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SAFFLOWER PRODUCTIVITY AS RELATED TO SOIL WATER STORAGE AND MANAGEMENT PRACTICES IN SEMIARID REGIONS

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ABSTRACT

In semiarid regions the availability of water has an important influence on dryland crop productivity. Water availability is closely related to soil organic matter (SOM) content, texture and soil thickness. Safflower (*Carthamus tinctorius* L.) is an important winter crop in some semiarid regions due to its deep roots and drought tolerance. However, its adaptation to different soil conditions is still not well known. The objective of this study was the evaluation of safflower productivity, in relation to soil properties, across 30 grower fields of the semiarid Pampas region of Argentina. The soils were Entic and Aridic Haplustolls under continuous row-cropping (CC) or pasture–

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row crop rotations (PC). Grain yields varied between 0 and 1600 kg ha^{-1}, and were positively correlated with the maximum soil water retention (SWR) of the top layer (0–20 cm) and the soil use management (SUM, $r = 0.93$, $p < 0.01$). Oil yield and plant growth was also positively correlated with SWR and SUM. This trend was explained on the basis of better water and nutrient supply to the plants in finer textured soils during the pronounced moisture deficiency that occurred at the flowering stage of the crop. In soils with similar textures, safflower production was highest in sites that included PC, had high SOM levels, and in which indurate sub-surface layers were absent. Highly productive dryland safflower crops in coarse textured soils from semiarid regions can be achieved by using cultural practices that increase SOM levels (pasture–arable crop rotation) and loosen compacted layers.

INTRODUCTION

Crop rotations are an important feature of sustainable agricultural production systems. They facilitate weed, pest and disease control, help in management of soil fertility and can contribute to the economic sustainability of such systems. Continuous monoculture can lead to soil degradation, thereby diminishing long-term productivity. Rotating crops improves soil physical properties and, mainly in dry years, contribute to yield advantages from rotating crops compared with continuous crops (1). Crop selection for use in rotational sequences is an important problem, particularly for dryland production systems in semiarid regions with coarse textured soils in which irrigation practices are not possible because the income producing crop alternatives are restricted to a few species. System manipulations to maximize rainfall storage in the root zone not only increase the productivity of dryland agricultural systems, but also protect the soils from erosion threats (2).

In such environments, the availability of water has an important influence on crop productivity on non-irrigated lands (3,4) either because of the quantity and distribution of rainfall or the capacity of soil to store water. Availability of water is closely linked to soil parameters such as organic matter content and texture (5–8). Increasing organic matter contents in sandy soils improves their water holding capacity due to changes in the porosity. One of the consequences of intensive use of sandy soils is the development of compacted layers due to animal or machinery traffic. Compacted layers can affect crops yields by reducing root penetration into the subsoil (9). The overall result is that the soil's total porosity is reduced, reducing soil water and nutrient availability to roots. Davidson et al. (10) found that, for similar textures, maximum compaction values were largely reduced with small increases in the organic carbon content of the soil as a consequence of different management practices. Thus, variations in soil texture and organic matter content can be expected to affect dryland crop productivity on coarse-textured soils from semiarid regions. When there are prolonged cash grain cycles, the tendency is towards decreased in organic matter content and wet aggregate stability, and increased susceptibility to compaction (11), which not only has adverse mechanical effects on plants but also give rise to a considerable reduction in hydraulic conductivity (12). Haynes et al. (13) describe changes in soil organic matter contents under mixed cropping rotations (pasture–cash grain). Changes in soil organic matter under crop sequences including pluriannual pastures should be less than under continuous annual crops, and thus, yields should be higher.

Safflower (*Carthamus tinctorius*) contributes partially in the world edible and industrial oil market, the by-products of oil extraction, whole seed or kernel meal, is available for stock feed. It is considered an important winter crop in some semiarid regions due to its deep roots and its drought tolerance (14,15). Zaman and Choudhuri (16) reported deeper water extraction from sandy loam soils under dryland safflower cultures than under irrigated cultures. Leaf area and evapotranspiration rate reduction, osmotic adjustment and increments in the cell density are other adaptative mechanisms of safflower plants to water stress conditions (17). The available information about dryland safflower productivity on sandy soils under growers' field conditions is limited. Therefore, we planned the following study to identify native and management induced soil properties that relate to safflower yields on sandy soils in semiarid regions.

MATERIALS AND METHODS

This study was conducted in a 120,000-km^2 area within the semiarid Pampas region of Argentina, located between 35°50′ and 37°30′S and 63°40′ and 64°20′W. The mean annual precipitation varies between 400 and 700 mm, with greater rainfall occurring during spring and summer. The mean annual temperature is between 15 and 17°C (18). The soils in this region, developed on holocenic eolic materials (loess), are classified as Molisolls and Entisolls (USDA taxonomy). They are mainly coarse textured, weakly structured, and therefore highly susceptible to be eroded by wind (19). Nitrogen deficiency increases as the organic matter content of the soil diminishes and the period in cash grain production after pastures. The potassium status of the Pampas soils is high, with exchangeable potassium levels above 10-meq kg^{-1} (20). Management of production systems in the semiarid Pampas region of Argentina traditionally comprised alternation of a 4 to 6 year period of cash crops, mainly winter wheat (*Triticum aestivum* L.) and sunflower (*Helianthus annus* L.) with 3 to 5 years period under alfalfa (*Medicago sativa* L.) and fescue (*Festuca arundinacea* L.) pastures for extensive livestock grazing.

Safflower productivity under dryland conditions was evaluated on 30 farmers' fields during the 1989–90 growing season. Crop and soil management practices were similar in all the fields. The fallow was started in March with a disking plow. Disking was repeated two to three times before sowing (June 1989). In all fields, the cultivar "Alcaidía" was sown at a rate of 50 seed m^{-2}. Fertilizers or irrigation were not applied in any field.

Sampling units were three 1 × 1 m plots randomly chosen within a uniform 100 m^2 area in each field. Soil and plant samples from each sampling unit were taken at maturity (January, 1990). Crop observations were total grain yield, plant height, stems per plant, grains per plant, oil content of the grain and individual weight of the grains. The number of grains per unit area was calculated from the grain yield and the individual weight of the grains.

Soil samples from the top layer (0–20 cm) were air dried and passed through a 2-mm sieve. The following determinations were carried out on each soil sample: total organic carbon (TOC) by wet combustion (21), available phosphorus (Pa) extracted with an acid-fluoride solution (22) and soil water pH. The soil water retention at 0.33 bar (SWR) was estimated from the soil water content (gravimetric method) in centrifuged samples (2500 rpm = 1000 g during 1 hour) after 24 hours of water saturation (23).

Six locations were selected on the basis of their SWR and management conditions. Soil water contents (gravimetric method) in 20-cm layers from the top to a depth of 80 cm and penetration resistance in 5-cm layers over the top to 40 cm with cone penetrometer (24) were determined monthly in each soil. Plant available water was calculated as the water remaining in a 80 cm profile above the lower limit of water extraction (wilting point) determined for suction at 1.5-MPa.

Multiple regression (stepwise) and correlation analyses between soil properties and crop yields were carried out on the results. The soil use management (fields under continuous row crops or under pasture rotation) was included as a class variable. Data from the six selected soils were subjected to analysis of variance and were compared according to LSD method at the 0.05 level of significance (25). In the comparisons between soils with similar texture and different soil use management and between soils with similar management and different textures the observed differences were attributed to these factors which were not replicated so the implications does not extend beyond the environmental conditions presented in this study (26).

RESULTS AND DISCUSSION

The 30 studied soils had sandy, loamy-sand and loam textures in the top layer (0–20 cm) with TOC contents ($11.3 \pm 3.4\,g\,kg^{-1}$) significantly correlated with SWR levels ($r = 0.71$, $p < 0.01$). Available phosphorus ($15.7 \pm 3.4\,mg\,kg^{-1}$) and pH ($6.72 \pm 0.3$) were not related with TOC or SWR contents.

At 30% of the sites, corresponding generally to the sandiest textured soils, safflower crops did not complete its life cycle. At the remaining sites, grain production varied between 80 and 1600 kg ha^{-1} and was correlated with SWR in the soil's 0–20 cm layer and the soil use management. For those 21 sites:

$$Y = 4.72 \times SWR + 341.12 - 138.39 \qquad (r = 0.88,\ p < 0.0001) \qquad (1)$$

where Y is the safflower grain yields in kg ha^{-1}, SWR the maximum soil water retention in g kg^{-1}, and SUM is the soil use management (SUM = 1 in pasture rotations and SUM = 0 in continuous row crop sequences). Analysis of the residuals from this yield prediction model separated site C from the others. This site had larger crop seed yields than expected by the regression line (Fig. 1). The high TOC content and favorable physical conditions inherited from previous management likely (Table 1) caused these differences. Exclusion of the site C from the linear regression (1) increased the percentage of yield explained by different SWR levels and SUM from 0.77 to 0.88. The fitting equation in this case

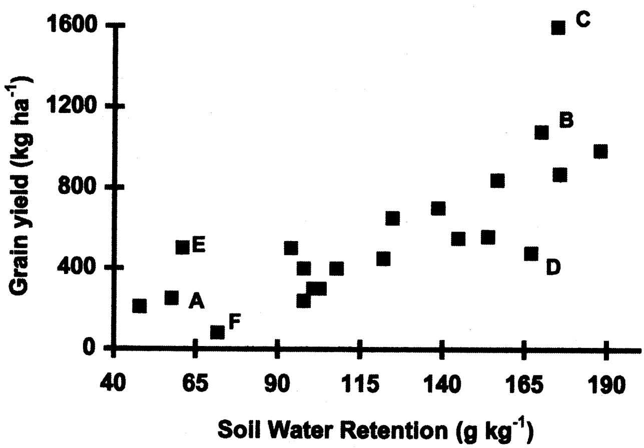

Figure 1. Safflower grain yields and soil water retention levels of the top layer (0–20 cm) in 21 farmers' fields from the semiarid pampas region of Argentina. Letters correspond with sites identified in Tables 1 and 3.

Table 1. Soil Properties and Safflower Yields in Four Farmers' Fields Under Contrasting Rotational Management Systems and Two Soil Types with Contrasting Fine Particle Contents in the Top Layer (0 to 20 cm)

Site	Soil	Rotation	"c + s" ($g\,kg^{-1}$)	TOC ($g\,kg^{-1}$)	Pa ($mg\,kg^{-1}$)	SR at 20–30 cm (MPa)	Yields ($kg\,ha^{-1}$)
C	Entic Haplustoll	PC	543	14.7	17	1.87	1600 a[a]
D	Entic Haplustoll	CC	519	16.5	14	4.67	480 b
E	Aridic Haplustoll	PC	189	7.2	14	1.87	500 a
F	Aridic Haplustoll	CC	223	8.9	13	3.04	80 b

PC = pasture–row crop rotation, CC = Continuous row cropping sequence, "c + s"= clay and silt content based on the soil water retention level (27), TOC = Total organic carbon, Pa = available phosphorus, SR = Soil penetration resistance.

[a] Yields values with the same letter are not significantly different at 0.05 level between soils with similar textures (C vs. D and E vs. F).

was:

$$Y = 3.97 \times SWR + 286.27\,SUM - 57.26 \quad (r = 0.93,\ p < 0.0001) \qquad (2)$$

The oil production, plant growth (height and number of heads per plant) and grain number were also correlated to SWR, SUM and/or TOC (Table 2).

Quiroga (27) demonstrated that "clay+silt" contents and soil water storage capacity are positively correlated in the weakly developed soils of the semiarid Pampas region of Argentina. They proposed an equation based on the SWR content measured by the method used in this study. Thus, the relationships between safflower grain yields and SWR can be explained on the basis of grater amounts of available water stored by finer textured soils, as well as better nutrient availability from larger associated organic reserves, than by coarser textured soils. Dryland winter wheat production in this area showed similar relations with SWR in years with low rainfall (28).

Based on the relation between SWR and "clay+silt" contents (27), the total water stored in the profile (0–80 cm) during the growing season was evaluated for two different textured soils, with similar rainfall amounts and distributions identified in Figure 1 as site A (sand) and site B (sandy loam). Figure 2 illustrates that the water content in the coarser textured soil was near or below the wilting point during the blooming stage, while in soil B, water deficiency was not so pronounced. According to Rao et al. (29), soil moisture stress during this stage significantly reduces safflower grain yields. Low water contents of these soils

Table 2. Relationships Between Stepwise Selected Soil and Management Properties with Safflower Productivity Components in Farmer's Fields from the Semiarid Pampas Region, Argentina (n = 20)

		r^2	Prob > F
Grain yield ($kg\,ha^{-1}$)	−57.3 + 3.97 SWR + 286.3 SUM	0.881	0.0001
Oil yield ($kg\,ha^{-1}$)	−43.2 + 1.66 SWR + 104.1 SUM	0.870	0.0001
Oil content ($g\,kg^{-1}$)	306.5 + 5.04 TOC	0.617	0.0001
Grain weight ($mg\,grain^{-1}$)	20.5 + 0.05 SWR	0.649	0.0001
Grain number m^{-2}	207.0 + 11.04 SWR + 1004.3 SUM	0.849	0.0001
Heads $plant^{-1}$	0.9 + 0.03 SWR	0.594	0.0001
Height (cm)	31.6 + 0.21 SWR + 15.0 SUM	0.705	0.0028

SWR ($g\,kg^{-1}$) = Soil water retention, SUM = soil use management (0 = in continuous row crop sequences, 1 = in pasture rotation), TOC ($g\,kg^{-1}$) = total organic carbon.

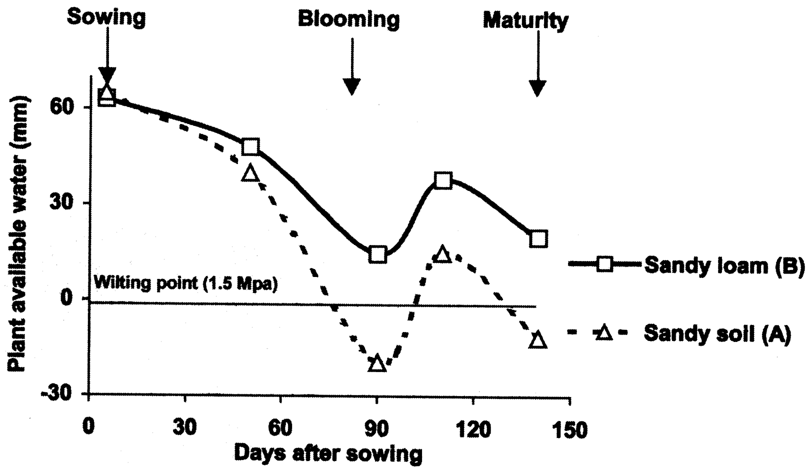

Figure 2. Available soil water (0–80 cm deep) during safflower growth in two soils with different top layer (0–20 cm) textures and similar rainfall levels and distributions. Letters correspond with sites identified in Table 3.

were due to limited rainfall during the safflower-growing season (winter and beginning of spring). This is the condition normally observed in the semiarid Pampas region because the rainfall period is between spring and fall (19).

Plant height, number of stems per plant, individual weight of grains, grain number per square meter and total grain yields were significantly lower in the sandy soil (A) than in the sandy loam soil (B) (Table 3). Hayashi and Hanada (30) pointed out that under water stress safflower internode elongation is inhibited, resulting in a short stem with few lateral branches, fewer inflorescences per plant and lower seed yields.

Also based on the relationship between SWR and "clay+silt" content (27), the effect of previous rotational management on safflower yields was evaluated in soils with similar textures. These are identified in the Fig. 1 as sites C and E under pasture–cash grain crop rotations, and sites D and F with more than 15 years under continuous cash grain cropping. The first pair of sites (C and E) have soils with thicker and better structured A horizons, and lower penetration resistance in the subsoil than the soils in the sites D and F (Table 1). Although safflower is considered an efficient crop in the extraction of water from the soil (31) it was observed that the presence of indurate subsurface layers significantly affects its production (32). Root growth rates generally are very low when soil mechanical impedance is greater than 3 MPa in sandy soils, the presence of compacted layers reduces crop yields during dry years (9,33). At sites D and F, levels of subsurface

Table 3. Safflower Seed Yields and Yield Components in Two Farmer's Fields with Different Top Layer (0–20 cm) Textures and Similar Rainfall Level and Distribution

	Site A	Site B
Texture	Sandy	Sandy loam
"Clay + silt" ($g\,kg^{-1}$)	181 a[a]	529 b
TOC ($g\,kg^{-1}$)	7.4 a	15.1 b
Grain yield ($kg\,ha^{-1}$)	259.0 a	1080.0 b
Plant height (cm)	44.0 a	70.0 b
Stems $plant^{-1}$	2 a	5 b
Grains $plant^{-1}$	22 a	81 b
Grains m^{-2}	1050 a	4252 b
Grain weight ($mg\,grain^{-1}$)	24.7 a	25.4 a
Oil grain content ($g\,kg^{-1}$)	380.0 a	397.0 b

TOC = total organic carbon, "c + s" = "clay and silt" content based on the soil water retention level (27).
[a] Values with the same letter are not significantly different at 0.05 level between soils.

compaction would have limited normal root development reducing safflower yield.

The achievement of highly productive safflower crops in coarse soils from semiarid regions can be obtained using cultural practices that minimize losses of soil organic carbon (pasture–cash grain crop rotation) and loosen compacted layers.

CONCLUSIONS

Soil texture, inherited from parent materials or altered by erosion controls safflower dryland productivity under water stress conditions in soils from the semiarid Pampas region of Argentina. The increment in yields due to increased SWR levels can be explained on the basis of larger amounts of fine particles that permit the greater storage of available water during the safflower growing season, as well as better nutrient availability from the associated organic reserves found in these soils.

In fields with similar texture, crop yield variability depends on total organic carbon content and related soil physical properties produced in rotational management of the soils. Sites in perennial grassland rotations and without subsurface compaction had higher yields than those continuously cash grain cropped.

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REFERENCES

1. Raimbault, B.A.; Vyn, T.J.; Tollenaar, M. Corn Response to Rye Cover Crop, Tillage Methods, and Planter Options. Agron. J. **1991**, *83*, 287–290.
2. Gimenez, C.; Orgaz, F.; Fereres, E. Productivity in Water-Limited Environments: Dryland Agricultural Systems. *Ecology in Agriculture*; Academic Press: New York, 1997, 117.
3. Read, D.W.L.; Warder, F.G. Influence of Soil and Climatic Factors on Fertilizer Response of Wheat Grown on Stubble Land in Southwestern Saskatchewan. Agron. J. **1974**, *66*, 245–248.
4. Tessier, S.; Peru, M.; Dick, F.B.; Zentner, F.P.; Campbell, C.A. Conservation Tillage for Spring Wheat Production in Semi-arid Saskatchewan. Soil Till. Res. **1990**, *18*, 73–89.
5. McDaniel, P.A.; Munn, L.C. Effect of Temperature on Organic Carbon–Texture Relationships in Mollisols and Aridisols. Soil Sci. Soc. Am. J. **1985**, *49*, 1486–1489.
6. Hutson, J.L. Water Retentivity of Some South African Soils in Relation to Particle Size Criteria and Bulk Density. S. Afr. J. Plant Soil **1986**, *3*, 151–155.
7. Tan Piow Meng, H.M.; Taylor, H.M.; Fryerear, D.W.; Gomez, J.F. Models to Predict Water Retention in Semiarid Sandy Soils. Soil Sci. Soc. Am. J. **1987**, *51*, 1563–1565.
8. Rawls, W.J.; Gish, T.J.; Brakensiek, D.L. Estimating Soil Water Retention from Soil Physical Properties and Characteristics. Adv. Soil Sci. **1991**, *16*, 213–234.
9. Vepraskas, M.J. Plant Response Mechanisms to Soil Compaction. In *Plant–Environment Interactions*; Wilkinson, R.E. Ed.; Marcel Dekker, Inc. New York, 1994, 263–287.
10. Davidson, K.J.; Gray, F.; Pinson, D. Changes in Soil Organic Matter and Bulk Density with Depth Under Two Cropping Systems. Agron. J. **1967**, *59*, 375–378.

11. Quiroga, A.R.; Buschiazzo, D.E.; Peinemann, N. Management Discriminant Properties in Semiarid Soils. Soil Sci. **1998**, *163*, 591–597.
12. Quiroga, A.R.; Buschiazzo, D.E.; Peinemann, N. Soil Compaction is Related to Management Practices in the Semiarid Argentine Pampas. Soil Till. Res. **1999**, *52*, 21–28.
13. Haynes, R.J.; Swift, R.S.; Stephen, R.C. Influence of Mixed Cropping Rotations (Pasture–Arable) on Organic Matter Content, Water Stable Aggregation and Clod Porosity in a Group of Soils. Soil Till. Res. **1991**, *19*, 77–87.
14. Rafey, A.; Prasad, N.K. Biological Potential and Economic Feasibility of Intercropping Oilseeds and Pulses with Safflower (*Carthamus tinctoriuos* L.) in Dryland. Indian J. Agric. Sci. **1991**, *61*, 893–897.
15. Blackshaw, R.E.; Morrison, R.J.; Muendel, H.H.; Roth, B.R. Weed Control in Safflower (*Carthamus tinctorius* L.) with Flurtamone. Weed Sci. **1992**, *40*, 110–114.
16. Zaman, A.; Choudhuri, S.K. Water Use Efficiency and Moisture Extraction Patterns of Safflower in Semi-arid Region of Indian Sub-tropics. Int. J. Trop. Agric. **1998**, *16*, 157–163.
17. Guerra Sanz, J.M.; Muriel Fernández, J.L. Efectos del Estres Hídrico Sobre el Crecimiento Foliar en Plantas de Dártamo (*Carthamus tinctoreous* L.). Ann. INIA, Ser. Agrícola **1982**, *21*, 143–154.
18. Servicio Meteorológico Nacional, *Estadísticas Climatológicas 1900–1960*; SMN: Buenos Aires, Argentina, 1965.
19. INTA, Gobierno de La Pampa, UNLPam, *Inventario Integrado de Los Recursos Naturales de La Provincia de La Pampa*; ISAG: Buenos Aires, Argentina, 1980.
20. Hall, A.J.; Rebella, C.M.; Ghersa, C.M.; Culot, J.P. Field-Crop Systems of the Pampas. In *Field Crop Ecosystems*; Pearson, C.J. Ed.; Elsevier: Amsterdam, 1992, 413–450.
21. Nelson, D.W.; Sommers, L.E. Organic Carbon, and Organic Matter. In *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties*; Page, A.L., Miller, R.H., Keeney, D.R. Eds.; ASA: Madison, WI, 1982, 539–579.
22. Bray, R.H.; Kurtz, L.T. Determination of Total, Organic, and Available Forms of Phosphorous in Soils. Soil Sci. **1945**, *59*, 39–45.
23. Schlichting, E.; Blume, H.P.; Stahr, K. *Bodenkundliches Praktikum*; Paul Parey Verlag: Hamburg, 1995.
24. O'Sullivan, M.E.; Dickson, J.W.; Campbell, D.J. Interpretation and Presentation of Cone Resistance Data in Tillage and Traffic Studies. J. Soil Sci. **1982**, *38*, 137–148.
25. SAS Institute, *SAS® Language: Reference, Version 6*; 1st Ed; 1042 pp. SAS Institute, Inc. Cary, NC, 1990.

26. Hurlbert, S.H. Psudoreplication and the Design of Ecological Field Experiments. Ecol. Monogr. **1984**, *54*, 187–211.
27. Quiroga, A.R.; Buschiazzo, D.E. Relaciones Entre Algunos Parámetros Hídricos, Densidad Aparente y Materia Orgánica Con Granulometría en Suelos de La Región Semiárida Pampeana Central. In *Actas del XII Congreso Argentino de la Ciencia del Suelo*; Asociación Argentina de la Ciencia del Suelo Ed.; AACS: Corrientes, Argentina, 1988.
28. Díaz-Zorita, M.; Buschiazzo, D.E.; Peinemann, N. Soil Organic Matter and Wheat Productivity in the Semiarid Argentine Pampas. Agron. J. **1999**, *91*, 276–279.
29. Rao, M.S.R.M.; Seshachalam, N.; Rao, V.R.; Ramachandram, M. Critical Stages for Moisture Stress in Different Crops. Mysore J. Agric. Sci. **1977**, *11*, 494–500.
30. Hayashi, H.; Hanada, K. Effects of Soil Water Deficit on Seed Yield and Yield Components of Safflower (*Carthamus tinctorius* L.) Plants. Jpn. J. Crop Sci. **1985**, *54*, 346–352.
31. Beech, D.F.; Leach, G.J. Comparative Growth, Water Use and Yield of Chickpea, Safflower and Wheat in Southeastern Queensland, Australian. Australian. J. Exp. Agric. **1989**, *29*, 655–662.
32. Brooke, H.D.; Coventry, D.R.; Reeves, T.G.; Jarvis, D.K. Liming and Deep Ripping Responses for a Range of Field Crops. Plant Soil **1989**, *115*, 1–6.
33. Dexter, A.R. Mechanics of Root Growth. Plant Soil **1989**, *98*, 303–312.