V.O., G.J. O'Leary, D.K. Roget. 2005. Crop response to compacted soil: capture efficiency in the use of water and radiation. Field Crop Research. 91:131-148.

Sasal M.C., A.E. Andriulo, M.A. Taboada. 2006. Soil porosity characteristics and water movement under zero tillage in silty soils in Argentinian Pampas. Soil & Tillage Research. 87:9-18.

Scheiner J.D., R.S. Lavado. 1999. Soil Water content, absorption of nutrient elements, and responses to fertilization of sunflower: a case study. Journal of Plant Nutrition. 22:369-377.

Scheiner J.D., F.H. Gutierrez-Boem, R.S. Lavado. 2000. Root growth and phosphorus uptake in wide and narrow row soybean. Journal of Plant Nutrition. 23:1241-1249.

Sessiz A., T. Sogut, A. Alp, R. Esgici. 2008. Tillage effects of sunflower emergence, yield, quality, and fuel consumption in double cropping system. Journal of Central European of Agriculture. 9:697-710.

Sharp R.E., W.K. Silk, T.C. Hsiao. 1988. Growth of the maize primary root at low water potential. I, spatial distribution and expansive growth. Plant Physiology. 87:50-57.

Taboada M.A., C.R. Alvarez. 2008. Root abundance of Maize (*Zea mays* L.) in conventionally-tilled and zero tilled soils of Argentina. Ciencia del Suelo. 32:2-11.

Taboada M.A., F.G. Micucci, D.J. Cosentino, R.S. Lavado. 1998. Comparison of compaction induced by conventional and zero tillage in two soils of the Rolling Pampa of Argentina. Soil & Tillage Research. 49:57-63.

Tardieu F., H. Manichon. 1988. Analysis of the spatial variability in maize root density .3. Effect of a wheel compaction on water extraction. Plant and Soil. 109:257-262.

Tennant D.. 1975. A test of a modified line intersect method of estimating root lentgh. Journal of Ecology. 63:995-1001.

Vanags C., B. Minasny, A.B. McBratney. 2006. The dynamic penetrometer for assessment of soil mechanical resistance. p. 1-7. In: Proc. 3rd Australian New Zealand Soils Conference, University of Sydney, Australia.

Wolfe D.W., D.T. Topoleski, N.A. Gundersheim, B.A. Ingall. 1995. Growth and yield sensitivity of four vegetable crops to soil compaction. Journal of American Society of Horticulture. 120:956-963.