University of Jordan
Faculty of Graduate Studies

Moisture Content and Some Physical Properties of Vertisols under Different Tillage and Crop Residue Management Practices

By
Ayman Abdallah Ahmed Suleiman

Supervised by
Prof. Dr. Anwar Munir Battikhi

Co-Supervised by
Dr. Hazel Harris

Submitted in Partial Fulfilment of The Requirements for The Degree of Master of Science in Soils and Irrigation, Faculty of Graduate Studies, University of Jordan.

October, 1994.

This thesis was defended successfully on Oct. 22, 1994 and approved by :

Committee Members :	**Signature**
1. Anwar Battikhi (Professor of Soil Physics)	A. M. Battikhi
2. Hazel Harris (Senior Scientist of Soil Moisture Conservation)	HHarris
3. Awni Taimeh (Professor of Soil Genesis and Classification)	Awni Taimeh
4. Muhammad Shatanawi (Associate Professor of Irrigation Engineering)	MR Shatanawi
5. Ibrahim Ghawi (Associate Professor of Soil Physics)	I. D. Ghawi

DEDICATION

To ....

My Mother, Father .....

Sisters, and Brothers ....

ACKNOWLEDGEMENTS

Thank God for supporting me with power, patience, and determination throughout each step of the preperation of this thesis.

I should express my deep thanks and appreciations to Prof. Anwar Battikhi who supported me by his intelligent pieces of advice and excellent guidance in the field work as well as in the preparation of this thesis in all its stages.

Thanks aare extended to the committee members; Dr. Hazel Harris from ICARDA, Prof. Awni Taimeh, Dr. Muhammad Shatanawi, and Dr. Ibrahim Ghawi for their helpful advice in the field of their specialization, and for reading and criticizing drafts of various parts of this thesis.

My deep thanks are also extended to Dr. Muhammad Al-Taba'a for his advice in the statistical analysis.

Special thanks are extended to ICARDA Centers in Amman and Aleppo for financial support. Thanks are also extended to the staff of the Mushaqar Agricultural Experiments Station for their cooperation.

I would also like to take this opportunity to express my thanks and appreciation to the National Center for Agricultural Research and Technology Transfer (NCARTT) and to the Technical Assistance and Services Office (TASO) for partially funding my research activities through the National Agricultural Development Project which is financed by the United State Agency for International Development (USAID).

Table of Contents

Page

List of Tables

List of Figures

List of Appendices

ABSTRACT

Moisture Content and Some Physical Properties of Vertisols under Different Tillage and Crop Residue Management Practices

By

Ayman Abdallah Ahmed Suleiman

Supervised by

Prof. Dr. Anwar Munir Battikhi

Co-Supervised by

Dr. Hazel Harris

Understanding the effects of tillage and plant residues incorporation on soil physical properties during plant growth period is strongly needed to improve tillage - residue management practices, especially in Vertisols because of their shrink-swell phenomenon which, in turn, affects their physical properties. From 1992 through 1994, the effects of two tillage practices and two residue management treatments on bulk density (B), soil strength (SS), infiltration rate (IR), soil moisture storage (SMS), evapotranspiration (ETC), and soil moisture depletions (SMD) in a Vertisol (very fine, smectitic, thermic, chromic Haploxeret) on less than 1% slope within lentil - wheat rotation, at Mushaqar

Agricultural Experiment Station, were determined. Evaluation of the neutron probe readings and the corresponding moisture contents was also done. The two tillage treatments were moldboard (T1) and chisel (T2). While the two residue treatments were : grazing after harvest for one month then incorporation in August by ploughing (R1); and grazing after harvest for one month then incorporation in the mid of October (R2).

Results indicated that moldboard plough gave significantly higher ETC and SMD (217.4 and 232.4 mm) than chisel plough (199.7 and 206.3 mm) in the first season (lentil season). While SMS only was significantly higher in T1 (205.3 mm) than in T2 (171.8 mm) in the second season (wheat season). Meanwhile there were no significant differences between the residue treatments with respect to soil moisture parameters for the two seasons. Immediate incorporation of residues treatments (R1) gave significantly higher B values than for R2, while the different tillage operations had no significant effect on B.

Soil strength values were significantly lower for T1 and R2 than other values obtained from other treatments. Basic infiltration rate was higher under T1 than under T2, in lentil season. While, for the wheat season, basic IR was lower under T1 than under T2. Soil surface moisture content, B, SS, and basic IR were significantly lower for the lentil season than for the wheat season.

Soil moisture parameters values which were calculated using the appropriate bulk density values were significantly lower than those which were calculated using a single value for the bulk density. Relationships between gravimetric soil moisture content (θg) with bulk density and cracks volume were determined. Corrections of neutron probe readings in the presence of cracks around the access tubes were also made.

In the laboratory study, it was found that R1 had significantly higher bulk density and lower soil specific volume and void ratio than R2. Whereas, T1 had significantly lower value of θg at 0.1 bar soil moisture tension and significantly higher values at 5, 10 and 15 bars soil moisture tension than for T2. Treatment T2 had significantly higher gravimetric and volumetric available moisture and R1 had significantly higher volumetic available moisture than the other treatments. In general, tillage operation tends to increase cracks volume and coefficient of linear extensibility, while decrease shrinkage characteristic, and available moisture.

1. Introduction

Vertisols in Jordan occur on less than 6% steepness and recieve an annual rainfall between 300 to 500 mm. They occupy about 30% of the total area planted to cereal crops. Furthermore, field crops occupy a large rainfed area in Jordan. About 0.49 million dunums are planted to wheat and other cereals. This constitues about 83% of the total rainfed area cultivated annually, which varies from region to region according to rainfall amount and distribution. Annual rainfall in these areas ranges from 300 to 450 mm, with an average cereal yield of 650-700 kg/ha(1).

One of the most important property of Vertisols is their ability to shrink and swell upon change of soil moisture content(2) which, in turn, affects their physical properties. These changes in physical properties might be sometimes advantageous(3).

Productivity and management of Vertisols are governed by four soil physical factors: soil water; soil aeration; soil temperature regimes; and the mechanical properties of the root zone(4). The use of a suitable tillage-residue management practices could improve some of these soil physical properties especially infiltration rate, mechanical properties of soil surface, soil water evaporation and soil moisture storage from precipitation(5).

It is believed that surface tillage operation (chisel) conserves more soil moisture than other conventional tillage (moldboard). Surface tillage does not invert the soil and keeps the soil moisture intact, also it gives a smooth suitable seed-bed. Meanwhile, conventional tillage inverts the upper 20 cm of soil surface which causes the drying out of soil moisture. In addition, surface tillage maintains crop residues on the soil surface, thus reducing evaporation losses and increasing the amount of intercepted rainfall, which may increase water infiltration and storage[6].

A study was conducted at Mushaqar Agricultural Experiment Station in the middle of Jordan aiming to achieve the following objectives :

1. determine the relationship between shrink-swell capacity and the moisture content of soil,
2. study the effect of shrink-swell on some soil physical properties (bulk density, soil strength, and infiltration rate),
3. relate the bulk density with the moisture content of soil with neutron probe readings, and
4. study the effect of different tillage practices and residue management (through changing ploughing date) on some of the soil physical properties (bulk density, soil strength, infiltration rate, shrink-swell capacity, and sorption curve).

2. Literature review

2.1 Definition :

Vertisols are soils which have 1) a layer of 25 cm or more thick, with an upper boundary within 100 cm of the mineral soil surface, that have either slickensides close enough to intersect or wedge-shaped aggregates, whose axes tilted 10 to 60 degrees from the horizontal, 2) a weighted average of 30 percent or more clay in the fine-earth fraction between a depth of 18 cm to a depth of 50 cm, or a lithic or paralithic contact, duripan, or petrocalcic horizon if shallower, and 3) cracks that open and close periodically(7).

2.2 Water Content :

According to Abu-Hammad (1993), in a study on Vertisol at Mushaqar Agricultural Experiments Station, soil treated with sweep tillage showed significantly higher volumetric water content (PV%) at 0.1, 0.3, 1, 10, and 15 bars soil moisture tensions (49.9, 45.4, 41.7, 32.3, and 29.9, respectively) and available water (15.6%), than those of moldboard tillage (47.3, 41.7, 37.8, 29.2, 27.6, respectively) and 14.1% for available water. As for soil covered with plant residue, immediate residue incorporation treatments had lower PV% at 0.1 and 0.3 bar soil moisture tensions (46.5% and 41.7%, resp.) and available water (13.5%) than those of late incorporation of residue treatments (50.4%, 44.8%, and 15.9% for available water, resp) which was higher than those of residue incorporation in August (48.8%, 44.1% and 15% for available water, resp)[8].

Hill *et al.* (1985), in a study on two Mollisols, found that the amount of water retained at any matric potential (0-37.22 Kpa) was the highest for reduced tillage (chisel) followed by no-tillage system and the lowest was for conventional tillage[9].

2.3 Bulk Density :

Soil scientists and engineers commonly require soil bulk density as a parameter input for simulation models for predicting a wide range of soil processes[10].

Abu-Hammad (1993), using the core method, found no significant difference in the bulk density between sweep and moldboard tillage plots. While bulk density of immediate incorporation of residue treatments was the lowest (1.02 g/cm^3). But, there was no significant difference between late incorporation of residue treatments (1.10g/cm^3) and incorporation of residue in August (1.08 g/cm^3)[8].

It was found that soil bulk density of fallow Holiville silty clay soil had increased from 1.13 to 1.5 Mg/m^3, and shrinkage characteristic (change of soil volume per change of water volume) had decreased from 0.796 to 0.419, when soil volumetric water content had decreased from 0.509 to 0.232 m^3/m^3[11]. Wires (1987), in a study on silt loam Orthic Humic Gleysol soil, found that the bulk density increased from 1.35 to 1.46 g/cm^3 when soil water content had decreased from field capacity to permanent wilting point(12).

Bronswijk (1991), in a study on heavy clay (Typic Fluvaquent) soil cores of 60 cm depth, found that the decrease in soil water storage was 45 mm and was accompanied by a shrinkage of a crack volume of 22 mm and surface subsidence of 12 mm(13).

Chan (1981) indicated that Fox (1964) derived the following theoretical relationships between bulk density and gravimetric moisture content for a field soil for both three-dimensional and one-dimensional shrinkage. For three- dimensional shrinkage,

$$B = B_{min} / [(B_{min} / A) + WB_{min} + E_{min}]^{\frac{1}{3}}$$

For one- dimensional shrinkage,

$$B = 1/[(1/A) + W + (E_{min} / B_{min})],$$

where B is bulk density of soil solid (g/cm^3), A is the particle density of soil (g/cm^3); W is the gravimetric moisture content (gg^{-1}); Bmin is the minimum bulk density ($g\ cm^{-3}$), and E_{min} is the entrapped air present in the soil at B_{min} ($cm^3\ cm^{-3}$)(14).

Yule and Ritchie (1980), in a study on eight soils representative of the range of Vertisol soil series in central Texas, found that the gravimetric water content (θg) and the bulk density (B) were related by the following equation :

$$\frac{B}{2.65} + B\theta g + 0.05 = 1$$

(assuming a particle density of 2.65 g/cm^3 and an air content at the swelling limit of 0.05 cm^3/cm^3)(15).

Ismail *et al.*(1994), in a study on a silt loam (Typic Paleudalf) soil, found that bulk density was not significantly different between no-tillage and moldboard tillage treatments(16).

2.4 Soil Strength :

Most field conditions that influence strength measurements, such as cracks, living organisms, plant cover, and residues, are difficult to duplicate in laboratory experiments. Therefore, it is desirable to measure and characterize the physical and mechanical features of the soil surface in the field(17).

Vyn and Raimbault (1993), in a long- term study on silt loam soil, found that no-tillage treatments had the highest penetrometer resistance. The differences in penetrometer resistance were in-significant at depths greater than 20 cm throughout the year. They, also, found that the penetrometer resistance of the moldboard plow plots increased at a slower rate with depth than for the chisel plow plots(18).

Radcliffe *et al.* (1988), in a study on a sandy clay loam (Typic Hapludult) soil, found that soil strength was low in moldboard plough treatments above 0.25 m. For no-tillage treatment there was a high strength zone that exsisted at 0.1 to 0.2 m depths. Soil strength exceeded 4 MPa at the center of the high strength zone in no-tillage treatments. They found also that soil strength was affected by tillage and depth of the measurement, and there was a significant interaction between them(19).

Soil strength has been shown to be an important soil physical property influencing root growth. Soil impedence within the upper soil profile has usually been observed to be greater under conservation tillage than under conventional tillage, in continuous long term studies(20).

According to Hill and Cruse (1985), in a study on two Mollisols, soil strength at depths of 7.5 and 12.5 cm under reduced tillage (85.9 and 107.1 kPa) was not significantly different from soils under no-tillage (68.7 and 87.2 kPa). The soils under these two tillage systems had greater soil strength than conventionally tilled soils (45.5 and 63.8 kPa)(21).

Abu Hammad (1993) found that basic infiltration rate was significantly higher in sweep tillage treatments (26.5 mm/hr) than that in moldboard tillage (20.6 mm/hr). Immediate incorporation of residue treatments caused significantly higher basic infiltration rate (30.6 mm/hr) than incorporation of residues in August (21.0 mm/hr) which was higher than that of late incorporation of residue treatments (mid of Octobor) (19.1 mm/hr)[8].

According to Zuzel *et al.* (1990), in a study on silt loam Typic Haploxerolls using a palouse rainfall simulator to measure infiltration rate, the analysis of variance of the final infiltration rate indicated that type of tillage (moldboard, disk and subsurface sweep) does not have a significant effect on infiltration capacity if the surface is 100% residue covered[26].

Dao (1993), in a study on two Paleiustolls, found that water infiltration into no-till soil was significantly higher than plowed soil (by moldboard) at similar water contents[27].

Unger (1992), in a study on a clay loam field using a rotating disk rainfall simulator to measure infiltration rate, studied tillage practices and residue management on infiltration rate for dry and wet runs. He found that the lowest initial infiltration rate values for the dry run were 73.2 and 79.2 mm h^{-1}, in the case of no-till with residues removed and moldboard plough treatments, respectively. The intermediate values were 81.7 and 81.9 mm h^{-1} in the cases of no-till with residues left in place and sweep tillage with residues removed treatments, respectively, while the highest value was 113.6 mm h^{-1} in the case of sweep tillage with residues left in place treatment. While for the wet run, initial infiltration rate values varied relatively little (27.7-48.2 mm h^{-1}) for the different treatments, with all values being less than those for the dry run. On the other hand, final infiltration rate values for the dry run ranged from 2.7 mm h^{-1} for moldboard tillage treatments to 3.3 mm h^{-1} for sweep tillage with residues left in place treatments. It increased to 9.2 mm h^{-1} for the no-till with residues removed treatment. While it ranged from 3.3 mm h^{-1} for no-till with residues left in place treatments to 5.2 mm h^{-1} for moldboard tillage treatment. It, also, increased to 26.3 mm h^{-1} for sweep tillage with residues left in place treatment, for the wet run. The final infiltration rates for the wet run did not differ greatly (5.9 mm h^{-1} or less) from those for the dry run, except that they were much higher for the sweep with residues left in place treatment for the wet run, and the reason for this was not apparent(28).

Ghazy *et al.* (1988), in a study on Vertisols, found the following relationships:

$$Y = 34.76 - 0.96X + 0.59\,X3 + 0.44\,X4 - 0.92X5 \qquad r^2 = 0.9$$

a significant factor with respect to infiltration rate, meanwhile tillage was not[19].

Chang and Lindwall (1989), in a study on a dark brown chemozemic clay loam soil, found that the mean ring infiltration rate of the soil in the summer fallow field (0.2 mm/hr), regardless of the tillage treatments , was about ten times higher than that in the stubble field (0.02 mm/hr)[29].

According to Starr (1990), in a study on a Delanco silt loam (Aquic Hapludults) soil planted with corn, the mean values of saturated hydraulic conductivity (Ks), sorptivity (S), and cumulative (1hr) infiltration (I) were significantly less when plants were inside the infiltration ring (1.32, 2.24, and 2.86 cm/hr, respectively) than those for without plants (1.68, 2.44, and 3.03 cm/hr). In addition, the Ks, S and I, were significantly higher for conservation tillage (1.68, 2.52 and 3.06 cm/hr, respectively) than those of conventional tillage (1.3, 2.14 and 2.75 cm/hr)[30].

Prieksat *et al.* (1994), in a study on Consteo silty clay loam (Typic Haploquolls) which was planted to corn, found that in chisel plough plots, infiltration rate for the center of a trafficked interrow (TRK) and center of an untrafficked interrow (UNT) position remained relatively constant, with temporary increase after tillage or cultivation. Between corn plants in row (BPIR) and directly over the base of plant in a row (OPIR) positions, infiltration rate increased steadily over the growing season. Infiltration rate, at the OPIR position, increased from 43 to 211 μms^{-1} in the first year and from 63 to 257 μms^{-1} in the second year. In no-till, infiltration rates at all positions, remained relatively constant throughout the growing season[31]. So, seasonal variability of field infiltration was more evident in plowed soil than in no-till soil[27].

2.6 Neutron Probe :

Direct or indirect measurement of soil water is needed in most situations of agricultural studies. Direct measurement of soil water is done by gravimetric method, by burning the soil with alcohol, or by using soil moisture determination flasks. Indirect methods include the use of electrical or electronic appliances including the neutron thermalisation or gamma-ray or neutron attenuation techniques. Each one of these methods has its own limitations[32].

It has been shown that the response of a neutron moisture probe is strongly influenced by the nature of the soil as well as its moisture content[33].

Wilson (1988) found that if the two soils (horizons) merge over a distance of about 30-40 cm, it is very likely that the measured water (by neutron probe) will not deviate very far from the real value[34].

3. Materials and Methods

3.1 Study Location:

To study the effect of tillage-residue management practices on soil physical properties, the experiment was conducted at Mushaqar Agricultural Experiments Station, 30 Km south west of Amman, with mean annual rainfall of 350 mm, altitude of 800 m above sea level, (31.4 North latitude, and 35.5 East longitude).

The soil at Mushaqar Experiments Station was classified as : Very fine, smectitic, thermic, chromic haploxerert[37]. It is on less than 1% slope.

3.2 Treatments and Experimental Design :

The experiment started in September, 1992. Before that, all the experimental location had been treated the same way for three previous years.

The experiment's treatments were selected subset from a large trial described by Abu-Hammad[8].

The tillage treatments for the two crops (lentil and wheat) were the following :

T1 : Moldboard, sweep and drill before rainfall.

T2 : Chisel, sweep and drill before rainfall.

Sweep plow is mainly used before drill sowing to prepare a good seed-bed. Moldboard and chisel plowing were to a depth of 25 and 20 cm, respectively, while sweep was to a depth of about 10 cm[8].

Residue treatments for wheat phase only, were as follows :

R1 : Residues was ploughed in August after harvesting, baling, and grazing for about one month.

R2: Residues were ploughed in October after harvesting, baling, and grazing for about one month.

The amount of residues incorporated with soil after grazing depends on the season. However, 50% of the available residues only allowed to graze.

The combinations of these different tillage-residue treatments (T1R1,T1R2, T2R1, T2R2) were arranged in a factorial randomized complete block design (RCBD) with three replications (blocks) within a lentil-wheat rotation. Size of the plot was 10 x 45 m as in Fig.1.

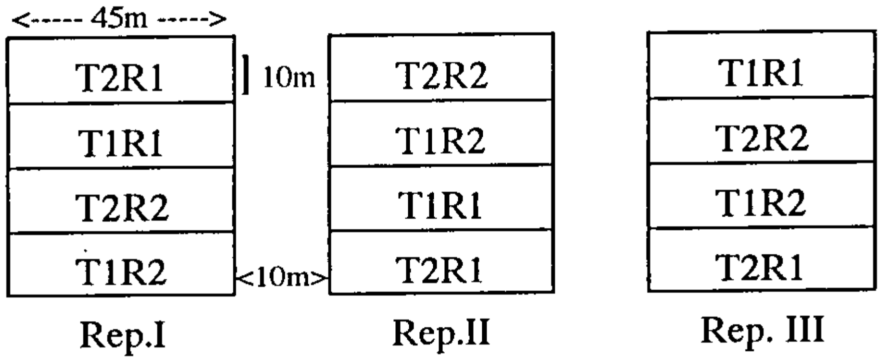

Fig. 1. Eperimental layout at Mushaqar Agricultural Experiments Station .

All treatments were fertilized by a constant rate of triple superphosphate (10 kg/du), for the two crops at sowing time, using band application. While treatments for wheat phase, were fertilized by a constant rate of urea at a rate of 7.5 kg/du, using hand broadcasting just before sowing. Seeding rate was 10 kg/du for wheat "Deir-Alla 6" and lentil "Jordan 3". Planting date was first of November. Planting was carried using sowing drill, with row spacing of 17.5 cm, and sowing depth of 8 cm, for the two crops.

Weed control for narrow leaf weed was done by spraying the whole experimental sites of lentil with Fusilade (Flauzitop - butyl as active material) at a rate of 1 L/ha. While weed control, for broad leaf weed was done by spraying the whole experimental site of wheat with Nitagron (2,4 -D ester butyl glycol as active material) at a rate of 0.7-1 L/ha. In addition to chemical weed control, manual weed control was done for broad leaf weed in lentil and for narrow leaf weed in wheat.

3.3 Soil Physical Properties:

3.3.1 Soil strength measurement :

Soil penetrability was measured using a penetrometer as described by Bradford(38). Soil strength was measured at soil depths of 5, 10, 15 and 20 cm with three measurements for each plot. Measurements were taken from 17 March, 1993 to 20 June, 1994. These dates were 17 March; 7, 13, and 19 April; 10 May; 1 August; 4 December in 1993; 15 February, 21 March, 17 April, 11 May, and 20 June in 1994.

An undisturbed soil core was taken from each plot at depth of 10 cm at the same time of measuring soil infiltration and soil strength. Bulk density was determined, using the core method as described by Blake and Hartage[39], and gravimetric soil moisture content for these samples was determined.

3.3.2 Infiltration measurement:

Infiltration rate was determined using the double ring infiltrometer method as described by Bouwer[40]. The internal diameter of the outer ring and the inner ring were 30 and 20 cm, respectively. All the rings were pushed 7 to 8 cm into the soil inter cracks, providing a tight fit between ring and soil. During infiltration, the depth of ponding (h) was allowed to vary from 10 to

4 cm in order to measure the infiltration rate using a graduated cylinder.

Places in which infiltration measurements were made, were free from cracks at the surface.

Infiltration measurements were taken on ten dates from 1 August, 1992 to 20 June, 1994. These dates were 1 August, 10 November, and 21 December in 1992; 23 January, 20 August, and 5 December in 1993; 14 February, 12 April, 15 May, and 20 June in 1994. Each set of 12 infiltration readings took 3 to 5 days to complete.

3.3.3 Neutron Probe Evaluation :

Soil moisture measurements were carried using the neutron probe device (Hydroprobe, Model 503). Depths of measurments were 7.5, 22.5, 45, 75, 1.05 and 135 cm. The readings for these soil depths represented the whole 150 cm soil profile. In addition, gravimetric method was used to check on neutron probe readings, especially for surface layers. A 150 cm long, steel galvanized access tube was installed into holes dug by a two inch diameter (ID) auger in each treatment.

Calibration curves for different soil layers were drawn by correlating soil moisture counts of neutron probe with gravimetric soil moisture samples at different times of the season, this will guarantee wide range of soil moisture with different counts. Two gravimetric soil moisture samples were taken for each count ratio in each layer, and the average soil moisture content was correlated with the corresponding count ratio. The regression analysis technique was used to calculate the calibration curves for each soil layer(8).

Neutron probe readings were taken after each rainfall incident as well as a weekly reading during winter season. While at summer time, a reading every two weeks period was taken.

To evaluate the neutron probe results, the following calculations were made :

1. Compare the values of crop evapotranspiration, ETc, (mm), soil moisture depletion, SMD, (mm), and soil moisture storage, SMS, (mm) which were calculated using only a single value of the bulk density for each layer, with those values which were calculated using the appropriate bulk density values that were derived from the curve of bulk density- soil moisture content relationship.

   Relations between gravimetric soil moisture content and bulk density were determined for each layer to use them in soil moisture parameters calculations by the second method.

2. Different crack volumes and shapes which occurred near the access tubes were studied by taking neutron probe readings before and after filling the cracks with soil from the surface. These readings were compared with gravimetric soil moisture content.

3.3.4 Shrinkage inflection points:

Three representative undisturbed soil cores (4.3 cm internal diameter and 4.7 cm long) were taken from the soil surface for each plot at 10 cm depth[14] in July, 1993 after harvesting, and three in November, 1993 after planting. These samples were used to determine; the soil moisture characteristic curves; subsidence, Δz; bulk density, B; shrinkage characteristic, m; cracks volume, Vcr; and coefficient of linear extensibility, COLE. Characteristic curves were made by using the ceramic plate extraction method as described by Klute[41], at tensions of 0.1, 0.3, 1, 5, 11, 15 bars.

Subsidence (the change in the length of the soil, Z, in a vertical direction relative to a fixed reference) of the soil surface in the ring at the above tensions was measured at ten random poistions using a caliber ($\pm$0.005 mm). The ten values were then averaged by assuming isotropic shrinkage, Δz can be related directly to changes in bulk volume[11, 13, 15, 42, and 43].

3.4 Calculations

ETc = Σ[Decrease in soil moisture (-ΔS)] + Σsoil moisture stored and then depleted during rainfall periods (from planting to harvest) (mm) ....(1)

SMD = Σ[Decrease in soil moisture (-ΔS)] + Σsoil moisture stored and then depleted during rainfall period (from beginning to end of season) (mm)..(2)

SMS = Σ[Increase in soil moisture (+ΔS)] + Σsoil moisture stored and then depleted during rainfall periods (from first rainfall event to last rainfall event during the winter season) (mm)..(3)

Where ETc : crop evapotranspiration (mm).

SMD : soil moisture depletion (mm).

SMS : soil moisture storage (mm), and

ΔS : the difference between the two neutron probe readings for the soil moisture storage taken after each rainfall and before the next rainfall.

Soil moisture stored and then depleted during rainfall periods was estimated from class A pan evaporation readings, using the following equation :

$$ETc = Ep^{*}\ Kp^{*}\ Kc \quad \text{..........} (4)$$

Where ETc : crop evapotranspiration during rainfall (mm).

Ep : class A pan evaporation (mm).

Kp : pan coeffecient, depending on wind velocity, relative humidity, and location of the pan FAO[44].

Kc : crop coeffecient,depending on wind velocity, relative humidity,and length of growing season for each crop FAO[44].

Periods through which ETc estimations were taken from the last neutron probe reading before each rainfall event to the next neutron probe reading. Then the summation of ETc during different rainfall events was taken over the whole winter season (from planting to last rainfall event).

$$\Delta V = \left[1 - \left(1 - \frac{\Delta Z}{Z}\right)^3\right] Z \quad \text{..........} (5a)$$

$$= 3\Delta Z - 3\frac{(\Delta Z)^2}{Z} + \frac{(\Delta Z)^3}{Z^2} \quad \text{..........} (5b)$$

where ΔV is the decrease in volume of the soil per unit area (m) and ΔZ is the decrease in layer thickness (m)[42, 43]

$$m = \frac{\partial Vs}{\partial Vw} \quad \text{..........} (6a)$$

Where Vs is the volume of the soil and Vw is the volume of soil water[11].

$$m = \frac{3\Delta Z - \frac{3(\Delta Z)^2}{Z} + \frac{(\Delta Z)^3}{Z^2}}{\Delta W} \qquad \text{.......(6b)}$$

Where ΔW is the water loss per unit area (ΔW has a dimension of length)(11).

$$Vcr = \Delta V - \Delta Z \qquad \text{.......(7)}$$

Where Vcr is cracks the volume(13).

$$COLE = \left(\frac{B1}{B2}\right)^{\frac{1}{3}} - 1 \qquad \text{.......(8)}$$

Where B1 and B2 are the bulk densities at 1500 and 33 kPa, respectively.

4. Results and Discussions

4.1 Soil Surface Moisture Content :

Samples for gravimetric soil surface moisture content were collected periodically with soil strength and infiltration readings.

Table 1 represents the analysis of variance for gravimetric soil surface moisture. According to statistical analysis tillage, and block had a significant effect with respect to the gravimetric soil surface moisture content for the two crops.

Table 1 : Analysis of variance for soil moisture in different tillage-residue treatments at depth of 10 cm.

Source of variation	df	Lentil	Wheat
Rep	2	*	*
T	1	**	**
R	1	ns	ns
T x R	1	ns	ns

T : Tillage, R : Residue, x : interaction, Rep : Replicate (block).
df : degrees of freedom.
* : significant; at probability level of 5%.
** : highly significant; at probability level of 1%.
ns : not significant; at probability level of 5%.

Using t-test as in appendix 3, it was found that block 2 had significantly higher gravimetric soil moisture content (23.4%) than that in both block 1 (22.6%) and block 3 (22.5%) at probability level of 5%. Moldboard plough treatments had significantly higher gravimetric soil moisture content (23.4%) than that in chisel plough treatments (22.4%) at probability level of 1%. It was, on the other hand, significantly higher in year 1994 (26.0%) than in year 1993 (19.6%) at probability level of 1%.

Table 2 shows the mean separation for gravimetric soil moisture content (%), in different tillage - residue treatments. Moldboard plough plots (T1) in March, April and December, 1993 March and April, 1994 were significantly higher than chisel plough plots (T2) with respect to gravimetric soil moisture content. One can notice that the significance disappeared when the soil was too wet or too dry. Residue incorporation plots didn't show significant differences except in April, 1993.

Table 2 : Mean separation for soil moisture content, in different tillage-residue treatments.

Year	Month	(year)	θg (%)			
			T_1	T_2	R_1	R_2
1993	Lentil	3	+ 34.0[a]	32.6[b]	32.6	33.1
		4	25.6[a]	23.4[b]	25.3[a]	23.8[b]
		5	15.1	14.9	15.1	15.0
		8	5.4	5.7	5.2	5.9
	Wheat	12	16.0[a]	13.7[b]	15.9	13.9
1994		2	29.5[a]	28.9[b]	29.3	29.1
		3	37.4	36.2	36.9	36.7
		4	21.4[a]	20.4[b]	20.7	21.1
		5	12.3	12.5	12.2	12.6
		6	8.5	8.7	8.6	8.6

+: Along rows, means without letters are not significantly different at the 5% probability level of the T - test.

In year, 1993, the experiment plots were planted to lentil, while in 1994 they were planted to wheat. Although wheat has deeper roots than lentil, the surface roots of lentil are higher. So, it is expected that lentil consumes more moisture from the soil surface than wheat. In general, tillage tends to increase soil moisture storage due to increase the soil moisture retention. But, the presence of residues after wheat season reduced that effect. Consequently, soil moisture content in summer after lentil season is lower than in summer after wheat season. Besides, the residue cover after wheat season decreases the evaporation[9, 27].

It is believed that surface tillage operation (chisel) conserves more soil moisture than other conventional tillage (moldboard)[6]. May be it is true for the whole soil profile. But, for soil surface only it is the opposite. In other words, moldboard plough treatments were higher than chisel plough treatments with respect to soil moisture. This is maybe because that moldboard destroys soil surface structure more than chisel which results in greater micropores than chisel. Therefore, moldboard tillage conserves more water than chisel tillage when the soil is neither too wet nor too dry. Because the increased capability to store moisture would be probably due to a rearrangement of the pore size distribution resulting from the tillage method[9].

Earlier operation of soil surface as in immediate residue incorporation (R1) destroys soil aggregates through wind effect which results in decreasing macropores and increasing micropores. However, it is not enough to conserve more water than late incorporation of residues (R2).

4.2 Bulk Density of the Soil Surface :

Samples for bulk density determination of the soil surface at a 10 cm depth were also collected periodically together with the gravimetric soil surface moisture content plus soil strength, and infiltration readings.

Table 3 represents the analysis of variance for the bulk density. This table shows that residue and block had significant effect on the bulk density for the two crops.

Table 3 : Analysis of variance for bulk density of soil surface in different tillage-residue treatments, at depth of 10 cm

Source of variation	df	Lentil	Wheat
Rep	2	*	*
T	1	ns	ns
R	1	*	**
T x R	1	ns	ns

* : significant; at probability level of 5%.
** : highly significant; at probability level of 1%.
ns : not significant; at probability level of 5%.

By applying t-test as in appendix 3, it was found that block 1 had lower bulk density (0.97 gm/cm^3) than both block 2 (1.00gm/cm^3) and block 3 (1.01 gm/cm^3). Immediate incorporation of residue treatments seems to have higher bulk density (1.01 gm/cm^3) than late incorporation of residue treatments (0.98 gm/cm^3). Furthermore, bulk density was significantly higher in year, 1994 (1.04 gm/cm^3) than in year, 1993 (0.94 gm/cm^3).

Mean separation for bulk density (gm/cm^3), in different tillage - residue treatments (Table 4). Moldboard plough plots, only in February, 1994, were significantly higher than chisel plough plots with respect to bulk density. While, in all other dates there was no significant difference between moldboard plough treatments and chisel plough treatments. Immediate incorporation of residue treatments, on the other hand, were significantly higher than late incorporation of residue treatments with respect to bulk density in the months; March, April, May and August, 1993, May and June, 1994. But in the months February and March, 1994 immediate incorporation of residue plots were significantly lower than late incorporation of residue plots with respect to bulk density. Also, there was no significant difference between the two residue treatments in December, 1993 and April, 1994.

Table 4 : Mean separation for bulk density of soil surface at depth of 10cm, in different tillage-residue treatments

Year	Month (year)		Bulk Density (gm/cm^3)			
			T_1	T_2	R_1	R_2
1993	Lentil	3	+0.94	0.95	0.98[a]	0.91[b]
		4	1.07	1.05	1.08[a]	1.04[b]
		5	1.13	1.14	1.18[a]	1.11[b]
		8	1.21	1.22	1.23[a]	1.19[b]
	Wheat	12	1.18	1.15	1.17	1.14
1994		2	1.00[a]	0.93[b]	0.91[b]	1.02[a]
		3	0.94	0.88	0.87[b]	0.95[a]
		4	0.94	0.92	0.93	0.93
		5	1.24	1.21	1.26[a]	1.19[b]
		6	1.27	1.25	1.31[a]	1.22[b]

+: Along rows, means without letters are not significantly different at the 5% probability level of the T - test.

Bulk density of immediate incorporation of residue plots, in year 1994 was sometimes higher and sometimes lower than late incorporation of residue plots (Table 4). This is probably due to the swelling process in February and March, 1994 and the shrinkage process in April, May, and June, 1994.

Immediate and late incorporation of residue treatments had the same amount of residue incorporated with the soil surface. But, in the former, plots were ploughed in August and, in the latter, plots were ploughed in the middle of October. Earlier plowing of soil surface destroys soil aggregates through wind effect, which results in decreasing macropores, and as a result, bulk density increases.

Nearly, moldboard plough destroys soil aggregates which results in decreasing macropores, but it is still not enough to increase the bulk density.

Bulk density in wheat treatments after lentil was greater than that for lentil after wheat. It is probably due to the absence of residue when the soil is ploughed in the first case. In general, ploughing destroys some of the soil aggregates, but residue decrease this effect. So, it results in lower bulk density in the second case.

4.3 Linear Relations Between Bulk Density and Soil Moisture Content for Field Study :

Linear regression analysis was made to correlate bulk density with gravimetric soil moisture content for field study at depth of 10 cm.

Figure 2 shows highly significant relationships between bulk density (gm/cm^3) and gravimetric soil moisture content (%) in different lentil-wheat treatments. The following equations were found:

For lentil season :

$$B = 1.32 - 0.009\theta g \qquad r^2 = 0.85$$

For wheat season :

$$B = 1.40 - 0.014\theta g \qquad r^2 = 0.70$$

These relations show the temporal variation of the bulk density during each season through the change of soil moisture content which clarify the shrink-swell phenomenon.

From these equations one can find that bulk density values at different soil moisture contents were higher in wheat season than in lentil seasnon. Also, the change of bulk density with moisture was higher in wheat season than in lentil season,

The correlation between bulk density and soil moisture content was lower in wheat season than in lentil season. There were two different curves in wheat season, which are the swelling curve during wetting period: and the shrinkage one during drying period. Whereas there was the shrinkage curve in the lentil season.

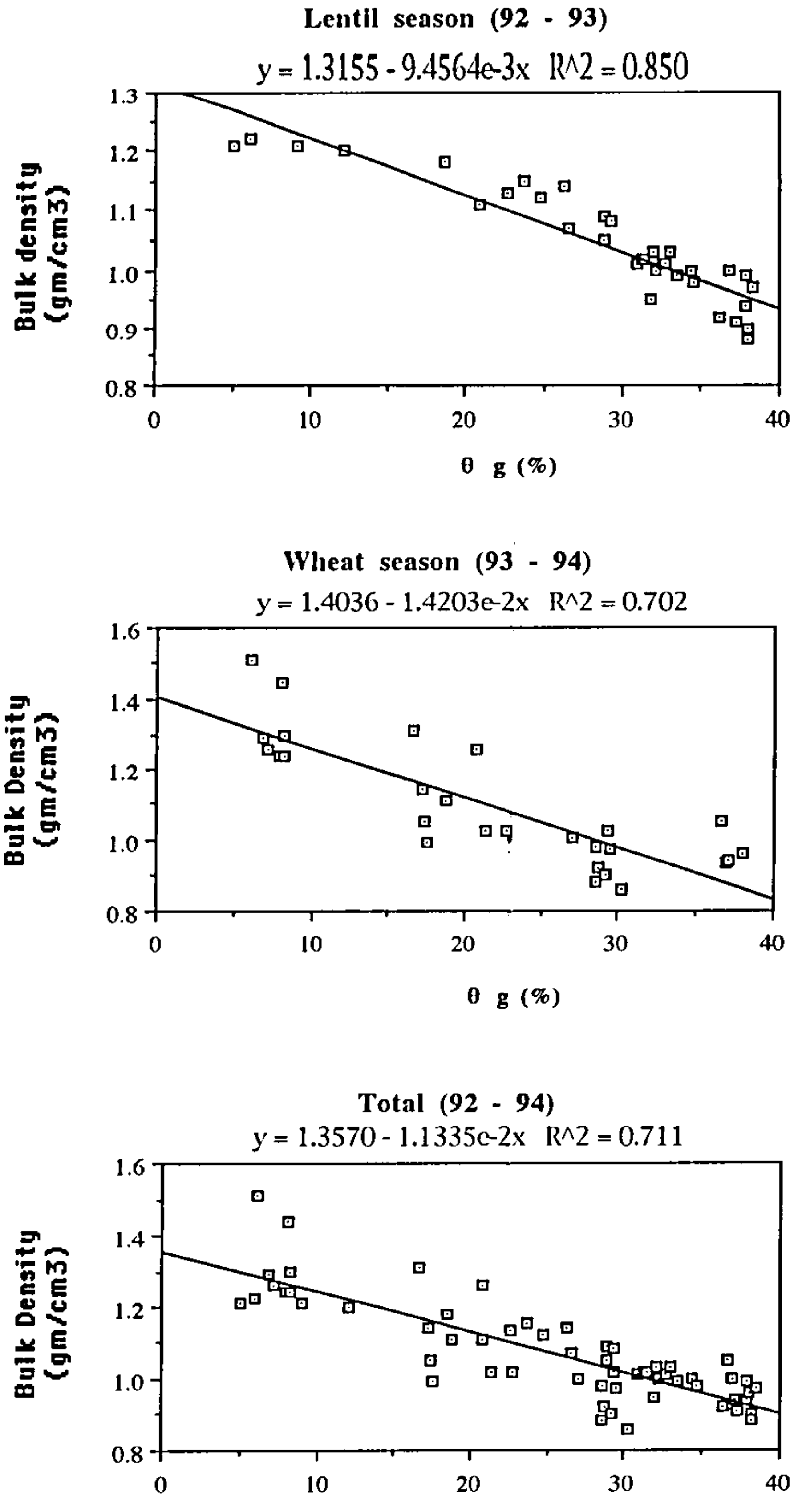

Fig. 2 : Relationships beween bulk density and soil moisture content for the lentil-wheat rotation treatments

strength was significantly higher (1.6 MPa) than that in lentil season (0.5 MPa). Besides, block 2 had a higher soil strength (1.13 MPa) than both block 1 (1.03 MPa) and block 3 (1.0 MPa).

Table 6 represents the mean separation for soil strength of soil surface at depths of 5, 10, 15 and 20 cm, in different tillage - residue treatments. In this table, only two months in 1993 and three months in 1994 were selected to represent the whole data. It shows that moldboard plough plots had lower soil strength than chisel plough plots in the months: August, 1993 at depth of 15 cm; April, 1994 at depths of 10, 15, and 20 cm; and June, 1994 at depths of 5, 10, and 15 cm. Whereas, the chisel had significantly lower soil strength at depth of 5 cm in February and April, 1994. On the other side, soil strength was not significantly different for the other depths in the other months.

Table 6 : **Mean separation for soil strength of soil at depths of 5, 10, 15, and 20 cm, in different tillage-residue treatments.**

Year	Month	Depth (cm)	Soil Strength (MPa)			
			T_1	T_2	R_1	R_2
1993	Lentil 4	5	$^{c}0.27^{*}$	$^{+}0.28^{*}$	$^{+}0.29^{*}$	$^{+}0.26^{*}$
		10	$^{b}0.49$	0.51	0.53	0.47
		15	$^{ab}0.55$	0.59	0.59	0.55
		20	$^{a}0.62$	0.68	0.66	0.64
	8	5	$^{d}0.97$	1.02	1.01	0.98
		10	$^{c}1.73$	1.76	1.72	1.77
		15	$^{b}2.29^{b}$	2.47^{a}	2.45	2.31
		20	$^{a}2.95$	2.99	3.12^{a}	2.81^{b}
1994	Wheat 2	5	$^{c}0.29^{a}$	0.11^{b}	0.24	0.16
		10	$^{b}0.44$	0.45	0.40	0.47
		15	$^{a}0.72$	0.63	0.67	0.68
		20	$^{a}0.75$	0.71	0.74	0.72
	4	5	$^{d}0.69^{a}$	0.41^{b}	0.67^{a}	0.43^{b}
		10	$^{c}1.03^{b}$	1.61^{a}	1.57^{a}	1.07^{b}
		15	$^{b}1.85^{b}$	2.29^{a}	2.27^{a}	1.87^{b}
		20	$^{a}2.67^{b}$	2.91^{a}	2.92^{a}	2.66^{b}
	6	5	$^{d}1.41^{b}$	1.89^{a}	1.80^{a}	1.50^{b}
		10	$^{c}2.68^{b}$	3.27^{a}	3.15^{a}	2.80^{b}
		15	$^{b}4.61^{b}$	5.02^{a}	4.81	4.62
		20	$^{a}5.04$	5.17	5.17	5.04

*: Along rows, means without letters on the right side of the number, are not significantly different at the 5% probability level of the T - test.
+: Along columns T1, T2, R1, and R2, means with the same letter on the left side of the number, are not significantly different at the 5% probability level of the T - test.

Immediate incorporation of residue treatments had higher soil strength values than late incorporation of residue treatments in August, 1993 at depth of 20 cm, and April and June, 1994 at all depths, except at 15 and 20 cm depths in June, in which there was no significant difference. Besides, there were no significant differences among the other dates and the other depths.

This table shows that 5 cm increment made a significant difference between soil strength values at the four depths. But, there was no significant difference between depth of 15 cm and 20 cm depth, when the soil had a high soil moisture content as in months April, 1993 and February, 1994.

Moldboard tillage destroys the soil structure more than chisel tillage and gives more loosening soil surface, while reduced soil disturbance under conservation tillage system may increase soil impedance within surface soil layer[20]. So, moldboard has lower soil strength values, especially in lower soil moisture content cases.

Immediate incorporation of residue allowed the soil aggregates to face the wind impact two months more than late incorporation of residue which resulted in more macropores and less compacted layer which means lower soil strength values, also, especially in lower soil moisture content cases.

Besides, moldboard tillage operation results in decreasing the macropores, and decreasing the soil compaction. In other words, it results in increasing soil loosening. The first effect tends to increase the soil strength, but the second one tends to decrease the soil strength. As a result, it appeared that moldboard tillage decreases the soil strength values which means that the second effect has a higher influence than the first one. In addition to that, the first effect makes the moldboard plough to conserve more water at the surface layer, as was discussed in section 4.1, and the second makes it to have higher infiltration rate in lentil season, as will be discussed in section 4.6.

Also, moldboard plough significantly lowered soil strength values than chisel plough, which may be partially due to higher soil water content at the time of measurement[18].

Soil strength values in wheat season were higher than lentil season. This is maybe due to the residue effect, since residue decreases the tillage effect

4.5 Exponential Relations Between Soil Strength with Soil Moisture Content and Bulk Density.

Non-linear regression analysis was made to correlate soil strength and both gravimetric soil moisture content and bulk density for field study at the four depths.

Figure 3 shows highly significant relationships between soil strength (MPa) and gravimetric soil moisture content (%), and Figure 4 shows relationships between soil strength (MPa) and bulk density (gm/cm^3).

These relations show the temporal variation of soil strength during the season through the change of soil moisture and bulk density.

From these curves it is appeared that soil strength values at different soil moisture and bulk density values were lower in lentil season than in wheat season.

The correlation between soil strength and both soil moisture content and bulk density was lower in lentil season than in wheat season. It increased with depth in the two seasons, so, poor correlation were at depth of 5 cm and 10 cm, while good one was at 15 and 20 in depths. The correlation also was higher between soil strength and soil moisture content than between soil strength and bulk density in lentil season, while it was the opposite in wheat season.

The following relations were found :

For lentil season:

For the 5 cm depth :

$SS = 0.89680 * 10^{(-1.1624e^{-2}\theta g)}$ $r^2 = 0.28$

$SS = 5.3615e\text{-}2 * 10^{(0.85013B)}$ $r^2 = 0.18$

For the 10 cm depth :

$SS = 2.2889 * 10^{(-1.4959e^{-2}\theta g)}$ $r^2 = 0.54$

$SS = 4.0018e\text{-}2 * 10^{(1.2708B)}$ $r^2 = 0.46$

For the 15 cm depth :

$$SS = 3.8461 * 10^{(-1.7837e^{-2\theta g})} \qquad r^2 = 0.73$$

$$SS = 2.9185e\text{-}2 * 10^{(1.5388B)} \qquad r^2 = 0.62$$

For the 20 cm depth :

$$SS = 5.7646 * 10^{(-2.1056e^{-2\theta g})} \qquad r^2 = 0.81$$

$$SS = 1.8542e\text{-}2 * 10^{(1.8070B)} \qquad r^2 = 0.69$$

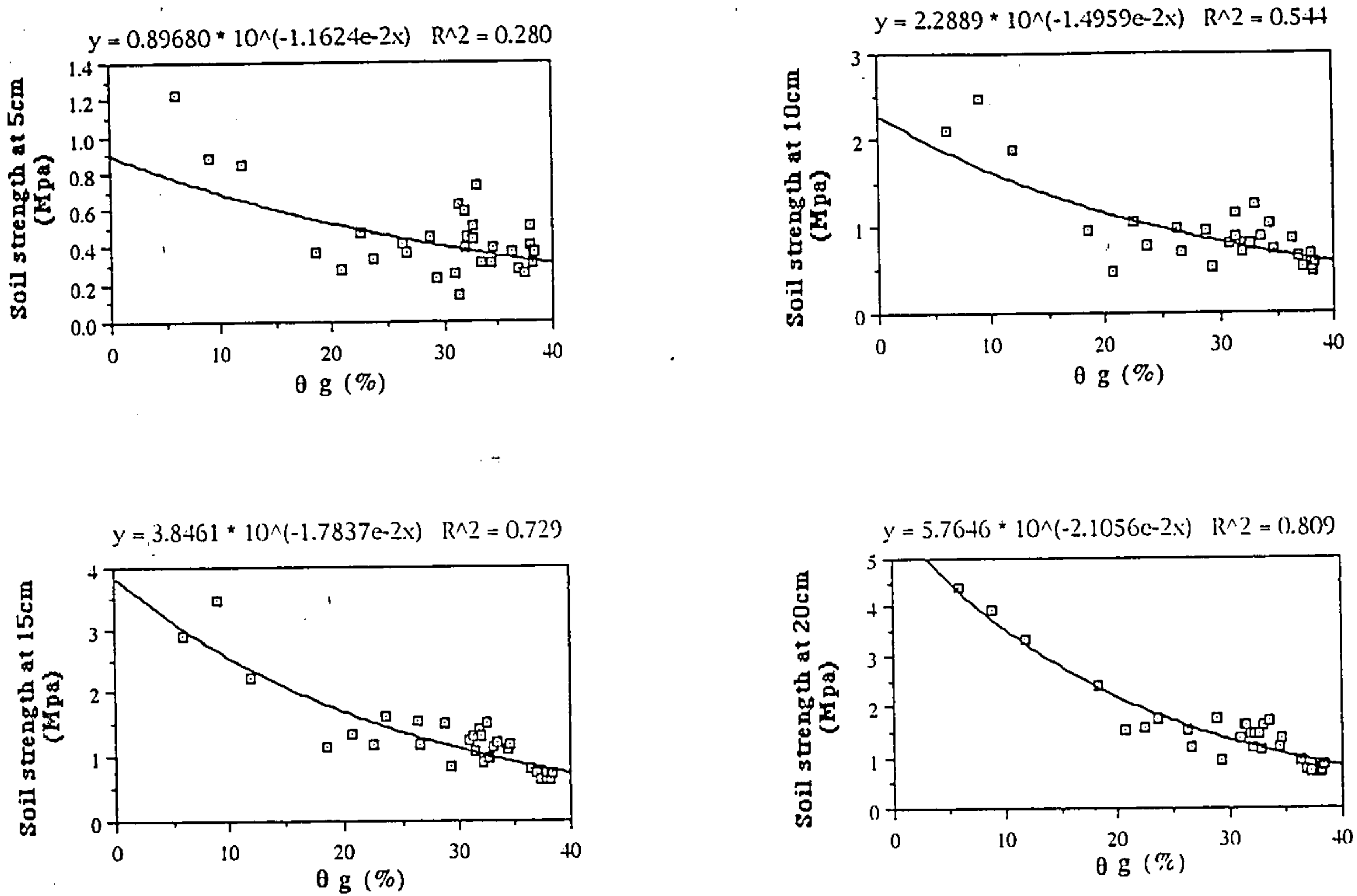

Fig. 3a: **Relationships between soil strength and soil moisture content for lentil treatments (1992 - 1993).**

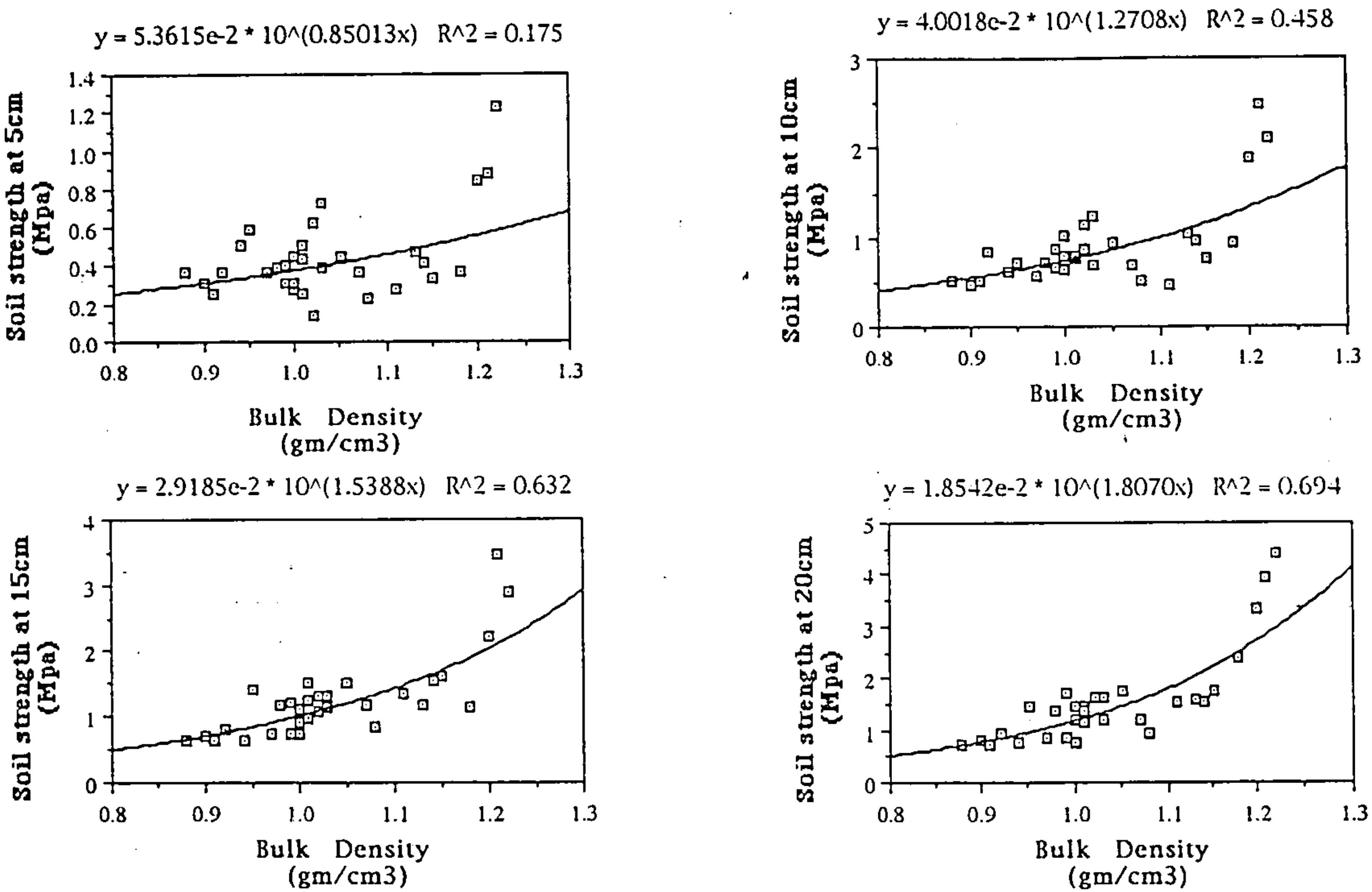

Fig. 3b: **Relationships between soil strength and bulk density for lentil treatments (1992 - 1993).**

For wheat season :

For the 5 cm depth :

$SS = 4.6336e\text{-}3 * 10^{(1.7731\theta g)}$ $r^2 = 0.57$

$SS = 2.3308 * 10^{(-3.1984e^{-2B})}$ $r^2 = 0.64$

For the 10 cm depth :

$SS = 3.3527e\text{-}2 * 10^{(1.3689\theta g)}$ $r^2 = 0.64$

$SS = 3.4607 * 10^{(-2.3708e^{-2B})}$ $r^2 = 0.67$

For the 15 cm depth :

$SS = 3.4575e\text{-}2 * 10^{(1.5144\theta g)}$ $r^2 = 0.73$

$SS = 6.4446 * 10^{(-2.8198e^{-2B})}$ $r^2 = 0.87$

For the 20 cm depth :

$SS = 3.6280e\text{-}2 * 10^{(1.5785\theta g)}$ $r^2 = 0.69$

$SS = 8.8704 * 10^{(-3.0395e^{-2B})}$ $r^2 = 0.89$

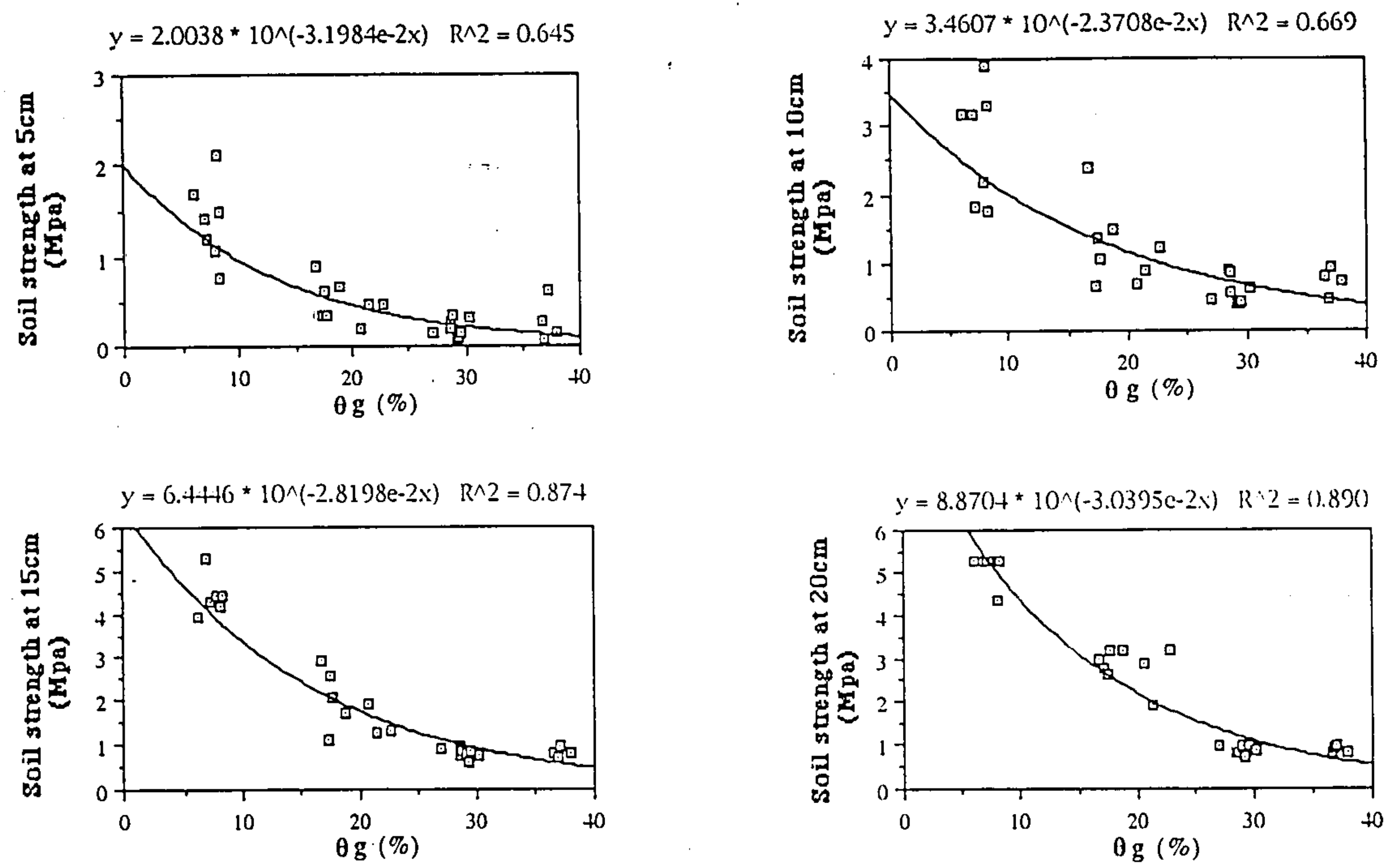

Fig. 4a: **Relationships between soil strength and soil moisture content for wheat treatments (1993 - 1994).**

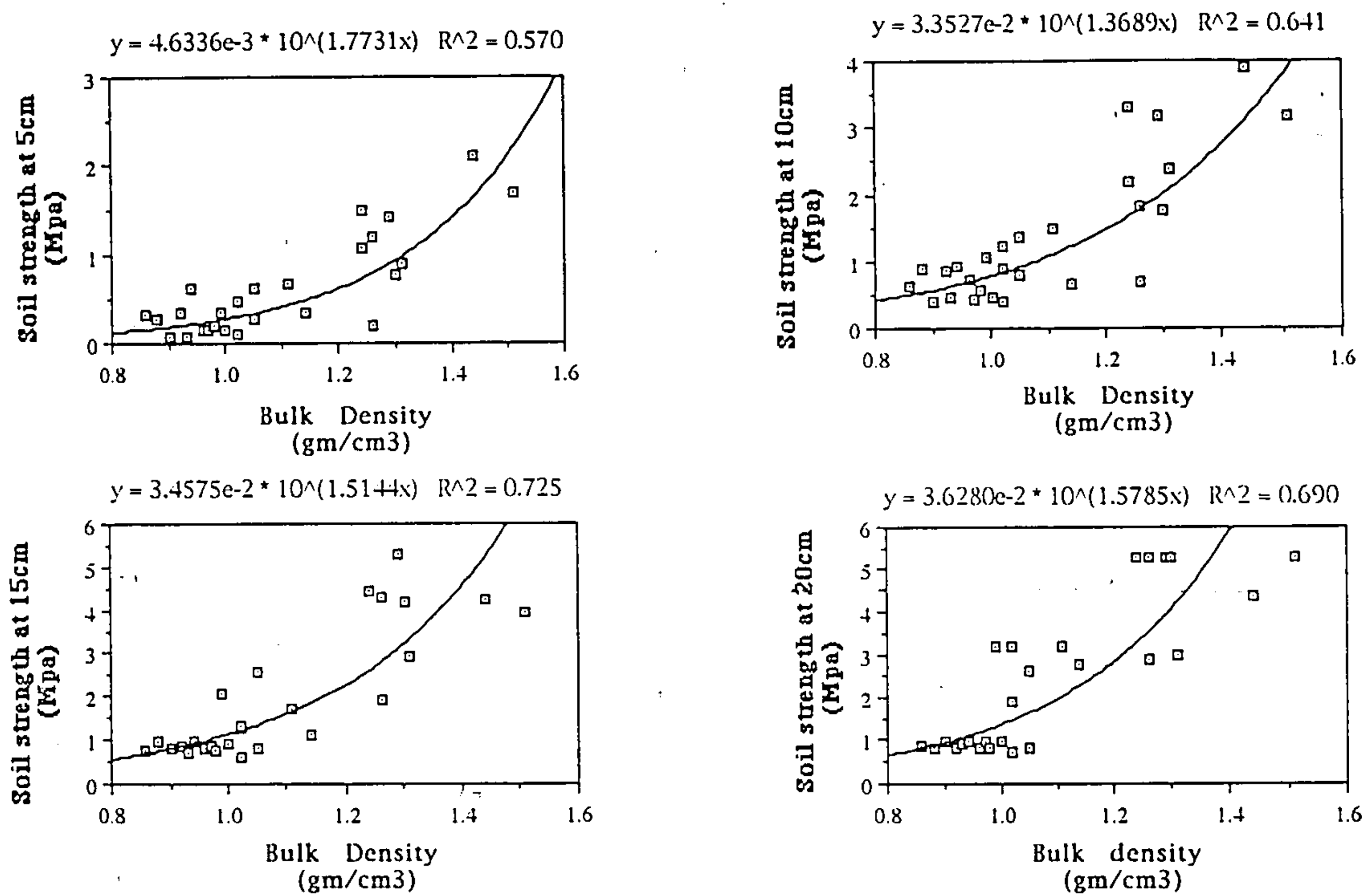

Fig. 4b: **Relationships between soil strength and bulk density for wheat treatments (1993 - 1994).**

4.6 Infiltration Rate :

The effects of tillage and residue on the infiltration rate and its relation to gravimetric soil moisture content and bulk density were studied.

The analysis of variance indicates that tillage-residue interaction had a significant effect on infiltration at 30 and 60 min elapsed time (Table 7). Besides that, tillage had a significant effect on basic infiltration rate.

Table 7 : Analysis of variance for infiltration rate at different times in different tillage-residue treatments for the two crops.

Source of variation	Time (minutes)								
	5	15	30	45	60	90	120	150	180
Rep	ns	ns	ns	ns	ns	ns	ns	ns	ns
T	ns	ns	ns	ns	ns	ns	ns	*	**
R	ns	ns	ns	ns	ns	ns	ns	ns	ns
T x R	ns	ns	*	ns	**	ns	ns	ns	ns

* : significant at 5% probability level.
** : highly significant at 1% probability level.
ns : not significant at 5% probability level.

The analysis also indicates that basic infiltration rate when the plots were planted to wheat was twice or higher than that in the previous year when the crop was lentil. In general, moldboard plough plots (10.8 cm/hr) had a lower basic infiltration rate than chisel plough plots (14.4 cm/hr). Moldboard gave lower infiltration rate at 30 min elapsed time with late incorporation of residue (11.1 cm/hr) than with immediate incorporation of residue (21.5 cm/hr).

Also, late incorporation of residue gave lower infiltration rate at 60 min elapsed time with moldboard plough (9.7 cm/hr) than with chisel plough (15.4 cm/hr).

The mean separation of basic infiltration rate values for selected dates to represent the whole data (Table 8). Only for wheat the basic infiltration rate was significantly higher in immediate residue incorporation (26.8 cm/hr) than that in late incorporation of residue (16.3 cm/hr) for February, 1994.

Table 8 : Mean separation for the basic infiltration rates, in different tillage-residue treatments.

Year	Month	Basic infiltration rate (cm/hr)			
		T_1	T_2	R_1	R_2
1992	Lentil 8	* 1.8	2.1 +	2.1	1.9
	11	3.1	2.4	3.1	2.4
1993	1	17.8	13.2	16.5	14.5
	8	7.8	7.2	7.1	8.0
	Wheat12	$^{ab}12.0^{b}$	$^{ab}19.9^{a}$	$^{ab}17.9$	$^{b}13.9$
1994	2	$^{a}19.1$	$^{a}24.1$	$^{a}26.8^{a}$	$^{ab}16.3^{b}$
	4	$^{a}22.8$	$^{a}25.8$	$^{a}25.7$	$^{a}22.9$
	6	$^{b}5.8$	$^{b}5.9$	$^{b}5.4$	$^{c}6.3$

+ : Along rows, mean without letters on the right side of the number, are not significantly different at the 5% probability level of the T - test.

* : Along columns T1, T2, R1, and R2, means with the same letter on the left side of the number, are not significantly different at the 5% probability level of the T-test.

Temporal variation is clearly observed in these dates, so that, basic infiltration rate varied significantly from month to month. Basic infiltration rate in winter is three to four times higher than that in summer.

In order to validate these results, two undisturbed core samples from each plot of the first replicate were taken to measure saturated hydraulic conductivities for one and half hours. On the average, saturated hydraulic conductivity values at 15 min of elapsed time ranged from 12 to 24.1 cm/hr, and at 90 min of elapsed time ranged from 7.2 to 14.9 cm/hr. These values were in agreement with basic infiltration rate values.

Initial soil moisture content has an effect on initial infiltration rate, not on the basic infiltration rate. Initial infiltration rate was expected to decrease as soil moisture content increased. But, the results obtained showed that infiltration rate for any elapsed time had increased with increasing soil moisture content in Vertisols. Why?!.

To answer this question and to understand this phenomenon, we have to discuss shrink - swell effect on the factors which affect the infiltration rate. These factors are related to soil porosity. So, increased infiltration has been associated with increased soil porosity[27].

Volume changes of the soil fabric result in changes of the nature and quantity of pore space[12]. Total porosity of the soil after drying was always lower than initial total porosity excluding cracks volume[45]. The volume percent pores greater than 30μ showed a highly significant negative correlation with bulk density. While the volume percent pores smaller than 10μ showed, also, a highly significant but positive correlation with bulk density[46]. On the average, saturated hydraulic conductivity of macropores reaches 40 cm/hr or more[47].

Increasing total porosity does not necessarily mean an increase macropores but, maybe, an increase micropores. It depends, maybe, on two factors: the first one is soil structure and its aggregate stability; and the second one is the swelling pressure and soil pressure against swelling pressure. From these two points, four possibilities maybe concluded :

First one : if a Vertisol has a good structure and stable aggregates, and swelling pressure was greater than soil resistance, so the mean diameter for the soil pores will increase because of the macropores among soil aggregates and larger pores among swollen particles. So infiltration increases i. e. as in our soil in Winter.

Second one : if a Vertisol has a good structure and stable aggregates and swelling pressure was less than soil resistance, so the mean diameter for the soil pores will decrease because of the compaction. So infiltration decreases i. e. as in our soil in Summer.

Third and fourth possibilities: if a Vertisol has a weak structure and unstable aggregates and swelling pressure was greater or less than soil resistance, so the mean diameter for the soil pores will decrease. But, the latter does lower infiltration because of more compaction.

Furthermore, the swelling phenomenon has the major role in the infiltration in Vertisols.

There are two additional reasons for increasing infiltration in winter. The first one is due to the process of filling in the cracks which were under the rings at the time of measuring infiltration rate; and the second, is due to roots effect during growing season.

Cracks which were closed due to tillage operations and wind and/or water erosion, may still have looser soil which would result in a high infiltration rate.

Increasing infiltration rates in the planted soil during the growing season may have been caused by plant root growth and water uptake. Plant roots die and new roots emerge through the life of the crop. Therefore, increased porosity in the planted soil may have resulted from macropores forming when some roots decay(31). Additionally, soil containing root systems may have increased pore conductivity compared with soil with no roots. Roots may provide linear pathways through a random soil matrix, decreasing tortuosity of water flow in soil, and increasing infiltration(31).

Tillage methods resulted in soil surface conditions that differed with respect to aggregate stability, aggregate size distribution, organic matter concentration, residues on the surface, and surface roughness[28].

Tillage may increase infiltration when it loosens soil surface, disrupts dense soil layers, or provides surface depressions for temporary storage of water. It may also decrease infiltration when it smoothes the surface, disrupts aggregates, eleminates surface residues, or cause compaction[28].

Moldboard tillage resulted in greater soil loosening than did chisel. But chisel had a significantly greater degree of surface roughness and higher stable aggregates being deposited on the surface. So, moldboard ploughing (soil - inverting tillage) results in lower final infiltration rates than chisel (non - inverting tillage)[28].

Also, moldboard plough may give higher micropores to macropores ratio, which results in lower infiltration rate. Also, the lower infiltration results from less stable aggregates being deposited on the surface by moldboard ploughing[28].

The higher infiltration rate in wheat season than in lentil season in winter may happen because loosening of the soil with tillage is effective for increasing water infiltration where surface residues are limited. While infiltration rate in summer after wheat is lower than after lentil. This is may be due to the compaction effect.

4.7 Linear Relations Between Basic Infiltration Rate and Both Soil Surface Moisture Content and Bulk Density

Linear regression analysis was made to correlate both initial soil surface moisture content and its bulk density with basic infiltration rate.

Figure 5 shows highly significant relationships between basic infiltration rate (BIR) and initial gravimetric soil surface moisture content and bulk density. Highly significant relationships were found between them.

These relations show the temporal variation of basic infiltration rate through the change of both soil moisture content and bulk density.

In these relations small r^2 is obtained. It is partialy due the block effect which had significant effect on soil moisture content and bulk density. While block had no significant effect on basic infiltration rate. And it is, on the other hand, because the treatments effect i.e. residues incorporation treatments made differences in bulk density values and at the same time had no significant effect on basic infiltration rate.

So that, when we took the mean values of basic infiltration rate, bulk density, and soil moisture content at each date and made relations using these means, r^2 values for these relations became

0.89, 0.92, 0.97, and 0.87 for BIR-θg and BIR-B in lentil season and BIR-θg and BIR-B in wheat season, respectively.

The following relations were found :

For the first season :

$$BIR = 3.70 + 0.299\theta g \qquad r^2 = 0.40$$

$$BIR = 66.20 - 47.172B \qquad r^2 = 0.53$$

For the second season :

$$BIR = -2.28 + 1.21\theta g \qquad r^2 = 0.80$$

$$BIR = 100.32 - 68.815B \qquad r^2 = 0.29$$

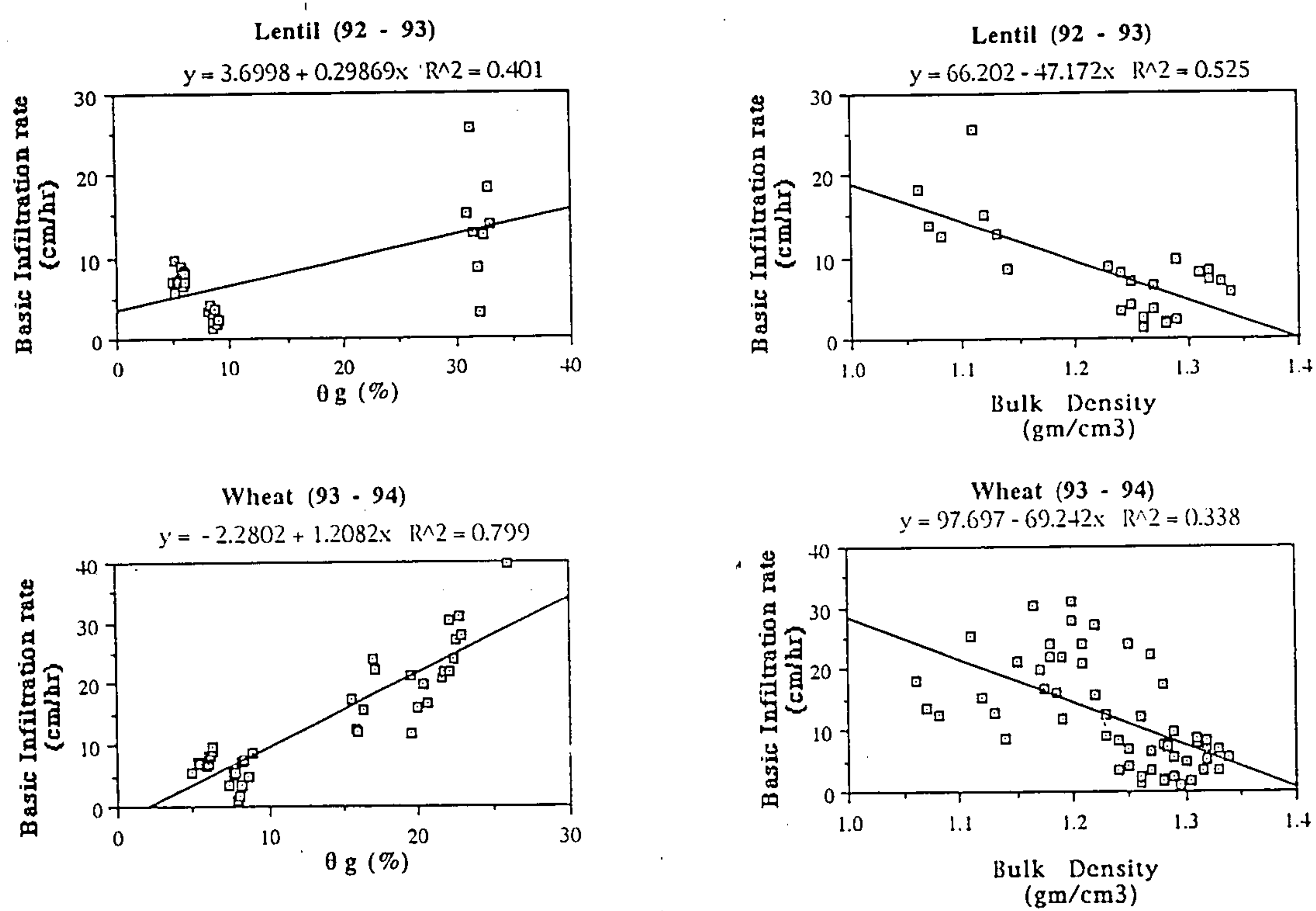

Fig. 5: **Relationships between basic infiltration rate and both: initial soil moisture content; and bulk density.**

4.8 Neutron Probe Evaluation :

1. Soil moisture parameters :

Soil moisture parameters namely: soil moisture storage, SMS; crop evapotranspiration, ETc; and soil moisture depletion, SMD were calculated by two methods to make a comparison between them.

In the first method, only one value for bulk density to calculate volumetric soil moisture content was used. While in the second method, multivalues of bulk density derived from the relation between gravimetric soil moisture and bulk density were used.

Table 9 represents the analysis of variance for the soil moisture parameters which were calculated by the two methods for the different lentil/wheat treatments (1992 - 1993 and 1993 - 1994). This table shows that, in the 1st season, only the tillage operation had a significant effect on all soil moisture parameters when they were calculated by the first method. The same results were found when they were calculated by the second method except for SMS in which there was no significant difference. While residue treatments and residue - tillage interaction had no significant effect on any of soil moisture parameters. Also, the same results were found in the second season, except that tillage had a significant effect only on soil moisture storage in the two methods of calculation.

It is noticed, in general, that probability level values varied between the two methods of calculation. Sometimes, the probability level increases in the second method as in tillage effect on SMS in 1993 - 1994 season. And, other times, it decreases as in tillage effect on SMS in 1992 - 1993 season.

Table 9 : Analysis of variance for soil moisture parameters which were calculated by two methods in different tillage-residue treatments.

Season	Method	Source of variation	Pr > F		
			SMS	ETc	SMD
92 - 93 (Lentil)	1	T	0.04 *	0.05 *	0.02 *
		R	0.09^{ns}	0.06^{ns}	0.27^{ns}
		T x R	0.91^{ns}	0.81^{ns}	0.51^{ns}
	2	T	0.17^{ns}	0.02 *	0.02 *
		R	0.65^{ns}	0.99^{ns}	0.99^{ns}
		T x R	0.71^{ns}	0.72^{ns}	0.72^{ns}
93 - 94 (Wheat)	1	T	0.05 *	0.61^{ns}	0.61^{ns}
		R	0.81^{ns}	0.91^{ns}	0.91^{ns}
		T x R	0.27^{ns}	0.3^{ns}	0.31^{ns}
	2	T	0.01**	0.61^{ns}	0.61^{ns}
		R	0.80^{ns}	0.87^{ns}	0.87^{ns}
		T x R	0.07^{ns}	0.09^{ns}	0.09^{ns}

* : significant at 5% probability level
** : highly significant at 1% pobability level
ns : not significant at 5% probability level

Table 10 represents the mean separation for soil moisture parameters which were calculated by the two methods for the different lentil/wheat treatments (1992 - 1993 and 1993 - 1994). Data, in table 10 show that moldboard tillage treatments, in lentil (1992 - 1993), had significantly higher values of SMS, ETc and SMD (268.8, 276.3 and 293.4 mm, respectively), when they were calculated by the first method, than chisel tillage treatments (240.1, 248.7 and 258.7 mm, respectively). But ETc and SMD only were significantly higher in moldboard tillage treatments (232.4 and 217.4 mm, respectively), when they were calculated by the second method, than those in chisel tillage treatments (214.7 and 199.7 mm, respectively) While, in wheat (1993 - 1994), only SMS was significantly higher in moldboard tillage treatments in the two methods (226 and 205.3 mm, respectively) than that in chisel tillage treatments (184.7 and 171.8 mm, respectively).

A very important point is that, soil moisture parameter values which were calculated by the second method were significantly lower than those which were calculated by the first way in lentil (1992 - 1993). But in the wheat, there was no significant difference in soil moisture parameter values between the two methods. However, there was a trend which indicated that the second method of calculation gave lower values than the first method of calculation eventhough there was no significant difference as in wheat (1993 - 1994).

Accordingly, it is noticed that using the appropriate bulk density values in calculated soil moisture parameters is mandatory. Otherwise, higher values will result and incorrect interpretations will be made.

Table 10 : Mean separation for soil water parameters which were calculated by two methods in different tillage-residue treatments.

Season	Method	SMS				ETc				SMD			
		T_1	T_2	R_1	R_2	T_1	T_2	R_1	R_2	T_1	T_2	R_1	R_2
(Lentil) 92 - 93	1	a+ 268.8 *a	b 240.1 a	248.1 a	260.8 a	a 276.3 a	b 248.7 a	249.9 a	275.1 a	a 293.4 a	b 258.2 a	266.8 a	284.8 a
	2	210.5 b	194.1 b	203.7 b	200.9 b	a 217.4 b	b 199.7 b	208.6 b	208.5 b	a 232.4 b	b 206.3 b	220.4 b	213.9 b
(Wheat) 93 - 94	1	a 226.0	b 184.7	208.7	201.8	177.5	157.8	163.6	166.7	187.1	169.9	171.8	176.2
	2	a 205.3	b 171.8	191.4	185.7	153.1	141.6	145.6	149.1	162.9	153.3	158.2	161.1

+: Along rows, means without letters on the upper side of the number, are not significantly different at the 5% probability level.
*: Along columns T1, T2, R1, and R2, means without letters on the lower side of the number, are not significantly different at the 5% probability level.

2. Cracks around access tubes :

Cracks near the access tubes resulted in lower count ratio values than the real values since some of neutrons escape far away. To solve this problem, one should try to avoid any cracks near the access tubes by adding soil from the surface into the crack when it begins to initiate. But if a crack is formed around an access tube, on one hand, it is better to fill it by surface soil before neutron probe reading. But, also, on the other hand, if one took a reading while a crack(s) was around an access tube, he would have a value to be corrected.

We tried to develop a mathematical approach to solve such a problem.

In general, it was found that : 1) the percent increase of count ratio,

$$\frac{CR2 - CR1}{CR1}$$

after crack filling decreased when the depth of reading was increased; 2) the percent of increased count ratio increased when the width of crack increased; 3) the extra depth of the crack under the desired depth had no significant effect on this percent; 4) when the number of cracks had increased, this percent increased; and 5) when the crack lies further away than 25 cm, it has no significant effect on neutron probe reading (count ratio).

As a result of these observations and this study we developed the following approach :

$$CR2 = a^n f\,[0.951{*}CR1 + 0.03971{*}W{*}CR1] \qquad r^2 = 0.85$$

Where: CR1, CR2 are the count ratio readings before and after filling the cracks, respectively; W is the width of the crack or the summation of widths of cracks at the soil surface around the access tube (cm) ; f is a coefficient depends on the crack depth, d (cm), and depth of reading, D (cm). It equals one when D = 7.5 cm, while it equals

$$\frac{D - 7.5\,(t1/t)}{D}$$

when D equals or greater than 15 cm, where t, t1: are the thickness of the layer and depth of crack in the layer, respectively. And it is equal one at maximum value of a, which is a coefficient dependent on the distance x, between an access tube and the crack surrounding, and

$$a = 1.00 + \frac{x}{500} \quad \text{if } x \leq 25 \text{ cm}$$

or

$$a = 1.05 \quad \text{if } x \geq 25 \text{ cm}$$

If no cracks x = 25 cm.

n is a coefficient that is dependent on the length of the crack, L (cm), and

$$n = 1 + \frac{L}{25}$$

but if L > 25 then n = 2.

By using this approach, one can get a valid count ratio to use it in the calculations. In addition to correct count ratios and use the second way of calculation which takes into consideration the soil moisture - bulk density relation, it is important to take into consideration the following :

1. Assuming a rootzone of 1 m, a 10 du land with 5% cracks volume has an actual volume of 9500 m^3. Consequently actual water depth would be the calculated one x (1-Vcr) for the area of 10 du. It is one of the minor errors, however, we can take it into consideration if we have a relationship between cracks volume and gravimetric soil moisture content.

2. Another source of error that should be corrected for, is the decrease in soil layer thickness due to subsidence which fluctuates with its soil moisture content. For part of the second layer would have been considered within the first layer, and part of the third layer would have been considered within the second layer, and so on ....

To overcome such problems, it might be better to consider layer thickness of 30 cm or more each horizon.

soil moisture content, bulk density, soil specific volume, void ratio, coeficient of linear extensibility, and volumetric available moisture. While tillage-residue interaction had no significant effect on these shrinkage inflection points.

Block and soil moisture tension had the same effect on these points in November as in July. Tillage-soil moisture tension had no significant effect on these points except on gravimetric soil moisture content. While residue-soil moisture tension had no significant effect on all of them.

Table 11 : Analysis of variance for shrinkage inflection points in July, 1993 in different tillage-residue treatments.

Source of variation	θg	θv	Δz	m	Vcr	B	Vs	E	COLE	Aθg	Aθv
Rep.	**	**	**	ns	**	*	*	*	**	**	**
T	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
R	ns	*	ns	ns	ns	*	*	*	ns	ns	ns
T x R	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rep.	**	**	**	ns	**	*	*	*	**	**	**
SMT	**	**	**	ns	**	**	**	**	-	-	-
T x SMT	ns	ns	ns	ns	ns	**	**	**	-	-	-
R x SMT	**	**	ns	ns	ns	**	*	*	-	-	-

* : significant; at probability level of 5%.
** : highly significant; at probability level of 1%.
ns : not significant; at probability level of 5%.

Table 12 : Analysis of variance for shrinkage inflection points in November, 1993 in different tillage-residue treatments.

Source of variation	θg	θv	Δz	m	Vcr	B	Vs	E	COLE	$A\theta g$	$A\theta v$
Rep.	**	**	**	ns	**	*	*	*	**	**	**
T	**	**	ns	ns	ns	ns	ns	ns	ns	*	*
R	ns	*	ns	ns	ns	**	**	*	*	ns	*
T x R	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
SMT	**	**	**	ns	**	**	**	**	-	-	-
T x SMT	ns	ns	ns	ns	ns	ns	ns	ns	-	-	-
R x SMT	**	ns	ns	ns	ns	ns	ns	ns	-	-	-

* : significant; at probability level of 5%.

** : highly significant; at probability level of 1%.

ns : not significant; at probability level of 5%.

By t-test, it is found that immediate incorporation of residue treatments gave lower θv, Vs and E values than late incorporation of residues which gave lower B. When soil moisture tensions increased, θg, θv, Vs and E decreased while Δz, Vcr and B increased. Gravimetric and volumetric soil moisture contents, Vcr, and B were significantly higher in November samples than in July samples. While m, Vs, E and $A\theta g$ and $A\theta v$ were significantly lower in November than July samples. These results are mainly due to the destroying of the soil aggregates and pores size distribution as discussed before in the field work.

Table 13 and 14 represent the mean values of shrinkage inflection points for different tillage residue treatments in July and November samples, respectively. In these tables we summarized the data by mentioning the comparisons only when there was a significant difference. Gravimetric soil moisture content (%) was significantly higher in November than in July samples at all soil moisture tensions except at 0.1 bar soil moisture tension as appeared also in Fig. 6. There was no significant difference between the two months in terms of Δz. Shrinkage characteristic, void ratio and soil specific volume were significantly higher in July samples than in November samples at all soil moisture tensions. While bulk density and cracks volume were significantly lower in July samples.

Increased soil moisture content in November samples compared to July samples may be due to increased micropores which results in increasing soil water retention. And the decreasing of macropores results in higher bulk density and lower void ratio and soil specific volume.

Table 13 : Mean separation for shrinkage inflection points in July, 1993.

SMT (bar)	θg (%)	Δz (mm)	m (%)	Vcr (mm)	B (gm/cm³)	Vs (cm³/gm)	E (%)
0.1	49.61	--	--	--	1.01	0.99	1.62
0.3	40.41	--	--	--	1.01	0.99	1.62
1	34.31	0.11	0.97	0.46	1.08	0.93	1.46
5	30.71	0.15	1.00	0.55	1.12	0.89	1.35
11	25.21	0.22	0.94	0.70	1.17	0.85	1.26
15	24.51	0.23	0.91	0.71	1.19	0.84	1.23

In November one can notice that immediate incorporation of residue gave a higher B and lower Vs and E than late incorporation of residues at all soil moisture tensions. As appeared in Fig. 6 and table 14 moldboard plough gave lower gravimetric soil moisture content at 0.1 bar, while higher gravimetric soil moisture content at 5, 11, and 15 bars than chisel plough.

Moldboard plough decreases macropores and increases micropores more than chisel plough. So, at 0.1 bar, chisel plough treatments had higher soil moisture content than moldboard plough treatments as appeared in Fig. 6 and table 14. This is due to higher soil moisture retention in chisel plough treatments at 0.1 bar. While, moldboard plough treatments had higher soil moisture content at 5, 11, and 15 bars than chisel plough treatments, because of soil water retention, also, which results from micropores.

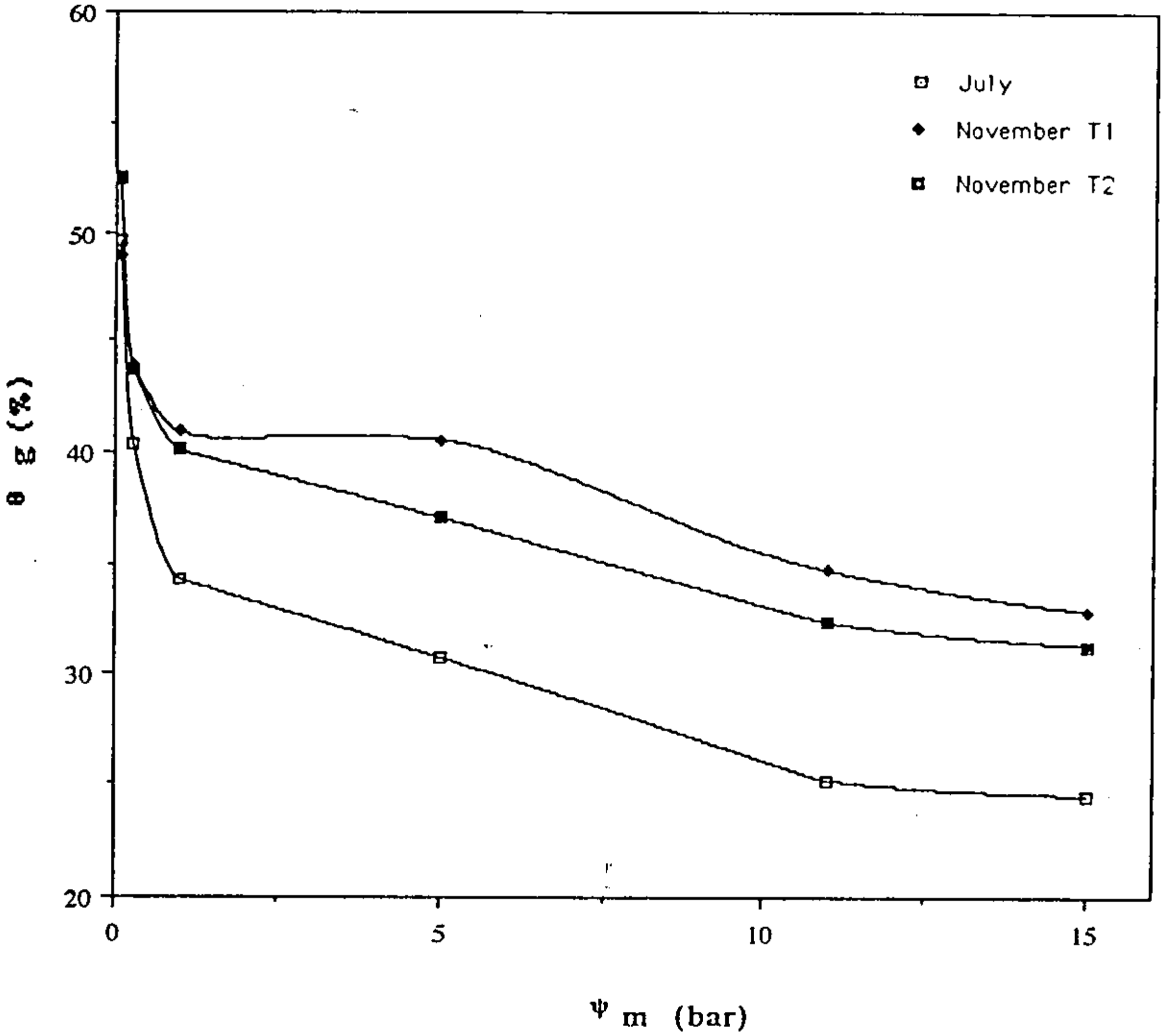

Fig. 6 : Soil moisture characteristic curves for July and November samples.

Immediate residue incorporation results in higher bulk density and lower soil specific volume and void ratio, because earlier operation results in less macropores.

Table 14 : Mean separation for shrinkage inflection points in November, 1993.

SMT (bar)	θg (%)		Δz (mm)	m (%)	Vcr (mm)	B (gm/cm³)		Vs (cm³/gm)		E (%)	
	T1	T2				R1	R2	R1	R2	R1	R2
0.1	49.0[b+]	52.5[a]	--	--	--	1.10[a]	0.98[b]	0.91[b]	1.02[a]	1.41[b]	1.7[a]
0.3	43.9	43.7	--	--	--	1.10[a]	0.98[b]	0.91[b]	1.02[a]	1.39[b]	1.72[a]
1	40.9	40.1	0.13	0.66	0.55	1.19[a]	1.05[b]	0.85[b]	0.95[a]	1.24[b]	1.52[a]
5	40.5[a]	37.0[b]	0.19	0.50	0.64	1.25[a]	1.08[b]	0.74[b]	0.93[a]	1.13[b]	1.45[a]
11	34.7[a]	32.3[b]	0.24	0.67	0.81	1.36[a]	1.13[b]	0.74[b]	0.85[a]	0.96[b]	1.26[a]
15	32.8[a]	31.2	0.26	0.69	0.86	1.41[a]	1.20[b]	0.72[b]	0.84[a]	0.90[b]	1.22[a]

+: Along rows, means without letters on the right side of the number, are not significantly different at the 5% probability level of the T - test.

Table 15 represents means separation for COLE, Aθg and Aθv in July and November samples in different tillage - residue treatments. It shows that moldboard tillage treatments were significantly higher than chisel tillage treatments in terms of both volumetric and gravimetric available moisture in November samples. While immediate residue incorporation treatments were significantly higher than late residue incorporation in terms of both gravimetric and volumetric available moisture. Gravimeteric and volumetric available moisture in general , were higher in July samples than in November samples. while COLE tends to be lower in July samples than in November samples. So, soil tillage with chisel or moldboard tends to increase gravimetric soil moisture content, bulk density, and decrease shrinkage characteristics and volumetric available water. This means that tillage tends to increase soil moisture storage, compaction, and aeration.

Table 15 : Mean separation for coefficient of linear extensibility and available water in different tillage-residue treatments.

Parameter>	COLE (x10-2)		Aθg		Aθv	
Month >	7	11	7	11	7	11
T1	*5.6+	7.0	14.1	11.1b	a10.4	b3.8b
T2	5.5	8.2	15.2	15.5a	11.0	7.8a
R1	5.4	8.2	15.0	13.1	11.4	8.2a
R2	5.8	7.0	14.3	13.5	a10.0	b3.4b

+: Along rows, means without letters on the left side of the number, are not significantly defferent at the 5% probability level.
*: Along columns, means without letters on the right side of the number, are not significantly defferent at the 5% probability level.

4.10 Linear Relations Between Bulk Density and Cracks Volume with Soil Moisture Content :

Linear regression analysis was made to correlate gravimetric soil moisture content and both bulk density and cracks volume.

Highly significant relations were found:

For July samples:

$B = 1.4 - 0.009\theta g$ $\quad r^2 = 0.87$

$Vcr = 1.35 - 0.026\theta g$ $\quad r^2 = 0.91$

For November samples:

$B = 1.67 - 0.011\theta g$ $\quad r^2 = 0.84$

$Vcr = 1.88 - 0.032\theta g$ $\quad r^2 = 0.91$

Generally speaking, after wheat harvest, the soil surface is still covered by residues, while there is no residues after lentil season. This results in differences in surface physical properties between wheat season and lentil season, since the effects of tillage and incorporation date on surface physical properties are strongly related to residues cover. So, the effect of tillage on surface physical properties may obtain contradictory results because it is time dependent[48].

Tillage, on one hand, could have a major influence on soil water content through its effect on infiltration rate, surface run-off, and water availability to plant. While the influence of tillage on soil water characteristics, on the other hand, will probably depend on tillage method, climate, and soil properties[48].

In general, the tillage increases soil moisture storage by increasing the infiltration rate and decreasing the water holding capacity. Also, it increases the ratio of evapotranspiration to soil moisture storage by increasing water availability.

5. Summary and Conclusions.

A study was carried out in Mushaqar Agricultural Experiment Station, 30 km south west of Amman. soil was classified as very fine, smectitic, thermic, chromic haploxerert.

Two different tillage treatments (moldboard and chisel) with two residue management practices (grazing with early or late incorporation of residue) were combined with each other. Each treatment has an area of 10 x 45 m^2 and replicated 3 times with a factorial arrangement in randomized complete block design (RCBD). The different tillage-residue combinations were introduced within wheat - lentil rotation. All treatments were fertilized by a constant rate of triple superphosphate at a rate of 10 kg/du, while all treatments in the wheat phase only were fertilized by a constant rate of urea at a rate of 7.5 kg/du.

Results and conclusions obtained can be summarized as follows :

1. Moldboard tillage treatments (T1) had significantly higher gravimetric soil surface moisture content than chisel tillage treatments (T2). While there was no significant difference between residues treatments.

2. Immediate incorporation of residues treatments (R1) had significantly higher bulk density than late incorporation of

residues treatments (R2). While tillage operation has no significant effect on bulk density.

3. Soil strength increased with depth and bulk density, while it decreased with soil moisture content.

4. Soil strength was significantly lower in moldboard tillage treatments (T1) and late incorporation of residues (R2) than the other treatments.

5. Basic infiltration rate was higher for moldboard tillage treatments (T1) than chisel (T2), in lentil season. While, in wheat season, basic infiltration rate was lower for (T1) than (T2).

6. Basic infiltration rate in winter is approximately three to four times higher than in summer.

7. Soil surface moisture content, bulk density, soil strength, and infiltration rate were significantly lower in lentil season than in wheat season.

8. In general, soil moisture storage, evapotranspiration and soil moisture depletion were significantly higher for moldboard tillage treatments (T1) than for chisel tillage treatments (T2). While there was no significant differentce between immediate

incorporation of residues (R1) and late incorporation of residues (R2) with respect to soil moisture parameters.

9. Soil moisture parameters values which were calculated using the appropriate bulk density values were significantly lower than those which were calculated by using a single value for the bulk density.

10. To calculate soil moisture parameters, relationships between gravimetric soil moisture content with bulk density and cracks volume are needed. Besides we should correct neutron probe readings when crack(s) is around access tube.

11. In the laboratory study, it was found that immediate incorporation of residues(R1) has significantly higher bulk density and significantly lower soil specific volume and void ratio than late incorporation of residues (R2), while chisel plough (T2) has higher gravimetric soil moisture content at 0.1 bar and lower at 5, 10, and 15 bars than moldboard plough (T1)

12. Chisel plough treatments (T2) and immediate incorporation of residues (R1) have significantly higher gravimetric and volumetric available moisture than the other treatments.

13. In general, tillage operation tends to increase cracks volume and coefficient of linear extensibility, while decrease shrinkage characteristics and volumetric available moisture.

6. References

1- Duwayri, M., M. Tell, S. Arabiat, T. P. Srivastara, W. K. Anderson, and K. Somel: 1984. "Cereal Improvement in The Dry Areas". A report on the Jordan cooperative cereal improvement project 1978 to 1982. Ministry of Agriculture of Jordan, University of Jordan, and ICARDA.

2- Hamdi, H., R. Tinsly, and A.Taher: 1988. "Management of The Heavy Clayey Soil of Egypt". Egypt. J. Soil Sci. 28(3) : 349-361.

3- Conghlan K. J., G. D. Smith, and D. F. Yule: 1989. "Soil Physical Research For Improved Dryland Crop Production on Vertisols in Queensland, Australia". 87-99: ICRISAT.

4- Jong, E. de and J. A. Elliott: "Physical Properties Affecting The Productivity and Management of Clay Soil in Saskatchewan". Sixth International Soil Classification Workshop. 29- 38.

5- Varvel, G. E: 1994. "Monoculture and Rotation System Effects on Precipitation Use Effeciency of Corn. Agron. J. 86 : 204- 208.

6- Mannering, J. V. and C. R. Fenster: 1983. What is Conservation Tillage?". J. of Soil and Water Conservation. 30 : 140-143.

7- Soil Survey Staff: 1992. Keys to Soil Taxonomy : Vertisols. Fifth edition. PP : 14 - 57.

8- Abu-Hammad, A. Y. : 1993. "Effect of Different Crop Rotations, Tillage- Residue Management on Soil Moisture Storage, Soil Physical Properties, and Yeilds in Rainfed Areas". M. Sc. Thesis, University of Jordan, Amman, Jordan.

9- Hill, R. L., R. Horton, and R. M. Cruse: 1985. "Effects on Soil Water Retention and Pore Size Distribution of Two Mollisols". Soil. Soc. Am. J. 49 : 1264-1270.

10- Manrigue, L.A. and C. A. Jones: 1991. "Bulk Density of Soils in Relation to Soil Physical and Chemical Properties". Soil Sci. Soc. Am. J. 55 : 476-481.

11- Mitchell, A. R. and M. Th van Genuchten: 1992. "Shrinkage of Bare and Cultivated Soil". Soil Sci. Soc. Am. J. 56 : 1036-1042.

12- Wires, K. C., W. D. Zebchuk, and G. C. Topp: 1987. "Pore Volume Changes in Structured Silt-loam Soil During Drying". Can. J. Soil Sci. 67 : 905-917.

13- Bronswijk, J. J. B.: 1991. "Drying, Cracking, and Subsidence of A Clay Soil in A Lysimeter". Soil Sci. 152 : 92-99.

14- Chan, K. Y. :1981. "Representative Sampling For Bulk Density in A Vertisol". Soil Sci. Soc. Am. J. 45 : 668- 669.

15- Yule, D. F. and J.T. Ritchie: 1980. "Soil Shrinkage Relationships of Texas Vertisols : I- Small Cores". Soil Sci. Soc. Am. J. 44 : 1285- 1291.

16- Ismail, I., R. L. Blevins, and W. W. Frye: 1994. "Long Term No-Tillage Effects on Soil Properties and Continuous Corn Yields". Soil Sci. Soc. Am. J. 58 : 193- 198.

17- Rolston, D. C., M. N. A. Bedaiwg , and D. T. Lonie: 1991. "Micropenetrometer for In Situ Measurement of Soil Surface Strength". Soil Sci. Soc. Am J. 55 : 481 - 485.

18- Vyn, T. J. and B. A. Raimbault: 1993. "Long-Term Effect of Five Tillage Systems on Corn Response and Soil Structure". Agron. J. 85 : 1074-1079.

19- Radcliffe, D. E., E. W. Tollner, W. L. Hargrove, R. L Clark, and M. H. Golabil: 1988. "Effect of Tillage Practices on Infiltration and Soil Strength of A Typic Hapludult Soil After Ten Years". Soil Sci. Soc. Am. J. 52 : 798- 804.

20- Hammel, J. E.: 1989. "Long- Term Tillage and Crop Rotation Effects on Bulk Density and Soil Impedence in Northern Idaho". Soil Sci. Soc. Am. J. 53 : 1515- 1519.

21- Hill, R .L. and R. U. Cruse: 1985. "Tillage Effects on Bulk Density and Soil Strength of Two Mollisols". Soil Sci. Soc. Am. J. 49 : 1270-1273.

22- Izaurralde, R. C., J. A. Hobbs, and C. W. Swallow: 1986. "Effect of Reduced Tillage on Continuous Wheat Production and on Soil Properties". Agron. J. 78 : 787- 791.

23- Fapohunda, H.O., W.D. Kemper, and D.F. Heerman: 1985. "Effect of Drying on Soil Strength and Corn Emergence". Irrig. Sci. 6 : 149- 158.

24- Lal, R., A. A. Mahboubi, and N. R. Fausey: 1994. "Long- Term Tillage and Rotation Effects on Properties of A Central Ohio Soil". Soil Sci. Soc. Am. J. 58 : 517- 522.

25- Ghazy, A., M. A. Wahab, M. S. Omar: 1988. "Infiltration Charcteristics as Related to Soil Physicochemical Properties of Vertisols in The Nile Delta". Egypt. J. Soil Sci. 28(1) : 75-90.

26- Zuzel J, F., J. L. Pikul, Jr, and P. E Rasmussen: 1990. "Tillage and Fertilizer Effects on Water Infiltration". Soil Sci. Soc. Am. J. 54 : 205- 208.

27- Dao, Th. H.: 1993. "Tillage and Winter Wheat Residue Management Effects on Water Infiltration and Storage". Soil Sci. Soc. Am. J. 57 : 1586- 1595.

28-Unger, P. W.: 1992. "Infiltration of Simulated Rainfall : Tillage System and Crop Residue Effects". Soil Sci. Soc. Am. J. 56: 283-289.

29- Chang, C., and C.W. Lindwall: 1989. "Effect of Long-Term Minimum Tillage on Some Physical Properties of A Chemozemic Clay Loam". Can. J. Soil Sci. 69: 443-449.

30- Starr, J. L.: 1990. "Spatial and Temporal Variation of Ponded Infiltration". Soil Sci. Soc. Am. J. 54 : 629- 636.

31- Prieksat M. A., T. C. Kaspar, and M. D. Ankeny: 1994. "Positional and Temporal Changes in Ponded Infiltration in A Corn Field". Soil Sci. Soc. Am. J. 58 : 181- 184.

32- Achar, H. P., V. S. Patil ,and M. R. Advani: 1980. "A Method for Estimation of Soil Moisture on Volume Weight Relationship". Indian J. Soc Soil Sci. 28(1) : 10 - 13 .

33- Wilson, D. J.: 1988. "Neutron Moisture Meters: The Minimum Error in The Derived Water Density". Aust. J. Soil Res. 26:97-104.

34- Wilson, D. J. : 1988. "Uncertainties in The Measurement of Soil Water Content Caused by Abrupt Soil Layer Changes, When Using A Neutron Probe". Aust. J. Soil Res. 26 : 87-96.

35- Yule D. E . and J. T. Ritchie: 1980. "Soil Shrinkage Relationship of Texas Vertisols : II. Large Cores". Soil Sci. Soc. Am. J. 44 : 1291-1295.

36- Mitchell, A. R. : 1991. "Soil Surface Shrinkage to Estimate Profile Soil Water". Irrig. Sci. 12 : 1-6.

37- Taimeh, A. Y., and S. A. Khreisat: Vertisols in Jordan, Properties and Distribution. 1st Edition, Publications of the University of Jordan, Amman, 1998, pp : 43 - 46.

38- Bradford, H. : 1986. "Penetrability : Pocket Penetrometer". Method of Soil Analysis. Part 1. Physical and Mineralogical Properties. 2nd Edition. Amerc. Soc. of Agron. and Soil Sci. Soc. of America. Madison, Wisconsin USA. pp : 466 - 468.

39- Blake, G. R., and K. H. Hartge: "Bulk Density". Methods of Soil Analysis. Part 1. Physical and Mineralogical Properties. 2nd Edition. Amer. Soc. of Agron., and Soil Sci. Soc. of America. Madison, Wisconsin, USA. 1986. pp : 33 - 367.

40- Bouwer, H. : 1986. "Intake Rate : Single, and Double-Ring Infiltrometers". Method of Soil Analysis. Part 1. Physical and Mineralogical Properties. 2nd. Edition. Amer. Soc. of Agron. and Soil Sci.Soc.of America. Madison, Wisconsin USA. PP. 835-838.

41- Klute, A. Water retention : "Laboratory Methods". Method of Soil analysis. Part 1. Physical and Mineralogical Properties. 2nd Edition. Amer. Soc. of Agron., and Soil Sci. Soc. of America. Madison, Wisconsin USA. 1986. pp : 648 - 662.

42- Bronswijk, J. J. B. : 1991. "Relation Between Vertical Soil Movements and Water- Content Changes in Cracking Clays". Soil Sci. Soc. Am. J. 55 : 1220- 1226.

43- Bronswijk, J. J. B. : 1990. "Shrinkage Geometry of A Heavy Clay Soil at Various Stresses". Soil Sci. Soc. Am. J. 54 : 1500-1502.

44- Doorenobs, J., and W. O. Pruitt : 1974. "Crop Water Requirements". FAO Irrig. and Drainage Paper .No. 24. Rome.

45- Thompson, M. L., J. F. Mclride, and R. Horton: 1985. "Effects of Drying Treatments on Porosity of Soil Materials". Soil Sci. Soc. Am. J. 49 : 1360-1364 .

46- (Notes). 1976. "Relationship Between Bulk Density and Pore-Size Distribution in A Sandy Loam Soil". Indian J. Soc. Soil Sci. 24(3) : 314-316.

47- Timlin, D. J., L. R. Ahuja, and M. D. Ankeny: 1994. "Comparison of Three Field Methods to Characterize Apparent Macropore Conductivity". Soil Sci. Soc. Am. J. 58 : 278-284.

48- Zhai, R., R. G. Kacharoski, and R. P. Voroney: 1990. "Tillage Effects on The Spatial and Temporal Variations of Soil Water". Soil Sci. Soc. Am. J. 54 : 186- 192.

7. Appendices

Appendix 1a :

Analysis of variance for the experiment design [factorial in randomized complete block design (RCBD)] for the infiltration rate.

Source of variation	df (symbols)	df
Total	rTR - 1	11
Block	r - 1	2
Tillage	T - 1	1
Residue	R - 1	1
T x R	(T - 1) (R - 1)	1
Error	(r - 1) (TR - 1)	6

r : replicate.
T : Tillage.
R : Residue.

Appendix 1b:

Analysis of variance for the soil strength and shrinkage inflection points.

Source of variation	df (symbols)	df
Total	srTR-1	35
Block	r-1	2
Tillage	T-1	1
Residue	R-1	1
T x R	(T-1)(R-1)	1
S(TxR)	(S-1)(TxR)	8
Error	(r-1)(sTR-1)	22

S(TxR): Sample within tillage-residue interaction

Appendix 2a:

Some soil physical properties for Mushaqar Agricultural Experiments Station at the beginning of the experiment.

Depth of layer (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class	Field capacity (%)*	Wilting point (%)*+	Bulk density (gm/cm3)*	Particle density (gm/cm3)	Basic infiltraion rate (mm/hr)*
0-15	19.7	42.3	38.0	Silty c. loam	44.4	25.9	1.21	2.76	15.9
15-30	22.1	37.4	40.5	clay	44.1	25.8	1.26	2.80	
30-60	25.7	31.7	42.6	clay	43.6	28.8	1.32	2.90	
60-90	29.0	27.2	43.8	clay	43.7	28.2	1.37	2.88	
90-120	20.4	36.9	42.7	clay	44.9	30.2	1.37	2.84	
120-150	23.5	34.6	41.9	clay	46.5	32.5	1.42	2.88	

\+ Volumetric water content.

* Values are average of three replicates.

Appendix 2b :

Some soil chemical properties and fertility status for Mushaqar Agricultural Experiments Station at the beginning of the experiment.

Depth of layer (cm)	EC (dS/m)	PH	$CaCO_3$ (%)	Available nitrogen (ppm)*	Available phosphorous (ppm)*	Available potassium (ppm)*	Organic matter (%)*
0-15	0.19	8.1	7.1	8.8	4.1	400.0	0.71
15-30	0.19	8.0	7.8				
30-60	0.20	8.2	8.8				
60-90	0.20	8.1	8.8				
90-120	0.20	8.1	7.1				
120-150	0.20	7.9	9.9				

* Values are average of sixteen replicates.

Appendix 3:

Mean separation for soil surface moisture, bulk density, soil strength, and basic infiltration rate for the lentil-wheat rotation.

	θg (%)	B (gm/cm³)	SS (MPa)	Basic IR (cm/hr)
Lentil	19.6[b]	0.94[b]	0.51[b]	7.6[b]
Wheat	26.0[a]	1.04[a]	1.60[a]	17.6[a]
Block 1	22.6[b]	0.97[b]	1.03[b]	12.6
Block 2	23.4[a]	1.00[a]	1.13[a]	12.4
Block 3	22.5[b]	1.01[a]	1.00[b]	12.7
T1	23.4[a]	1.00	1.02[b]	10.8[b]
T2	22.4[b]	0.98	1.08[a]	14.4[a]
R1	23.0	1.01[a]	1.10[a]	12.8
R2	22.7	0.98[b]	1.01[b]	12.4

+: Along rows, means without letters on the right side of the number, are not significantly different at the 5% probability level of the T - test.

الملخص

المحتوى الرطوبي وبعض الخصائص الفيزيائية
للأتربة الطينية المتشققة (Vertisols) تحت معاملات مختلفة
من الحراثات وإدارة بقايا المحصول

إعداد
أيمن عبدالله أحمد سليمان

بإشراف
الأستاذ الدكتور أنور البطيخي

ومشاركة الدكتورة هيزل هرس

تعتبر دراسة أثر الحراثة وإدارة بقايا المحصول على الخصائص الفيزيائية للتربة في أثناء نمو النبات ذات فائدة كبيرة في تحسين إدارة العمليات الزراعية، خصوصاً في الأتربة الطينية المتشققة (Vertisols) التي تمتاز بظاهرة الإنكماش - الإنتفاخ التي تؤثر على خصائصها الفيزيائية الأخرى. منذ ١٩٩٢ وحتى ١٩٩٤، تمت دراسة أثر معاملتين من الحراثات ومعاملتين من إدارة بقايا المحصول على الكثافة الظاهرية ومقاومة التربة للإختراق ومعدل رشح الماء وتخزين التربة للماء والبخر-النتح وكمية الإستنفاذ المائي للتربة على تربة طينية متشققة ذات ميلان أقل من ١٪ ضمن دورة زراعية ثنائية عدس-قمح في محطة المشقر للبحوث الزراعية. إضافة إلى ذلك، تم تقييم قراءات جهاز المجس النيوتروني وربطها بالمحتوى الرطوبي للتربة. وكانت معاملة الحرث بإستخدام محراث السكة (T1) أو بالمحراث الإزميلي (T2). بينما كانت معاملتا إدارة بقايا المحصول هي رعي بقايا المحصول لمدة شهر ثم خلط الباقي بالتربة مباشرة في بداية شهر آب (R1) أو تأخير الخلط لمنتصف شهر تشرين الأول (R2).

ودلت النتائج على أن المعاملات المحروثة بمحراث السكة (T1) كانت أعلى معنوياً في كمية البخر-النتح والإستنفاذ المائي للتربة عنه في المعاملات المحروثة بالمحراث الإزميلي (T2) في موسم العدس، بينما كانت أعلى معنوياً منها في تخزين الماء في موسم القمح. ولم يكن لإدارة بقايا المحصول أي أثر معنوي على كمية البخر-النتح وتخزين التربة للماء، أو إستنفاذ التربة للماء في الموسمين.

وأعطى خلط بقايا المحصول مباشرة (R1) قيماً أعلى معنوياً للكثافة الظاهرية منه في خلط بقايا المحصول المتأخر (R2)، بينما لم يكن هناك أي أثر معنوي لمعاملتي الحراثة على الكثافة الظاهرية. وكانت مقاومة التربة للإختراق أعلى معنوياً في المعاملات المحروثة بالمحراث الإزميلي (T2) أو المعاملات ذات الخلط المباشر (R1) منها في المعاملات الأخرى. وكان معدل رشح الماء الأساسي أعلى معنوياً في المعاملات المحروثة بمحراث السكة (T1)منه في المعاملات المحروثة بالمحراث الإزميلي (T2) في موسم العدس، بينما كان معدل رشح الماء الأساسي في موسم القمح أعلى معنوياً في المعاملات المحروثة بالمحراث الإزميلي (T2) منه في المعاملات المحروثة بمحراث السكة (T1)، علماً بأنه لم يكن لمعاملتي خلط بقايا المحصول أي أثر معنوي على معدل رشح الماء الأساسي. وقد تبين أن المحتوى الرطوبي والكثافة الظاهرية ومقاومة التربة للإختراق ومعدل رشح الماء الأساسي كانت جميعها أعلى معنوياً في موسم القمح منها في موسم العدس.

ويعطي تقدير كل من البخر-النتح وتخزين التربة للماء واستنفاذها له باستخدام قيمة واحدة للكثافة الظاهرية قيماً أعلى معنوياً منها باستخدام القيم المناسبة للكثافة الظاهرية. وتم تحديد علاقات تربط بين المحتوى الرطوبي الوزني مع الكثافة الظاهرية وحجم الشقوق. كما تم استنتاج معادلة لتعديل قراءات جهاز المجس النيوتروني للمواقع التي يوجد فيها شقوق قريبة من الأنابيب التي تؤخذ فيها قراءات الرطوبة.

وفي الدراسة المخبرية، وجد أن الكثافة الظاهرية كانت أعلى معنوياً، بينما كان الحجم النوعي للتربة ونسبة الفراغات فيها أقل معنوياً، في المعاملات ذات الخلط المباشر (R1) عنها في المعاملات ذات الخلط المتأخر (R2). ووجد أن المحتوى الرطوبي الوزني للمعاملات المحروثة بمحراث السكة (T1) كان أقل معنوياً عند شد رطوبي ١,٠ بار وأعلى معنوياً عند شد رطوبي ٥، ١١، ١٥ بار منه في المعاملات المحروثة بالمحراث الإزميلي (T2). بينما وجد أن الرطوبة المتاحة الحجمية أو الوزنية في المعاملات المحروثة بالمحراث الإزميلي (T2) والرطوبة المتاحة الحجمية في المعاملات ذات الخلط المبكر (R1) أعلى منه في المعاملات الأخرى.