University of Jordan
Faculty of Graduate Studies

The Effect of Soil Moisture Content and Management Practices on Some Physical Properties of Vertisol under Three Course Rotation

Jawad Al-Bakri

Supervised by
Prof. Dr. Anwar Battikhi

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

January, 1996

This thesis was defended successfully on January 2, 1996 and approved by :

Committee Members : **Signature**

1. Dr. Anwar Battikhi ....
   Professor of Soil Physics,
   Chairman of committee

2. Dr. Basam Snobar ....
   Professor of Farm Machinary,
   Member of committee

3. Dr. Butros Hattar ....
   Associate professor of Soil Fertility,
   Member of Committee

4. Dr. AbdelNabi Fardous ....
   Soil Physicist, National Center for Agricultural Research and Technology Transfer (NCARTT),
   Member of Committee

Dedication

To

My Mother ...

Father ...

Brothers ...

and Sisters ...

Acknowledgement

At first, thanks God for supporting me with power, patience, and determination throughout the preparation of this thesis.

Secondly, I would like to express my profound gratitude, and true appreciation to my advisor Dr. Anwar Battikhi for his valuable supervision and practical suggestion throughout this study. The sincere guidance and constructive discussion provided by Dr. Battikhi on all phases of research and thesis preparation are deeply appreciated.

Also, I wish to express my deepest gratitude, and indebtedness to committee members, Dr. Basam Snobar, Dr. Botrus Hattar and Dr. AbdelNabi Fardous for their valuable suggestions in their specialization, and for reading and criticizing drafts of various parts of this thesis.

Special thanks are expressed to the staff of Soil and Irrigation Department for their cooperation.

Finally, thanks are extended to the staff of the Maru Agricultural Research Station for their cooperation.

Table of Contents

List of Tables

List of Appendices

Abstract

The Effect of Soil Moisture Content and Management Practices on Some Physical Properties of Vertisol under Three Course Rotation

Jawad Al-Bakri

Supervised by
Prof. Dr. Anwar Battikhi

A proper management of tillage and plant residue is a basic need for improving physical properties of Vertisols which are highly affected by shrink-swell phenomenon. Improvement of soil physical properties will create a good soil environment for seed emergence and plant growth. An experiment was carried out at Maru Agricultural Research Station in the northern region of Jordan. Soil was classified as fine, smectitic, thermic, typic chromoxerert. The experiment aimed to study the effects of different tillage and plant residues management practices on some physical properties of Vertisol and neutron probe certainty in vertisol.

Tillage treatments were moldboard (T1), and chisel plow (T2). Whereas residue treatments were early incorporation of residue in August (R1), and late incorporation of residue in mid of October (R2). Both residue treatments were grazed for one month after wheat harvesting.

Results showed a temporal variations between the different treatments with respect to gravimetric soil moisture content. While, soil surface bulk density and soil strength were significantly higher under treatments of chisel plow combined with early or late incorporation of plant residue than other treatments for both wheat and lentil seasons.

Initial infiltration rate was significantly higher under treatment of moldboard plow combined with early incorporation of plant residue than other treatments for both seasons. While basic infiltration rate did not differ significantly between the different treatments.

The results showed that using appropriate value of bulk density in calculating soil moisture parameters in Vertisol is mandatory, otherwise, obtained values will be overestimation. Also, it was found that the presence of crack(s) around access tube affects neutron probe readings and so the reading should be corrected depending on crack width and length.

Finally, the results showed that soil moisture characteristic curve had not been affected by crop type. But, it was found that volumetric soil moisture content was significantly lower after planting than after harvesting.

1. Introduction

Jordan is located in aridic and semiaridic climatic zones. About 91% of the total area is classified as aridic region, with less than 200mm mean annual rainfall. While 6% of the total area has a semiaridic climate, with 200 to 350mm annual rainfall. This ensures the necessity to have suitable soil management practices in terms of tillage and residue managment, which will lead inturn, to better soil moisture use and more stored soil moisture for subsequent crop production(1).

Vertisol is the most important soil in Jordan where rainfed agriculture is practiced. This is due to the fact that this soil is deep and occupies flat areas that recieves more than 300mm of annual precipitation. Consequently most of the field crops are largely grown on Vertisols(2).

The most noted feature of Vertisols is their ability to shrink and swell upon change of moisture content, whereas fissures of considerable width are formed(3). Soil moisture content, crop type, and management practices affect shrink-swell capacity of the soil(4).

The existence of soil physical constraints increases the risk of crop failure, and the cost and difficulty of implementing good soil management practices. Those constraints include low plant available water capacity (PAWC), coarsely structured soils which cause root damage, high content of clay minerals that cause shrinking, and high degree of compaction that restricts root penetration(5).

It is well known that certain tillage-residue management practices could improve in some soil physical properties, and soil fertility and could increase the conservation of soil moisture(6). Proper soil management practices allow crops to be grown both in rainy and post rainy seasons. It has been noticed that surface tillage (10-15cm) is required for improved systems of Vertisols management whereas deep plowing is not recomended(7).

An experiment was carried out at Maru Agricultural Research Station, located in the north region of Jordan aiming to achieve the following objectives :

1. Studying some physical properties of Vertisol (infiltration rate, bulk density, soil strength, sorption curve, aggregate size distribution, soil porosity and pore size distribution), as affected by different tillage-plant residues management practices.
2. Determining the shrink swell capacity of the Vertisol, and its relation with soil moisture content, under different tillage-plant residues managment practices, and
3. Studying the effect of shrink-swell capacity on the infiltration rate, bulk density, soil strength, and neutron probe readings.

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(8).

2.2 Water Content :

According to Sulieman (1994), tillage tends to increase Vertisol moisture storage from rainfall due to the increase of soil moisture retention. Whereas, this effect tends to be reduced when residues are present. Moldboard plough treatments were higher than chisel plough with respect to surface soil moisture content(9).

In a study on Vertisol at Mushaqar Agricultural Experiments Station, results indicated a significant increase in volumetric water content (Pv at 0.1 bar soil moisture tension) for sweep tillage and late incorporation of residue (R2) over different tillage and residue treatments : 47% for moldboard, 50% for sweep, and 46% for immediate incorporation at first of July (R1), 50% for R2(6).

Kharouf and Battikhi (1991), in a study of the effect of fall tillage plows on soil moisture storage from rainfall, depletion, at Mushaqar Agricultural Research Station, found that there were no significant differences between moldboard and chisel plows with repsect to soil moisture storage and depletion (387 and 376 mm for storage, 377 and 378 mm for depletion, respectively)(10).

While according to Abu Hammad (1995), sweep plow treatments attained the highest significant soil moisture storage from rainfall (446, 400, and 410 mm stored moisture at Mushaqar, 379, 361, and 349 mm stored moisture at Rabba, for sweep, chisel, and moldboard for wheat in 1991 - 1992, respectively). Also, sweep plow treatments attained significantly higher soil moisture depletion, rainfall storage efficiency, and water use efficiency.

2.3 Bulk Density :

Bulk density is one of the most commonly used indices for evaluation of soil physical conditions. A knowledge of the relationship between bulk density and pore size distribution is important for judging the effect of soil compaction on the aeration, porosity and the amount of water stored in the soil(12).

Using core method, Abu-Hammad (1993), found that late incorporation of residue revealed a significant increase in bulk density over the immediate incorporation treatment (1.10 g/cm^3 and 1.02 g/cm^3 respectively) in Mushaqar Station Soils. The same results were obtained for Rabba Station Soils but with relatively higher values (1.2 g/cm^3 and 1.08 g/cm^3 for late incorporation and immediate incorporation treatments respectively)[6].

According to Battikhi and Sulieman (1995), tillage treatments (moldboard and chisel) had no significant effect on bulk density. While residue incorporation treatment in August gave significantly higher bulk density than that incorporated in October[13].

In a study on Vertisol, Gupta (1978) found that bulk density had increased from 1.37 to 1.75 g/cm^3 when soil moisture content had decreased from 0.25 to 0.05 g/g[14]. On the other hand, Yule (1980) found that bulk density of a Vertisol had increased from 1.24 to 1.40 g/cm^3 when soil moisture content had decreased from 0.41 to 0.14 cm^3/cm^3, while bulk density of the oven dried sample was 1.69 g/cm^3[15].

The change of soil bulk density upon changing of soil moisture content is valid in soils other than Vertisols; Mitchel (1992) found that bulk density of fallow Holiville Silty Clay soil had increased from 1.13 to 1.59 Mg/m^3 when soil volumetric water content had decreased from 0.451 to 0.232 m^3/m^3[16]. Whereas Wires (1987) reported that bulk density of Silt Loam Orthic Humic Gleysol had increased from 1.35 to 1.46 g/cm^3 when soil water content had decreased from field capacity to permenant wilting point[17].

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

1. for three-dimensional shrinkage :
$B = B_{min}/[(B_{min}/A) + WB_{min} + E_{min}]^{1/3}$

2. For one-dimensional shrinkage :
$B = 1/[(1/A) + W + (E_{min}/B_{min})]$,

Where :

B = bulk density of soil solid (g/cm^3).
A = particle density of soil (g/cm^3).
W = gravimetric moisture content (g/g).
B_{min} = minimum bulk density (g/cm^3).
E_{min} = entrapped air present in the soil at B_{min} (cm^3/cm^3)(18).

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

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

Where :

θg = gravimetric water content (g/g).
B = bulk density (g/cm^3)

(assuming particle density of 2.65 g/cm^3 and an air content at the swelling limit of 0.05 cm^3/cm^3)(19).

2.4 Soil strength :

The general purpose of tillage practices and plant residues management is to create a favorable soil environment for seed emergence and plant growth[20].

Most field conditions that influence soil strength measurement, such as : presence of cracks, amount of living organisms, type and extent of plant cover, and amount of incorporated plant 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, so as to predict seed emergence and plant growth conditions[21].

In a study on sandy clay loam (Typic Hapludult) soil, Radcliffe *et al.* (1988) found that soil strength was low in moldboard plow treatment in the surface layer (0 - 0.25 m). While for no-tillage treatments there was a high strength zone that existed at 0.1 to 0.2 m depths. Soil strength was affected by the interaction of both tillage and depth of measurement[22].

Soil strength has been shown to be an important soil physical property influencing root growth. In continuous long term studies on silty clay loam (Typic Haplaquoll) soil. The upper soil profile had shown greater impedance under conservation tillage (no tillage) than under conventional tillage (moldboard), soil strength was significantly higher in chisel plow and no-tillage treatments (1.43

and 1.53 MPa respectively) than moldboard plow treatment (1.21 MPa)[23].

Bauder *et al.* (1981) found that soil strength of clay loam soil was higher under no-tillage treatment than conventional tillage treatment. The higher soil strength was obtained above a depth of 0.40 m[24].

Izaurralde *et al.* (1986) reported that soil strength of Mollisol at 3 and 8.5 cm was significantly lower in moldboard treatment (0.86 and 4.18 MPa) than in no-tillage treatments (4.09 and 5.17 MPa)[25].

In a long term study on silt loam soil, Vyn and Raimbult (1993) found that no-tillage treatments significantly had the highest soil penetrometer resistance than moldboard. Significancy has disappeared at depths greater than 20 cm throughout the year. Also it was found that penetrometer resistance of the moldboard plow plots increased with depth at a slower rate than for the chisel plow plots[26].

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). But both systems had greater soil strength than conventionally tilled soils (45.5 and 63.8 KPa)[27].

Battikhi and Sulieman (1995), in a study of tillage and crop residue effect on soil strength of a Vertisol in Mushaqar Station, found that moldboard resulted in lower soil strength than chisel tillage, due to more surface loosening under moldboard plow treatments. Whereas, plant residues incorporation treatments had no direct effect on soil strength. But, immediate plant residues incorporation increases bulk density as result of more destroyed aggregates through wind effect, which results in decreasing macropores, and as a result soil strength increases under it. They also found that soil strength values were higher in summer after wheat season than in summer after lentil season(28).

Soil strength tends to increase as water content decreases. Besides, the straw mulch was effective in delaying the drying and development of soil strength(29). On the other hand, penetrometer resistance decreased by increasing soil moisture content at time of sampling(30).

2.5 Infiltration rate :

Water infiltration is a very changeable soil property, depending not only on a momentary condition, but also on every agro-technical operation. In addition, the infiltration is influenced by a number of other soil properties, namely : Texture; structure; pore-size distribution and aggregates stability. However, there are some favorable agricultural practices which influence infiltration such as limig crop rotation, and soil moisture(31).

The use of suitable tillage-plant residues management practices could improve some of soil physical properties especially infiltration rate and mechanical properties of soil surface[32].

Infiltration directly affects surface-water run off, soil erosion, soil water storage, and deep percolation. Factors that affect the infiltration rate include pore-size distribution, bulk density, structure, water content, chemical concentration, topography and biotic factors. Both soil and biotic factors can vary greatly in both space and time. So, it is also expected that infiltration would vary in both space and time[33].

Battikhi and Sulieman (1995), in a study on Vertisol found that the final infiltration rate was higher under moldboard than chisel in lentil season, while for the wheat season it was lower under moldboard than chisel. Whereas, dates of plant residue incorporation had no effect on final infiltration rate. Final infiltration rate in winter was approximately three to four times higher than in summer. And it was significantly lower in lentil season than in wheat season[34].

According to Abu-Hammad (1995), sweep tillage has a significant increase in basic infiltration rate (in summer season) than moldboard. It was found to be : 21 mm/hr for moldboard; and 27 mm/hr for sweep, in Mushaqar; and 22 mm/hr for moldboard; and 26 mm/hr for sweep, in Rabba. While immediate incorportaion of plant residues (R1), showed a significant increase in basic infiltration rate (in summer) over the late incorporation treatment (R2). It was found to be : 31 mm/hr for R1; and 21 mm/hr for R2, in Mushaqar; and 28 mm/hr for R1, and 18 mm/hr for R2, in Rabba(6).

In a study on two Paleustolls, it was found that water infiltration into no-till soil was significantly higher than plowed soil at similar water content(20). In another experiment on silt loam Typic Haploxerolls, 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(35).

Chang and Lindwall (1989), in a study on a dark brown Chernozemic clay loam soil, found that regardless of the tillage treatment, infiltration rate of the soil in summer was about ten times higher than that in the stubble field (0.2 mm/hr and 0.02 mm/hr, respectively). Also the basic infiltration was significantly lower (in Summer) in moldboard treatment than in no-till treatment (3.31×10^{-8} m/s and 8.20×10^{-8} m/s, respectively). While, there were no significant differences in basic infiltration rates between moldboard and minimum tillage treatments (3.31×10^{-8} m/s and 6.68×10^{-8} m/s, respectively)(36).

In a study on a clay loam soil, Unger (1992) found that the lowest initial infiltration rate values for dry run for no-till and moldboard (both with residues removed) were 73.2 and 79.2 mmh^{-1}, respectively. For sweep tillage with removed residue and no-till with residue left, the intermediate values were 81.9 and 81.7 mmh^{-1}, respectively. While the highest value (113.6 mmh^{-1}) was under sweep tillage with residues left in place treatments. On the other hand, for wet run initial infiltration rate values showed little variation for the different treatments (27.7 to 48.2 mmh^{-1}), with all values being less than the dry run. The final infiltration rate values for the dry run ranged from 2.7 mmh^{-1} for moldboard treatments to 3.3 mmh^{-1} for sweep tillage with residues left in place treatments. While for the no-till with residues removed it reaches 9.2 mmh^{-1}. Also the final infiltration rate reaches 26.3 mmh^{-1} for sweep tillage with residues left in place treatments, for the dry run. The final infiltration rate for the wet run did not differ greatly (5.9 mmh^{-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. The reason for obtaining these results was not clear[37].

Ghazy *et al.* (1988), in a study on Vertisols, found the following relationships between infiltration and soil physical parameters :

$$Y = 18.22 - 0.86\,X \qquad (r^2 = 44.89\%)$$

$$Y = 22.67 - 0.53\,X - 0.74\,X1 - 0.43\,X2 \qquad (r^2 = 84.64\%)$$

$$Y = 34.76 - 0.96\,X + 0.59\,X3 + 0.44\,X4 + 0.92\,X5 \quad (r^2 = 90.25\%)$$

Where :

Y = infiltration rate (mm/hr)

X = gravimetric moisture content (%)

X1 = clay contnet (%)

X2 = fine capillary pores (F.C.P.)

X3 = volume drainable pores (V.D.P.)

X4 = water stable aggregates (W.S.A.)

X5 = total porosity (T.P.)

From the results of stepwise analysis, it was concluded that the initial moisture content of the soil had a great influence on infiltration rate by 44.89%. Also infiltration rate is not only a function of porosity and texture, but also of soil structure(31).

Hamdi *et al.* (1988), in a study on Vertisol, had related the cumulative infiltrated depth with accumulated time. The relationship has been represented by different equations depending on crop type :

$$d = 0.78.T^{0.32} \qquad \text{(for cotton)}$$

$$d = 1.6.T^{0.38} \qquad \text{(for wheat)}$$

where :

d = cumulative depth (cm)

T = accumulated time (min)

الصفحة غير موجودة من أصل المصدر

Although effects of bulk density and distribution of water within the soil profile on the neutron calibration curve have been noted by several investigators, the data were limited to only a relatively few soils. Considerably more information on many field soils, covering a wide variety of soil physical conditions, is needed to further evaluate these effects[39].

According to Chanasky (1986), bulk density did affect calibration of neutron probe, but not enough to warrant calibration based on bulk density. On the other hand, a neutron probe should not be expected to measure either absolute amounts of soil moisture or changes in moisture content over a given time period accurately if the manufacturer's calibration is used[38].

In a study on five tropical ferrallitic soils, bulk density was found to have a significant effect on the neutron probe calibration. For 20 percent volumetric moisture content the count ratio changed from 0.568 for dry density of 1.0 gcm^{-3} to 0.943 with twice the value of soil density[40].

In a study on a Vertisol, Battikhi and Sulieman (1995), found that cracks around access tubes resulted in lower count ratio values than the real values since some of neutrons escape far away. It has been found that relationship between gravimetric soil moisture content and both bulk density and cracks volume are needed to calculate soil moisture parameters. Besides that a mathematical approach was created to correct the neutron probe readings that were taken when cracks were around acess tube as following :

$$CR_2 = 0.951 \times CR_1 + 0.03971 \times W \times CR_1 \qquad r^2 = 0.69$$

Where :

CR1, CR2 are the count ratio readings before and after filling the cracks, W is the width of crack or the summation of widths of cracks (cm) at the soil surface around the access tube[41].

3. Materials and Methods

3.1 Study Location :

To study the effect of different tillage-plant residues management practices on soil physical properties, the experiment was carried out at Maru Agricultural Research Station, located in the northern region of Jordan. The annual precipitation is about 400 mm, and latitude is 460m[2].

The soil was classified as : Fine, smectitic, thermic, typic chromoxerert[2]. The land slope was less than 6%.

3.2 Treatments and Experimental Design :

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

T1 : Moldboard, sweep and drill before rainfall.

T2 : Chisel, sweep and drill before rainfall.

Sweep plow was 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.

Residue treatments for wheat phase only, were as follows :

R1 : Residues incorporation in August. (after harvesting, baling, and grazing for about one month).

R2 : Residues incorporation in October. (after harvesting, baling and grazing for about one month).

The combinations of these different tillage-residues treatments (T1R1, T1R2, T2R1, T2R2) were arranged in a factorial randomized complete block design (RCBD) with three replications (Blocks). Size of each plot was 10m x 15m as shown in Fig. 1. Treatments of tillage-plant residues incorporation were applied for wheat, lentil and melon in a three course rotation. The wheat-lentil part was studied within this rotation, the previous crop was wheat.

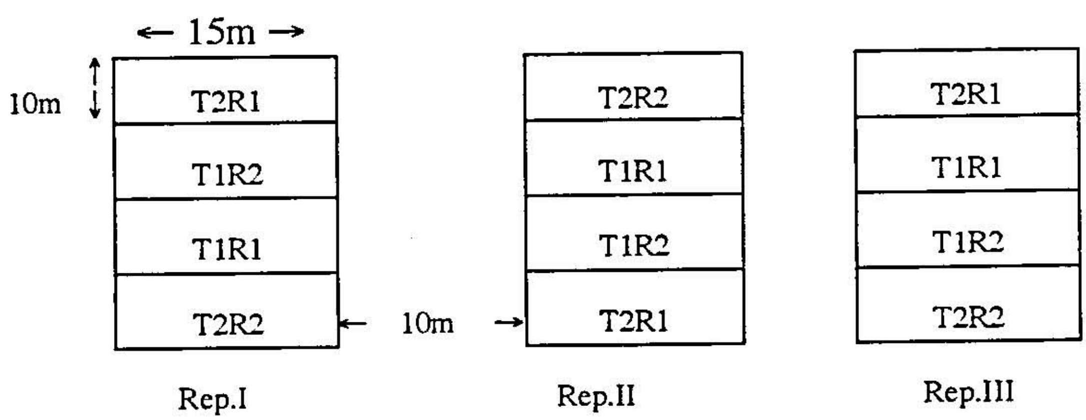

Fig. 1 Experimental layout at Maru Agricultural Research Station.

The four treatments were fertilized by a constant rate of triple superphosphate (4.5 kg P_2O_5/du), for the two crops at sowing time, using band application. While a constant rate of urea (7.5 kg/du) was used for wheat crop. Seeding rate was 10 kg/du for wheat

"Deir-Alla 6" and lentil "Jordan 3". Planting was carried on first of November using sowing drill, with row spacing of 17.5 cm, and depth of 8cm for the two crops.

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

3.3 Measurements of Soil Physical Properties :

3.3.1 Soil Strength :

Soil penetrability was measured using hand pocket penetrometer as described by Bradford[42]. Soil strength was measured at depths of 5, 10, 15 and 20cm with three measurements for each plot. Measurements were taken throughout the growing seasons for wheat and lentil (from 26 March 1994, to 7 June 1995).

3.3.2 Infiltration rate measurement

Infiltration rate was measured using the double ring infiltrometer method as described by Bouwer[42]. The internal diameters of the outer and inner ring were 30 and 20 cm, respectively. Both rings were pushed 7 to 10 cm into the soil inter cracks, providing a tight fit between ring and soil. During infiltration, the depth of ponding water (h) was allowed to vary from 10 to 4 cm. Places in which infiltration measurements were made, were free from surface cracks.

Infiltration measurements were taken on different dates from 26 March 1994, to 7 June 1995. An undisturbed soil core were taken from each plot to a depth of 10 cm at the same time of measuring soil infiltration and soil strength. Bulk density was determined, using core method as described by Blake and Hartage[44], also gravimetric soil moisture content of these samples were determined.

3.3.3 Neutron Probe Evaluation :

Soil moisture measurements were carried using the neutron probe device (Hydroprobe, Model 503). Measurements were taken at depths of 7.5, 22.5, 45, 75 and 105cm, representing the whole 120 cm soil profile. In addition, gravimetric method was used to check on neutron probe readings for surface layer. A 120 cm long, steel galvanized access tube was installed into a hole dug by a two inch diameter (ID) auger in each treatment.

Calibration curves for the five soil layers were drawn by correlating soil moisture counts of neutron probe with gravimetric soil mositure samples at different times of the season, to guarantee a wide range of soil moisture with different counts. The linear regression analysis technique was used to calculate the calibration curve equation for each soil layer[9].

Neutron probe readings were taken weekly in winter and after each rainfall incident. While at summer time, a reading every two weeks was taken.

To evaluate neutron probe results, the following procedure was done :

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

2. Different crack parameters (length, width and depth) which occured 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 (about 4.2 cm internal diameter and 4.8 cm long) were taken from soil surface layer for each plot[18] in July, 1994 (after wheat harvesting), December, 1994 (after planting of lentil), and in June 1995 (after lentil harvesting). These samples were used to study the follwoing : Soil moisture characteristic curve; subsidence, ΔZ; bulk density, B; shrinkage characteristic, m; cracks volume, Vcr; coefficient of linear extensibility, COLE; soil porosity, P; macroporosity, MA; and microporosity, MI.

Soil moisture characteristic curves were made by using ceramic plate extraction method as described by Klute[45], at tensions of 0.1, 0.2, 0.3, 0.5, 0.6, 0.7, 1, 3, 5, 8, 11, and 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 core at the above tensions was measured at ten random positions using a caliber (± 0.05mm). The ten readings were averaged and isotropic shrinkage was assumed so ΔZ can be related directly to changes in bulk volume[16, 17, 19, 46, 47].

Finally, three composite soil samples were collected from surface layer from each plot before harvest for both wheat and lentil seasons. Those samples were prepared for wet sieving procedure to determine aggregate size distribution as described by Kemper and Chepil[48].

3.4 Calculations :

3.4.1 Soil moisture parameters.

ETc = Σ[Decrease in soil moisture ($-\Delta S$)] + Σsoil moisture stored and then depleted during rainy days (from planting to harvest) (mm) ....(1)

SMS = Σ[Increase in soil moisture ($+\Delta S$)] + Σsoil moisture stored and then depleted during rainy days (from first rainfall event to last rainfall event during the winter season) (mm) ....(2)

Where :

ETc : crop evaportranspiration (mm).

SMS : soil moisture storage from rainfall (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.

The value of ΔS depends on the value of the two readings. of neutron probe. When ΔS is a positive value, this means that soil has stored moisture from rainfall and in this case the value of ΔS is used in the calculation of SMS. While, when ΔS is a negative value, this means that moisture has been depleted and in this case ΔS is used in ETc calculations.

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

$$ETc^* = Ep \times Kp \times Kc \quad \text{.......(3)}$$

Where :

ETc* : crop evapotranspiration druing a certain period (mm).

Ep : class A pan evaporation (mm).

Kp : pan coeffecient, depending on wind velocity, relative humidity, and location of the pan FAO[49].

Kc : crop coeffeient, FAO[49].

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 rainy days was taken over the whole winter season (from planting to last rainfall event).

3.4.2 Shrinkage inflection points.

Two parameters are used to represent the shrinkage of soil. The first parameter is the shrinkage characteristic, m, which is defined as the volume changes of soil with changing water content. The second parameter is the volume of cracks which equals to the difference between three dimensional volume changes and change in layer thickness[16, 46].

$$m = \frac{\partial Vs}{\partial Vw} \quad \text{.......(4)}$$

Where Vs is the volume of the soil and Vw is the volume of soil water[16].

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

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

Where ΔV is the decrease in volume of the soil per unit area (m) and ΔZ is the decrease in layer thickness (m)[46, 47].

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

Where ΔW is the water loss per unit area (ΔW has a dimension of length)[16].

$$V_{cr} = \Delta V - \Delta Z \quad \text{.........(6)}$$

Where Vcr is the cracks volume[16].

$$COLE = \left(\frac{B1}{B2}\right)^{\frac{1}{3}} - 1 \quad \text{.........(7)}$$

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

$$R = \frac{\sum_{n=0}^{N} V_n \cdot r_n}{\sum_{n=0}^{N} V_n} \quad \text{.........(9)}$$

Where R is the average macro or micro pore (μm), Vn is the volume of water released at a suction for which the corresponding radius is r_n, and r_N is the pore radius corresponding to 60 cm suction (with the assumption that all the macropores are desorbed at 60 cm suction)[50].

The pore radii for different values of suction calculated by utilizing the capillary rise equation :

$$r = \frac{2t\,Cos\theta}{hpg} \quad \text{...}(10)$$

Where :

r : is the pore radius (cm).

t : is the surface tension of water, dynes cm^{-1}.

θ : is the contact angle, which was taken equal to 0.

h : is the suction, cm of water.

g : is the acceleration due to growing, cm sec^{-2} and

P : is the density of water, gcm^{-3}(50).

4. Results and Discussion

4.1 Soil Surface Moisture Content :

Mean separation for gravimetric soil moisture content (θg), in different tillage-residue treatments for both wheat and lentil seasons (Table 1), shows that chisel plow treatment combined with early incorporation (T2R1) had significantly higher gravimetric soil moisture content than other treatments in May for wheat season and in December for lentil season. Plots of T2R2, on the other hand, attained significantly higher gravimetric soil moisture content in January for lentil season.

Plots of T1R1 attained significantly higher gravimetric soil moisture content than other treatments in October for wheat season. While, plots of T1R1 and T1R2 attained significantly higher gravimetric soil moisture content than other treatments in March for lentil season. Finally, treatment T1R2 had significantly higher gravimetric soil moisture content in February and June for lentil season.

It is believed that chisel tillage operation retains higher soil moisture content than that of moldboard conventional tillage[51]. This is valid when soil is wet; because in this case soil moisture retention depends greatly on macropores volume rather than total porosity. The average macropore radius (table 2) was significantly higher under T2R2, T1R2 and T2R1 than T1R1 in wheat season and so, higher gravimetric soil moisture content was attained under T2R1 in May, and under plots of T2R2 and T2R1 in March for wheat season.

Table 1 : Mean separation for soil surface gravimetric moisture content (θg), in different tillage-residue management treatments.

Year	Season	Month (Year)	θg (%)			
			T1R1	T1R2	T2R1	T2R2
1994	Wheat	3	+30.5b	29.8c	32.1a	31.7a
		4	25.4ab	25.1b	25.9a	23.9c
		5	17.6b	17.5b	19.4a	15.0c
		7	13.5ab	13.5ab	13.9a	12.9b
		10	14.4a	11.8b	12.0b	12.5b
	lentil	12(1994)	39.5c	40.9b	41.9a	40.5b
1995		1	40.8b	41.2b	41.6b	42.6a
		2	35.8b	39.6a	38.8b	34.9c
		3	30.6a	30.0ab	29.8b	28.6c
		4	22.9b	24.1a	23.8a	21.7c
		6	12.6c	13.9a	13.2b	11.9d

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

For lentil season, treatments of T2R2 and T1R2 attained significantly higher macropores volume and significantly higher gravimetric soil moisture content was obtained under plots of T2R2 than other treatments in January. The same trend was noticed for T1R2 treatment which had higher macropores volume than T2R1 and T1R1 for lentil season, and so higher gravimetric soil moisture content under plots of T1R2 than other treatments was obtained in February and June.

Table 2 : Mean separation for average macropore radius (MA) and micropore radius (MI), in different tillage-residue management treatments.

Crop (Year)	MA (μm)				MI (μm)			
	T1R1	T1R2	T2R1	T2R2	T1R1	T1R2	T2R1	T2R2
Wheat (1994)	+19.5b	23.7a	23.3a	23.7a	2.48a	2.32c	2.33bc	2.40b
Lentil (1995)	21.4c	24.6a	23.5b	25.2a	2.42a	2.36b	2.36b	2.25c

MA : Soil macropore radius; MI : Soil micropore radius.
\+ : Along rows for each parameter, means with the same letters on the right side of number are not significantly different at the 5% probability level of the t-test.

As the soil dries out the moisture content depends greatly on the portions of soil total porosity and micropores. The average micropores volume for wheat season was significantly higher under moldboard plow combined with early incorporation of residue (T1R1) than other treatments so, higher gravimetric soil moisture content was attained under this treatment for October in wheat season. This is mainly because moldboard plow causes more destruction for soil surface structure and results in greater micropores volume than chisel. Therefore, the gravimetric soil surface moisture content was significantly higher under moldboard plow combined with either early or late incorporation of residue than under other treatments as the soil becomes drier.

In addition, plots of early residue incorporation combined with moldboard are subjected to clods breakdown by further weathering that causes more destruction for surface leading to low macropores volume and higher micropores volume that lead to higher soil moisture retention when soil becomes dry.

Another possible factor that contribute to soil moisture retention is the soil moisture content at time of plowing[36]. This factor seems to have had no contribution to the above results; since the treatments were ploughed at relatively low values of soil moisture content values.

4.2 Bulk Density of the Soil Surface :

Mean separation for bulk density (Table 3), shows that plots of T2R2 and T1R1 attained significantly higher bulk density than the other treatments for wheat season. While, for lentil season plots of T2R2 attained significantly higher bulk density than other treatments in April and June, while in March plots of T2R1 attained significantly higher bulk density than other treatments.

Table 3 : Mean separation for bulk density of soil surface at depth of 10 cm, in different tillage-residue management treatments.

Year	Crop	(Month)	Bulk Density (g/cm^3)			
			T1R1	T1R2	T2R1	T2R2
1994	Wheat	3	+0.88a	0.81b	0.81b	0.89a
		4	0.97a	0.92b	0.90b	0.95a
		5	1.13a	1.08b	1.14a	1.15a
		7	1.25a	1.16b	1.23a	1.26a
		10	1.18b	1.20b	1.24a	1.12c
1995	Lentil	12	0.85	0.82	0.85	0.83
		1	0.76a	0.78a	0.72b	0.78a
		2	0.78	0.79	0.80	0.84
		3	0.85c	0.93b	1.05a	0.80d
		4	0.99b	0.96b	0.94b	1.06a
		6	1.17ab	1.13c	1.16b	1.19a

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

In general moldboard tillage destroys soil surface structure more than chisel tillage causing more loosening for soil surface, while reduced soil disturbance under conservation tillage system may increase impedance within surface soil layer[23]. So, plots of chisel plow combined with late incorporation (T2R2) had significantly higher bulk density of surface soil layer than other treatments in April and June for lentil season. Also, the same effect resulted in significantly higher bulk density under plots of T2R2 than plots of T1R2 in May and July for wheat season.

Another important factor than contributes to the obtained results is soil moisture content and its effect on shrink-swell of soil. Soil shrink-swell will, in turn, affects soil bulk density. This effect was attributed to lower bulk density of T1R2 treatment in May and June for wheat season. Plots of T1R2 in those months attained significantly lower soil moisture content than plots of T2R1(section 4.1) and so, significantly higher bulk density than other treatments in May and June for wheat season.

The effect of soil moisture content on bulk density can be noticed at higher soil moisture content, i.e when soil is swollen, and this effect tends to be reduced when soil moisture content decreases, i.e when soil is shrunk.

In addition, the significantly higher bulk density values under early incorporation can be related to soil shrinkage. Late incorporation of residue tends to has more stable aggregates and higher void space than early incorporation of residue and so lower shrinkage(16).

4.2.1 Linear Relations between Bulk Density and Soil Moisture Content for Field Study.

A linear regression analysis has been made between soil moisture content and soil bulk density. The regression (as shown in Fig.2) shows highly significant relationships between soil moisture content (%) and bulk density (g/cm^3) in the different treatments for both wheat and lentil seasons. The following equations were found :

For both seasons :

$B = 1.36 - 0.015\theta g$ $\quad\quad r^2 = 0.89$

For wheat season :

$B = 1.47 - 0.020\theta g$ $\quad\quad r^2 = 0.92$

For lentil season :

$B = 1.32 - 0.013\theta g$ $\quad\quad r^2 = 0.88$

From the above equations, it is noticed that a slightly higher correlation between bulk density and soil moisture content is found under wheat season than lentil season. Also, changes of bulk density upon changing soil moisture content is expected to be higher under wheat than lentil. Bulk density values are expected to be higher under wheat than lentil at same soil moisture contents.

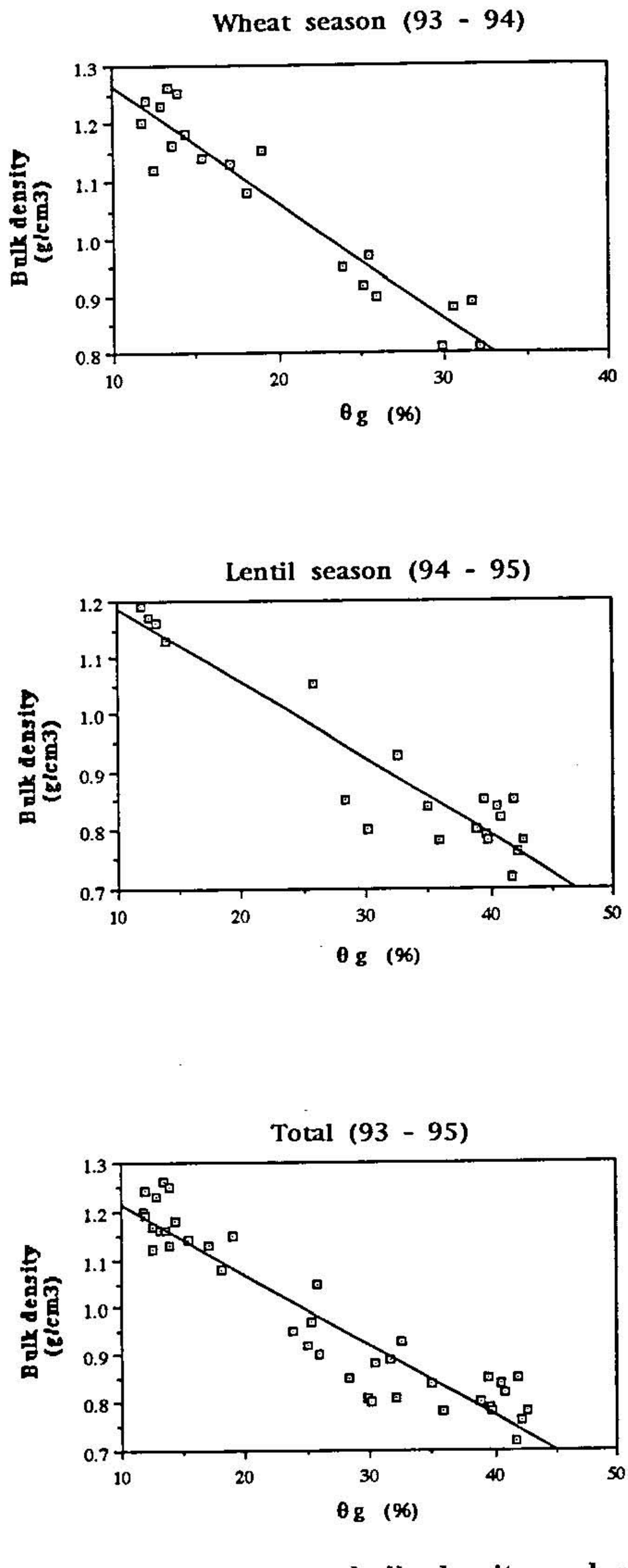

Fig. 2 : **Relationships between bulk density and soil moisture content (θg) for wheat-lentil seasons.**

4.3 Soil Strength :

Mean separation (Table 4) shows that plots of T2R1 had significantly higher soil strength than plots of T1R2 at depths of 10 and 15 cm in March and May for wheat season. While for lentil season, in January plots of moldboard combined with early incorporation had significantly higher soil strength, at depths of 5, 10 and 20 cm than plots of chisel plow combined with late incorporation of residue.

In June, on the other hand, plots of chisel plow combined with early or late incorporation had significantly higher soil strength at depths of 5 and 10 cm than those of moldboard combined with early incorporation.

Table 4 : Mean separation for soil strength at depths of 5, 10, 15 and 20 cm, in different tillage-residue management treatments.

Year	Crop	Month	Depth cm	Soil Strength (MPa) T1R1	T1R2	T2R1	T2R2
1994	Wheat	3	5	c0.71	0.72	0.77	0.99
			10	b1.29ab	1.16b	1.40a	1.27ab
			15	ab1.41ab	1.27b	1.47a	1.43ab
			20	a1.58	1.50	1.59	1.49
		5	5	d1.17	1.17	1.10	1.01
			10	c2.49ab	2.20b	2.96a	1.84b
			15	b4.02ab	4.36ab	4.74a	3.79b
			20	a4.77	5.02	4.95	4.89
1995	Lentil	1	5	d0.46a	0.33ab	0.39ab	0.30b
			10	c0.75a	0.72ab	0.71ab	0.61b
			15	b0.86	0.87	0.88	0.76
			20	a1.05a	0.89b	0.89b	0.96ab
		6	5	c1.36b	1.62ab	1.99a	1.92a
			10	b3.03b	3.52ab	4.15a	3.88a
			15	a4.92	4.93	4.95	4.94
			20	a5.25	5.25	5.25	5.25

*: 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.

Moldboard plow causes more surface loosening for soil surface than chisel plow, while reduced soil disturbance under conservation tillage system may increase impedance within soil surface(23). This effect resulted in higher soil strength under chisel plow treatments combined with early incroporation than plots of moldboard combined with late incorporation in March and May for wheat season, and significantly higher soil strength under plots of T2R1 and T2R2 than plots of T1R1.

Another factor that contributes to the obtained results is the soil moisture content at time of measurements(26). Moldboard plow combined with early incorporation had significantly lower soil moisture content and subsequently higher soil strength than chisel plow combined with late incorporation, in June for lentil season. In addition, plots of moldboard plow combined with early incorporation of residue are subjected for more surface structure deterionation since they were plowed two months earlier and this, in turn, will lead to higher shrinkage(16) that will lead to higher soil strength.

From Table 4, one can notice that soil strength had increased significantly with depth in all months. Also, it is noticed that 5 cm increment was enough to show significant differences in soil strength between depths at relatively high soil moisture content.

Finally, there were no significant differences between soil strength values at depths of 15 and 20 cm when soil become at relatively low soil moisture content (July 1994, and June 1995), and this can be attributed to high shrinkage of soil at low soil moisture content. This shrinkage causes layers merging and therefore increases soil strength. Soil strength at 15 cm depth did not differ significantly from that at 20 cm depth, i.e significance tends to disappear at a depth greater than 15 cm. Besides, the results show that soil strength of moldboard treatment combined with late incorporation of residue increased at depth of 10 cm at a slower rate than that for chisel plow combined with early incorporation of residue[26].

4.3.1 Relations between Soil Strength and Soil Moisture Content and Bulk Density

A regression analysis has been made between soil strength (SS) and gravimetric soil moisture content (θg) and between soil strength and soil bulk denstiy (B) for both wheat and lentil seasons. The following equations were found :

<u>For wheat season :</u>

a. Soil strength (SS) and gravimetric soil moisture content (θg) (Fig. 3) :

- at 5 cm depth :
  $SS = 1.82 \times 10^{(-0.012\theta g)}$ $\quad r^2 = 0.78$
- at 10 cm depth :
  $SS = 5.59 \times 10^{(-0.02\theta g)}$ $\quad r^2 = 0.84$
- at 15 cm depth :
  $SS = 12.38 \times 10^{(-0.028\theta g)}$ $\quad r^2 = 0.93$
- at 20 cm depth :
  $SS = 12.36 \times 10^{(-0.026\theta g)}$ $\quad r^2 = 0.84$

b. Soil strength (SS) and bulk density (B) (Fig. 4) :

- at 5 cm depth :
  $$SS = 0.31 \times 10^{(0.51B)} \qquad r^2 = 0.68$$
- at 10 cm depth :
  $$SS = 0.23 \times 10^{(0.92B)} \qquad r^2 = 0.81$$
- at 15 cm depth :
  $$SS = 0.14 \times 10^{(1.30B)} \qquad r^2 = 0.86$$
- at 20 cm depth :
  $$SS = 0.22 \times 10^{(1.16B)} \qquad r^2 = 0.75$$

For lentil season :

a. Soil strength (SS) and gravimetric soil moisture content (θg) (Fig. 5) :

- at 5 cm depth :
  $$SS = 3.46 \times 10^{(-0.023\theta g)} \qquad r^2 = 0.92$$
- at 10 cm depth :
  $$SS = 7.88 \times 10^{(-0.025\theta g)} \qquad r^2 = 0.95$$
- at 15 cm depth :
  $$SS = 11.36 \times 10^{(-0.026\theta g)} \qquad r^2 = 0.95$$
- at 20 cm depth :
  $$SS = 12.26 \times 10^{(-0.026\theta g)} \qquad r^2 = 0.92$$

b. Soil strength (SS) and bulk density (B) (Fig. 6) :

- at 5 cm depth :
  $$SS = 0.027 \times 10^{(1.52B)} \qquad r^2 = 0.77$$
- at 10 cm depth :
  $$SS = 0.043 \times 10^{(1.62B)} \qquad r^2 = 0.77$$

- at 15 cm depth :

$$SS = 0.049 \times 10^{(1.70B)} \qquad r^2 = 0.75$$

- at 20 cm depth :

$$SS = 0.064 \times 10^{(1.62B)} \qquad r^2 = 0.71$$

From the above relations it is noticed that soil strength increases as depth of measurement increases. Also, soil strength decreases as soil moisture increases, but the decrease in soil strength is not linear.

The effect of crop type on soil strength can be noticed from the above relations and from the values of r^2.

Soil strength under wheat is less than that under lentil at the same soil moisture content for all depths of measurement. This may be attributed to the root system of lentil which is concentrated in the surface layer, which may cause more anchoring for soil and in turn higher resistance to penetration. Also, the correlation between soil strength and gravimetric soil moisture content was higher under lentil than wheat.

Correlation between soil strength and bulk density was higher at depths 10, 15 and 20 cm for wheat season than lentil, while at 5 cm depth higher correlation was obtained under lentil.

Finally, the correlation between soil strength and both soil moisture content and bulk denstiy tends to increase as depth of measurement increase until the depth of 20 cm where it decreases.

This decrease in correlation for the depth of 20 cm is probably due to the value of gravimetric soil moisture content. Since the value of soil moisture content and bulk density for soil surface used in correlation represent the upper soil layer (0 - 15 cm) and may not represent the correct value at depth of 20 cm.

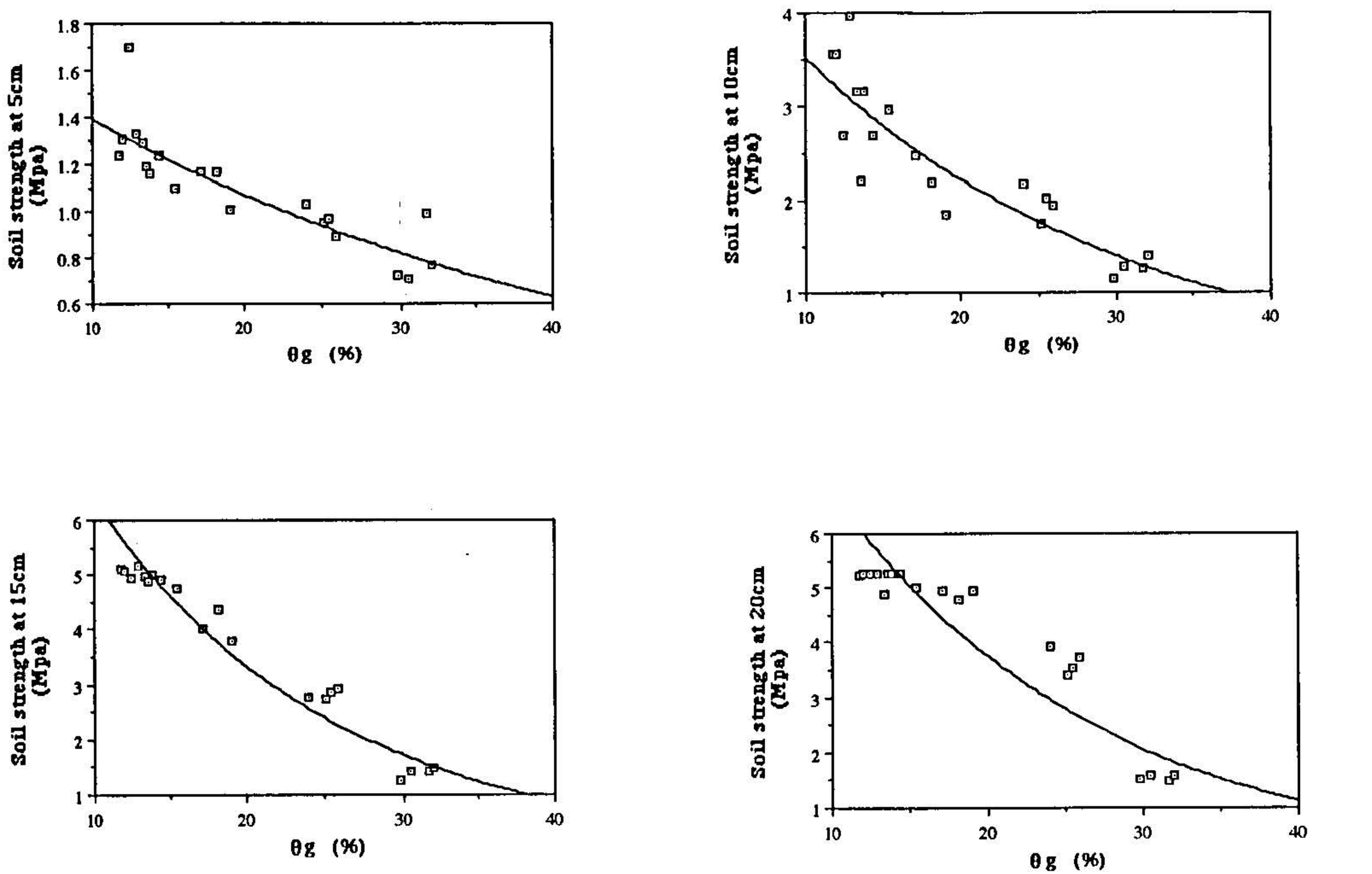

Fig. 4: **Relationships between soil strength and soil bulk density, at depths of 5, 10, 15, and 20 cm for wheat season (1993 - 1994).**

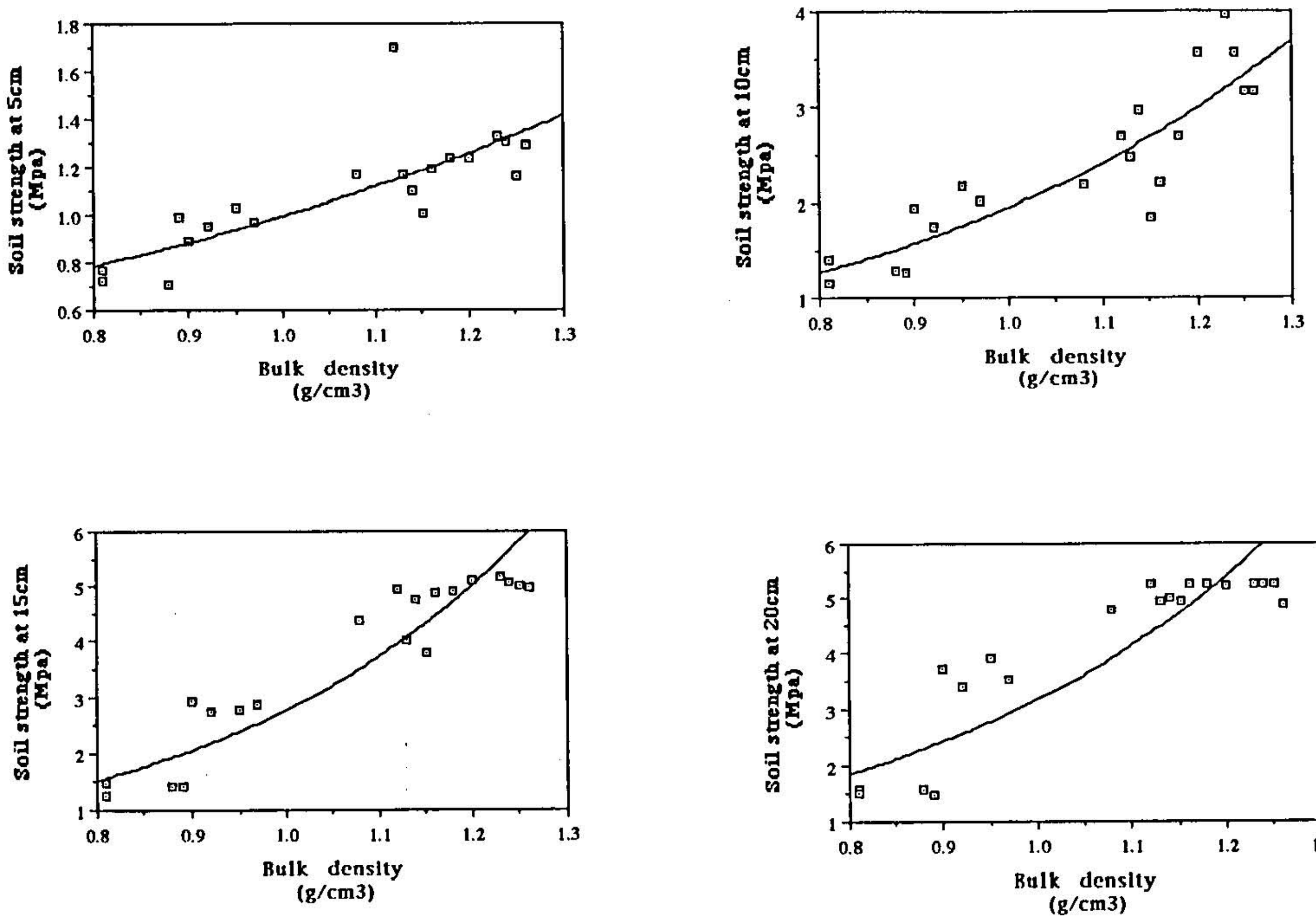

Fig. 4: Relationships between soil strength and soil bulk density, at depths of 5, 10, 15, and 20 cm for wheat season (1993 - 1994).

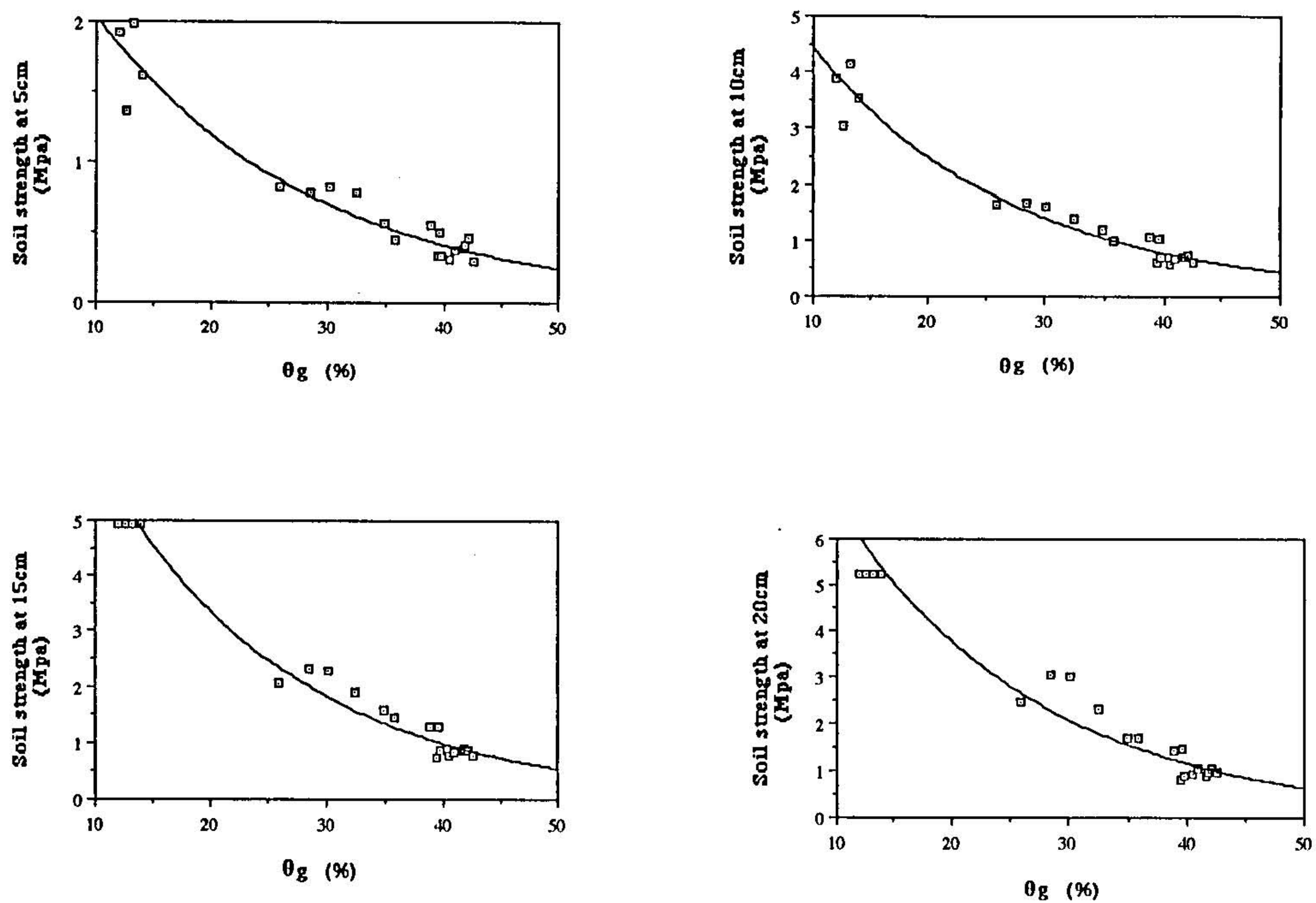

Fig. 5: **Relationships between soil strength and gravimetric soil moisture content, at depths of 5, 10, 15, and 20 cm for lentil season (1994 - 1995).**

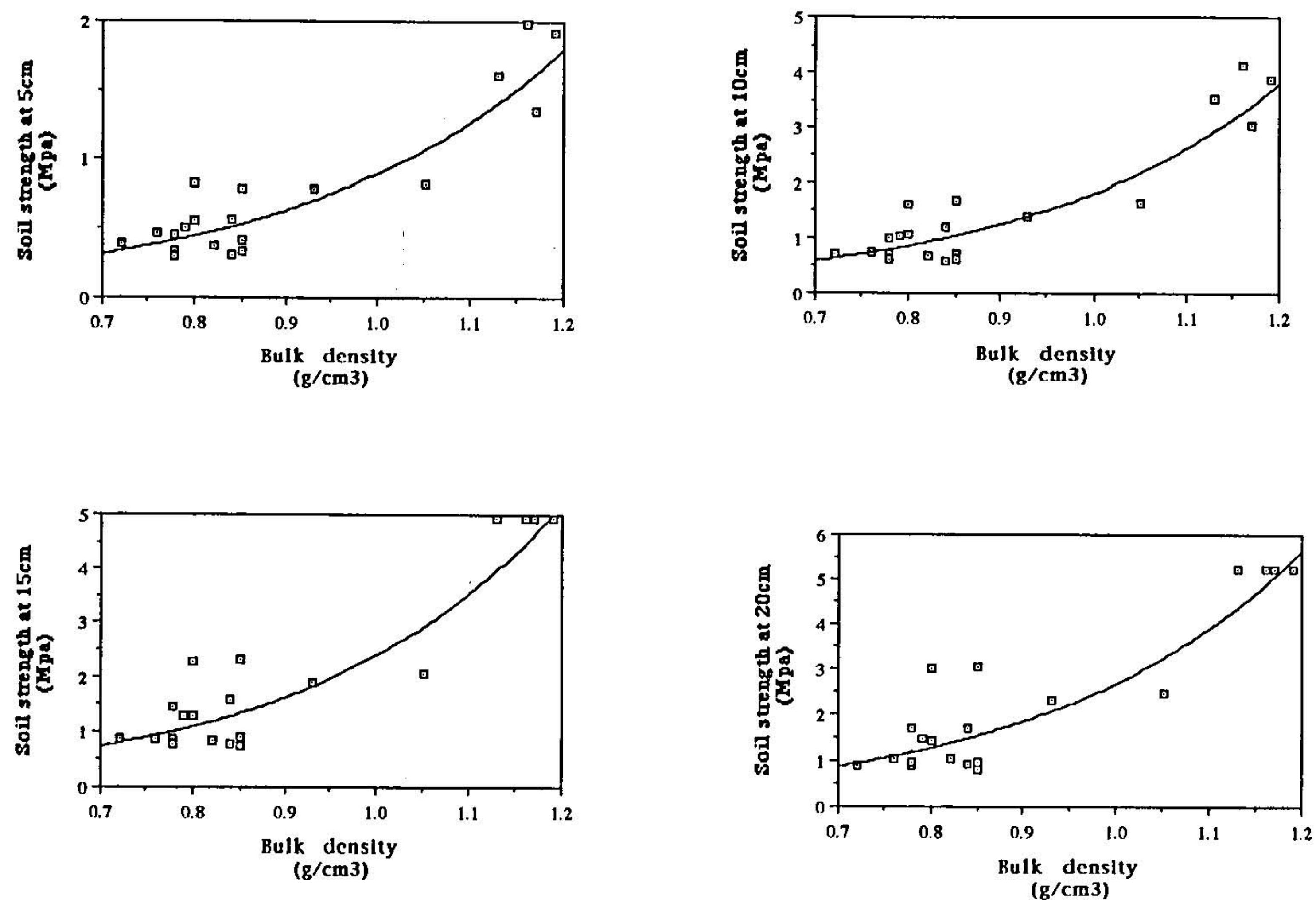

Fig. 6: Relationships between soil strength and soil bulk density, at depths of 5, 10, 15, and 20cm for lentil season (1994 - 1995).

4.4 Infiltration Rate :

Mean separation (Table 5) for initial infiltration rate at 5 minutes elapsed time, shows that moldboard plow combined with early incorporation of residue had significantly higher initial infiltration rate than plots of chisel plow combined with early or late incorporation of residue in March, April, May and June for wheat season, and in December for lentil season. Plots of T2R2, on the other hand, had significantly lower initial infiltration than other treatments in January.

Table 5 : Mean separation for initial infiltration rate (5 min.), in different tillage-residue management treatments.

Year	Season	Month	Initial infiltration rate (cm/hr)			
			T1R1	T1R2	T2R1	T2R2
1994	Wheat	3	*a27.4a	23.0ab	21.4b	20.2b
		4	a25.8a	21.7b	20.0b	20.8b
		5	b12.2a	11.9ab	10.5bc	10.1c
		7	b13.6a	13.2a	11.0b	12.8ab
		10	b10.6	9.8	10.4	10.5
1995	lentil	12	ab27.7a	25.5ab	21.7bc	22.9b
		1	ab27.9a	28.7a	26.5a	21.7b
		2	a32.8	34.0	32.0	32.2
		3	bc21.2	20.4	19.0	20.2
		4	c13.0	13.6	11.4	13.8
		6	c14.8	15.6	14.4	12.4

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

Tillage may increase infiltration when it loosens soil surface, disrupts dense soil layer, or provides surface depressions for temporary storage of water. It may also decrease infiltration when smoothes the surface, disrupts aggregates, eliminates surface residues, or causes compaction(37).

Moldboard tillage resulted in greater soil surface loosening than did chisel(51). Infiltration research implied that surface effects are more important than underlying soil properties during short term infiltration(22). This fact contributes to the higher initial rate under moldboard plow combined with early incorporation of residue. Soil surface loosening cause aggregate disruption and so, increases fine soil material that has higher water sorptivity especially when soil is dry.

In addition, early incorporation of residue by moldboard causes more surface deterioration, and fine material is dominated. So, higher initial infiltration rate was obtained under T1R1 treatments for wheat season. For lentil season, this effect was reduced by residue cover on soil surface, since lentil was planted after wheat where a considerable amount of residue was available. The residue cover may protect soil surface from deterionation and disintegration.

The results also indicated that initial infiltration rate was significantly higher in winter than in summer for the two seasons. The above results can be explained by soil shrink-swell capacity and its relation with soil porosity. Volume changes of the soil fabric result in changes of the nature and quantity of pore space[17]. Soil total porosity after drying excluding cracks volume is always lower than initial total porosity[52]. This was the case in summer where infiltration measurements were made when soil was highly shrunk. Shrinking process in this case had lead to low soil total porosity and so low initial infiltration rate.

On the other hand, higher soil moisture content in winter means highly swollen soil with higher total porosity that results in increasing infiltration rate. It should be noticed that higher total porosity doesn't necessarily mean an increase in macroporosity. But, increased infiltration has been associated with increased soil porosity[20].

Mean separation for basic infiltration rate (Table 10) shows that tillage, residue, and tillage-residue interaction had no significant effect with respect to basic infiltration rate. Also, there were no significant differences between summer and winter with respect to basic infiltration rate.

In general, basic infiltration rate doesn't differ significantly under tillage system combined with residue incorporation. But, in most cases basic infiltration rate was shown to be higher under conservation tillage than conventional tillage[22, 33, 36].

Mean weight diameter (MWD) was significantly higher for plots of late incorporation of residue combined with moldboard or chisel plow for both seasons (table 7). This may indicate higher aggregate stability under those treatments. but, the differences in mean weight diameter did not cause significants differences in basic infiltration. So, aggregate stability seems to have low effect on basic infiltration rate in our study case. Also there was no significant differences between the two seasons with respect to MWD, showing that crop type had no significant effect on soil aggregate stability.

Table 7 : Mean separation for mean weight diameter in different tillage-residue management treatments.

Season	Mean weight diameter (mm)			
	T1R1	T1R2	T2R1	T2R2
Wheat	+0.57c*	0.95a	0.76b	0.90a
Lentil	0.59c	0.81ab	0.69bc	0.88a

\+ Along rows, means without letters 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.

Although aggregate stability, may contribute to basic infiltration rate, but its effect did not give significant differences with respect to basic infiltration rate, and there was no conclusive evidence that it was the dominant soil factor, that may control basic infiltration rate.

Another factor that contributes to the results is the disintegration of aggregate and translocation of fine soil particles from soil surface, and this will result in decreasing infiltration rate(37), and this was the case under moldboard plow combined with early incorporation of residue, where fine soil material is expected to form impermeable material below soil surface that decreases basic infiltration rate.

Finally, higher infiltration rate values obtained in both wheat and lentil seasons can be explained by two main factors : Soil cracking; and crop effect. In the dry state different cracks are formed, those cracks are refilled with loose material that cause infiltration rate to be relatively high even when soil becomes moist. This may demonstrate the beneficial effect of cracking on water infiltration(53). Plant roots, on the other hand, influence preferential flow because continuous macropores can be created when roots dessicate or decomposed(54). Macropores formed by crop roots highly influence infiltration rate and tends to increase infiltration rate(55).

4.4.1 Linear Relationships between Initial Infiltration Rate and Gravimetric Soil Moisture Content :

A regression analysis was made to correlate infiltration rate and gravimetric soil moisture content. It was found that there was no correlation between basic infiltration rate and gravimetric soil moisture content, while there was a linear relationship between initial infiltration rate (IR) and gravimetric soil moisture content (θg), and between initial infiltration rate (IR) and soil bulk density (B). The following relationships were found :

a. For wheat season (Fig. 7) :

$IR = 1.16 + 0.74\theta g$ $\quad r^2 = 0.86$

$IR = 53.62 - 35.5B$ $\quad r^2 = 0.85$

b. For lentil season (Fig. 7) :

$IR = 5.11 + 0.54\theta g$ $r^2 = 0.64$

$IR = 59.44 - 41.35B$ $r^2 = 0.67$

Where IR is the initial infiltration rate (cm/hr).

It was found that higher correlation was obtained under wheat season. Also, from the equations it is noticed that the changes of initial infiltratin rate upon changing of soil moisture content is higher under wheat than lentil.

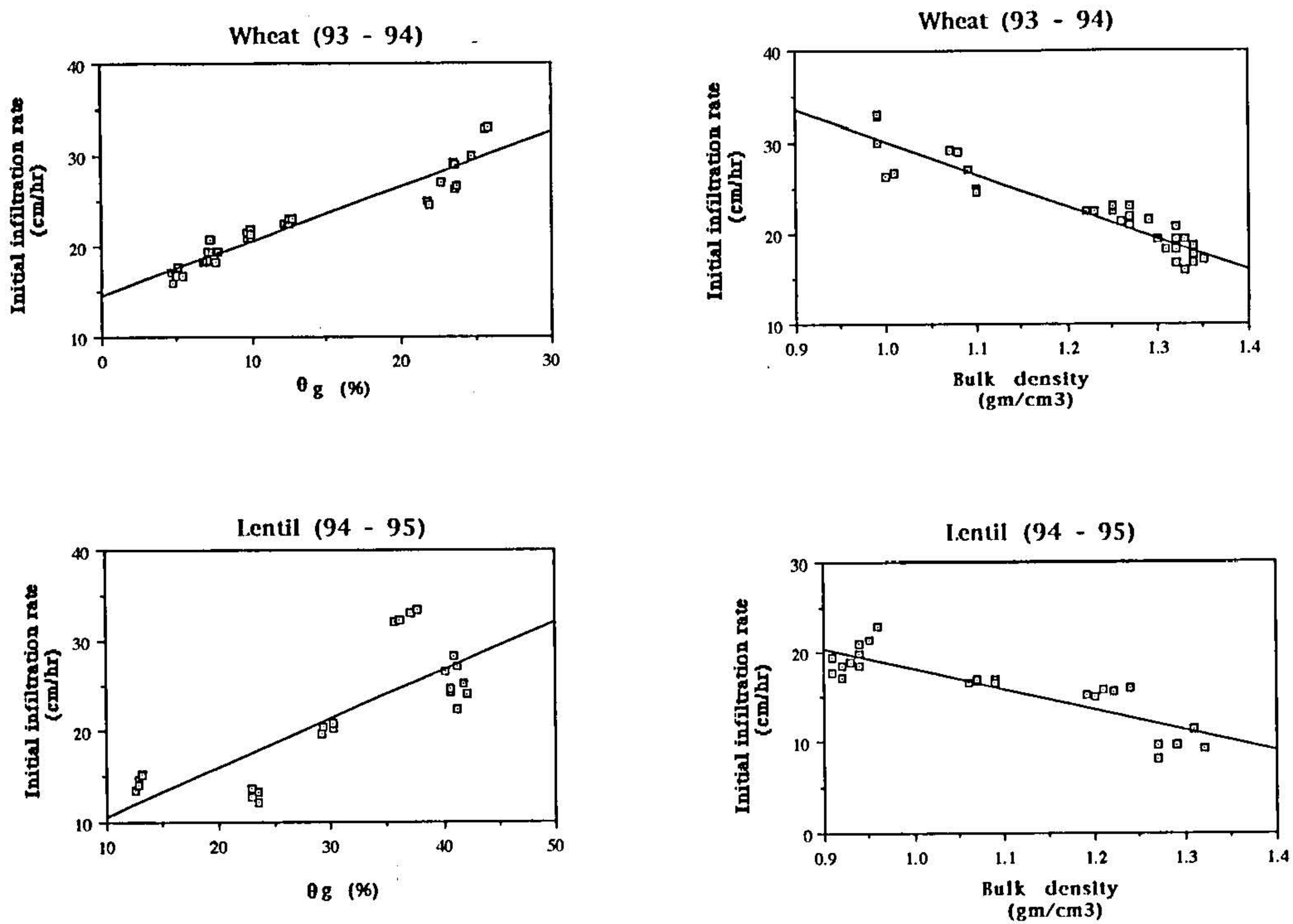

Fig. 7: **Relationships between initial infiltration rate and both: gravimetric soil moisture content; and soil bulk density for wheat and lentil seasons.**

4.5 Neutron Probe readings evaluation :

1. Soil Moisture Parameters :

Soil moisture storage from raifall, SMS, and crop evapotranspiration, ETc, were calculated by two different methods to be compared between the different tillage-residue treatemtns.

In the first method one value of bulk density (in dry run) was used to calculate the volumetric soil mositure content. While in the second method bulk density value varied depending on soil moisture content.

Relationships between gravimetric soil moisture content of soil surface (section 4.3) were used for each season. The same procedure was considered for subsurface layers.

Mean separation for ETc and SMS (Table 8), shows that for wheat season there were no significant differences between the different treatment with respect to ETc when the first method was used. While when the second method was used, plots of T2R1 and T2R2 attained significantly higher ETc than other treatments.

For lentil season, plots of T2R2 and T2R1 attained significantly higher SMS than other treatments for both methods of calculation. Also, plots of T2R1 attained significantly higher ETc than other treatements for both methods of calculation.

Table 8 : Mean separation for soil moisture parameters (SMS and ETc) which were calculated by two different methods in different tillage-residue management treatments for wheat and lentil seasons.

Season	Method	ETc (mm)				SMS (mm)			
		T1R1	T1R2	T2R1	T2R2	T1R1	T1R2	T2R1	T2R2
Wheat 1993/94	1	+ 270.2 a*	265.8 a	277.0 a	275.0 a	b 283.7 a	c 270.0 a	a 300.0 a	a 297.0 a
	2	b 215.4 b	c 209.8 b	a 228.4 b	a 220.7 b	b 227.7 b	c 218.5 b	a 247.9 b	a 240.4 b
Lentil 1993/94	1	c 239.0 a	c 236.0 a	a 261.0 a	b 249.0 a	b 263.0 a	c 250.0 a	a 291.0 a	a 287.0 a
	2	c 197.6 b	c 187.5 b	a 208.6 b	b 200.3 b	b 217.3 b	c 206.4 b	a 236.5 b	a 230.1 b

+ : Along rows, for each parameter, means without letters on the upper side of the number, are not significantly different at the 5% probability level of the t-test.

* : Along columns, for each season means without letters on the lower side of the number, are not significantly different at the 5% probability level of the t-test.

It is noticed that soil moisture parameters calculated by the second method were significantly lower than those calculated by the first method, for both lentil and wheat seasons for all tillage and residue treatments. This result can be explained by soil moisture content-bulk density relationship.

In the frist method, fixed value of bulk density was used in calibration curves for calculation of volumetric soil moisture content. This value of bulk denstiy was higher than the appropriate one since it was taken in summer where soil was dry (shrunk).

On the other hand, value of bulk density in the second method was variable depending on soil moisture content. In addition, soil moisture parameters were calculated in period where the soil is at high soil moisture content (swollen), and so using appropriate bulk density is more accurate, while using fixed bulk density is misleading.

2. Cracks around access tubes :

Presence of crack(s) around access tube resulted in lower count ratio than the real value. The error in count ratio value depends on width, length and depth of crack(s). So, to avoid crack(s) effect on count ratio, soil from surface should be added into the crack(s) as soon as the crack appears.

But, if the crack is already formed, two possible solutions are suggested : 1) either to fill the crack by soil from the surface 2) or to take the reading in the presence of the crack(s) and in this case it should be corrected depending on crack(s) width and length.

The second solution was followed by correlating count ratio before and after filling the crack(s) with soil from the surface. Neutron probe readings were at depths of 7.5, 22.5, 45, 75 and 105 cm. The following equations were found :

4.6 Shrinkage Inflection Points :

According to statistical analysis there were no significant differences between the different tillage-residue treatments with respect to shrinkage inflection points for the different dates (mean values of shrinkage inflection points are presented in appendices 3a, 3b and 3c).

Regarding other parameters COLE; Aθg; and Aθv, chisel plow combined with early incorporation of residue had significantly higher available volumetric soil moisture content than plots of moldboard combined with early or late incorporation of residue for samples of November, 1994 (Table 9). This mainly due to higher macropores volume under those treatments that lead to higher availability of water and this effect was the reason for higher ETc and SMS obtained under those treatments (section 4.5).

Table 9 : Mean separation for coefficient of linear extensibility and available water in different tillage-residue treatments.

Parameter	COLE ($x10^{-2}$)			Aθg			Aθv		
Date ⇒	7/94	11/94	6/95	7/94	11/94	6/95	7/94	11/94	6/95
T1R1	*2.9+	2.6	1.9	a9.9	a9.4	9.0	6.6a	b5.6b	6.8a
T1R2	2.7	2.2	2.3	ab9.1	b8.0	8.8	6.6a	b5.4b	6.4a
T2R1	2.3	2.0	2.3	b8.5b	a10a	8.8b	6.4	a6.8	6.6
T2R2	2.1	2.4	2.5	ab9.5	a9.8	8.6	7.0a	ab6.2ab	5.8b

\+ 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.

One can notice that there are no significant differences between different tillage residue management treatments or between the different dates with respect to coefficient of linear extensibility, COLE.

Plots of chisel plow combined with early or late incorporation had significantly higher available soil moisture content than plots of moldboard combined with late incorporation of residue for samples of November, 1994. Meanwhile, available volumetric soil moisture content was significantly lower for samples of November, 1994 than samples of July, 1994 and June, 1995 under plots of T1R1 and T1R2, while for plots of T2R2 available volumetric soil moisture was significantly higher for samples of July, 1994 than for samples of June, 1995.

Table (10) represents mean separation for gravimetric soil moisture content, soil bulk density, and volumetric soil moisture content for soil samples taken at different dates (July 1994, November 1994, and June 1995). There were no significant differences between the three dates with respect to gravimetric soil moisture content at 0.3, 1 and 15 bars tension. While at 0.1 bar soil moisture tension, gravimetric soil moisture content was higher under wheat season (July 1994) than that under lentil season.

الصفحة غير موجودة من أصل المصدر

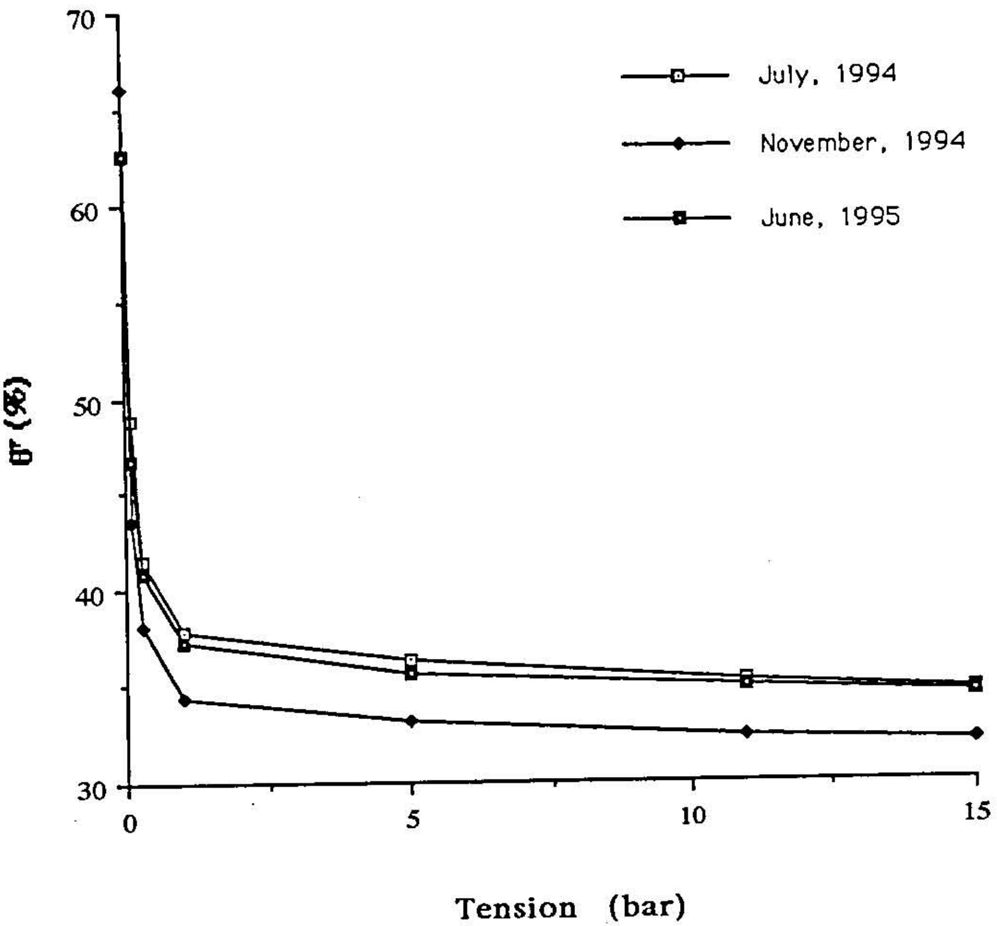

Fig. 8 : **Soil moisture characteristic curve for the three different dates of wheat and lentil seasons.**

4.7 Relations between Bulk Density and Cracks Volume with Soil Moisture Content :

Regression analyses were made to correlate gravimetric soil moisture content (θg) and bulk density (B) and between gravimetric soil moisture content (θg) and crack volume (Vcr). The relationship were found to be linear and the following equations were found :

1. For July samples (after wheat harvesting) :

   $B = 1.31 - 0.0074\theta g$ $\qquad r^2 = 0.67$

   $Vcr = 7.28 - 0.16\theta g$ $\qquad r^2 = 0.66$

2. For November samples (after lentil planting) :

   $B = 1.22 - 0.0072\theta g$ $\qquad r^2 = 0.58$

   $Vcr = 6.90 - 0.15\theta g$ $\qquad r^2 = 0.89$

3. For June samples (after lentil harvesting) :

   $B = 1.32 - 0.008\theta g$ $\qquad r^2 = 0.76$

   $Vcr = 6.76 - 0.16\theta g$ $\qquad r^2 = 0.90$

The above equations show that higher correlation exists between soil bulk density and gravimetric soil moisture content for soil samples after harvesting. Higher correlation under lentil was obtained when compared to wheat. In addition, bulk density values were close to each other for lentil and wheat after harvesting, while soil bulk density is noticed to be lower for samples of November when compared with the other two dates. Those results show that tillage had a significant effect on soil bulk density, while the crop effect seems to be smaller. Although tillage caused surface loosening but this effect seems to be beneficial for soil physical properties, and not necessarily means dense and compacted soil.

Regarding volume of cracks, it appears clearly from the closest relations that crop has no effect on cracks volume and this can be explained by two reasons: the first is that shrinkage characteristic, m, is not affected by crop type. i.e. no differences are expected between wheat and lentil; and the second reason is that studying cracking of Vertisol in laboratory by using small cores does not necessarily reflect the situation in the field[16, 19].

smectitic, thermic, typic, Chromoxerert. A three course rotation was applied (wheat/lentil/melon), and wheat-lentil phases were studied. Two tillage treatments (moldboard and chisel) were combined with two residue treatments (early incorporation and late incorporation) and arranged in randomized complete block design with three replicates. All treatments were fertilized by a constant rate of triple super phosphate (4.4 kg P2O5/du), while for wheat phase only a constant rate of urea (7.5 kg urea/du) was applied.

The following conclusions were obtained :

1. At relatively high soil moisture content plots of chisel plow combined with early or late incorporation of residue attained significantly higher gravimetric soil moisture content than other treatments. While, when soil dries out plots of moldboard combined with early or late incorporation attained significantly higher soil moisture content.

2. Macropore volume was significantly lower under plots of

3. Bulk density was higher under wheat than lentil.

4. Soil strength was significantly higher under plots of chisel plow combined with early incorporation of residue than plots of moldboard combined with late incorporation of residue for wheat season.

5. Initial infiltration rate was significantly higher under plots of moldboard plow combined with early incorporation of residue than other treatments for both seasons.

6. Bulk density - soil moisture relationship should be considered in calculating soil moisture parameters. ETc and SMS calculated by using appropriate bulk density were significantly lower than these calculated using single value of bulk density.

7. Available water was significantly higher for samples taken after harvesting than those taken after planting for plots of chisel plow combined with early or late incorporation of residue.

8. Soil surface bulk density, and volumetric soil moisture content were significantly higher after harvesting than after planting.

Based on the study results, the followings can be recommended :

1. Using chisel plow combined with early or late incorporation of residue.
2. Using appropriate bulk density in calculating soil moisture parameters.
3. Correcting neutron probe readings in the presence of crack(s), based on crack with and length.

6. References

1. Battikhi, A., Snobar, B., Katkhuda, N., and Khattari, S. : "Tillage-Plant Residues Management Practices, Soil Moisture, and Crop Yield in Vertisols," in press.

2. Taimeh, A.Y., and Khreisat, S.A. : Vertisols in Jordan, Properties and Distribution. 1st edition, Publications of the University of Jordan, Amman, 1988.

3. Hamdi, H., Tinsley, R., and Taher, A. : "Management of the Heavy Clayey Soils of Egypt," Egypt.J.Soil Sci., Vol. 28, No.3, 1988, PP. 349 - 361.

4. Dasog, G.S., Acton, D.F., Mermut, A.R., and Jong, E.De : 1988. "Shrink-Swell Potential and Cracking in Clay Soils of Saskatchewan". Can. J. Soil Sci., Vol. 68, 1988, PP. 251 - 260.

5. Coughlan, K.J., Smith, G.D., and Yule, D.F. : "Soil Physical Research for Improved Dryland Crop Production on Vertisols in Queensland, Australia," 1989, PP. 91 - 93 : ICRISAT.

6. Abu-Hammad, A.Y., and Battikhi, A.M. : "Tillage-Residue Management Practices and Soil Physical Properties," Dirasat, Vol. 22B, No.2, 1995, PP. 413 - 422.

7. Mayande, V.M., Bansal, R.K., and Smith, G.D. : "A Comparison of Moldboard Plows for Dry Season Tillage of Vertisols," Soil and Tillage Research (Netherland), Vol. 15, 1990, PP. 349 - 358.

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

9. Sulieman, A.A. : "Moisture Content and Some Physical Properties of Vertisols under Different Tillage and Crop Residue Management Practices," M.Sc. Thesis, University of Jordan, Amman, Jordan, 1994.

10. Kharouf, M.A., and Battikhi, A.M. : "Soil Moisture Storage and Depletion as Influenced by Fall Tillage and Fertilizer rate for wheat Production in Mushaqar Region," Dirasat., Vol. 18B ,No.1, 1991, PP. 33 - 45.

11. Abu Hammad, A.H., and Battikhi, A.M. : "Tillage-Residue Management Practices, Soil Moisture, and Crop Yield in Rainfed Areas of Jordan," Dirasat., Vol. 23B, No. 2, 1995, PP. 445 - 462.

12. Sarma, K.S., and Rao, Y.N. : "Relationship between Bulk Density and Pore-size Distribution in a Sandy Loam Soil," J. Indian Soil Sci., Vol. 24, No. 3, 1976, PP. 314 - 316.

13. Battikhi, A.M., and Sulieman, A.A. : "Effect of Tillage System on Soil Strength and Bulk Density of Vertisols," in press.

14. Gupta, R.K., and Gupta, U.S. : "Volume Change in a Swelling Clay and its Influence on Soil Moisture Relations," J.Indian Soil Sci., Vol. 26, No. 4, 1978, PP. 323 - 327.

15. Yule, D.F., and Ritchie, J.T. : "Soil Shrinkage Relationships of Texas Vertisols : 11. Large Cores," Soil Sci. Soc. Am.J., Vol. 44, 1980, PP. 1291 - 1292.

16. Mitchel, A.R., and Genuchlen, M.Th. Van : "Shrinkage of Bare and Cultivated Soil," Soil Sci. Soc. Am. J., Vol. 56, 1992, PP. 1036 - 1042.

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

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

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

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

21. Rolston, D.C., Bedwaig, M.N.A., and Lonie, D.T. : "Micro-pentrometer for In Situ Measurement of Soil Surface Strength". Soil Sci. Soc. Am.J., Vol. 55, 1991, PP. 481 - 485.

22. Radcliffe., D.E., Tollner, E.W., Hargrove, H.L., Clark, R.L., and Globil, M.H. : "Effect of Tillage Practices on Infiltration and Soil Strength of a Typic Halpudult Soil after Ten Years," Soil Sci. Soc. Am.J., Vol. 52, 1988, PP. 798 - 804.

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

24. Bauder, T.W., Randall, G.W. and Swann, J.B. : "Effect of Four Continuous Tillage Systems on Mechanical Impedence of a Clay Loam Soil," Soil Sci.Soc.Am.J., Vol. 45, 1981, PP. 802 - 806.

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

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

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

28. Battikhi, A.M., and Suleiman, A.A. : "Effects of Tillage System on Soil Strength and Bulk Density of Vertisols," in press.

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

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

31. Ghazy, A., Wahab, M.A., and Omar, M.S. : "Infiltration Characteriestics as Related to Soil Physiochemical Properties of Vertisols in The Nile Delta," Egypt J. Soil Sci., Vol. 22, No. 1, 1988, PP. 75 - 90.

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

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

34. Battikhi, A.M., And Sulieman, A. A. : "Temporal Variation of Infiltration Rate in A Vertisol under Lentil-Wheat Rotation," in press.

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

36. Chang, C. and Lindwall, C.W. : "Effect of Long-Term Minimum Tillage on Some Physical Properties of A Chernozemic Clay Loam," Can. J. Soil Sci., Vol. 69, 1989, PP. 443 - 444.

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

38. Chanasky, D.S., and Mckenzie, R.H. : "Field Calibration of A Neutron Probe," Can. J. Soil Sci., Vol. 66, 1986, PP. 173 - 176.

39. Cannell, G.H., and Asbell, C.W. : "The Effects of Soil-Profile Variations and Related Factors on Neutron-Moderation Measurements," Soil Sci., Vol. 117, No. 2, 1974, PP. 124 - 128.

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.

الصفحة غير موجودة من أصل المصدر

Appendices

Appendix (1a) : Analysis of variance for the experiment design [factorial in randomized complete block design (RCBD)] for the infiltration rate, soil surface gravemetric moisture content, and bulk density.

Suource of Variation	df (symols)	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 (Block).
T : Tillage.
R : Residue.
df : degree of freedom.

Appendix (1b) : Analysis of variance for the soil strength, aggregate size distribution, and shrinkage inflection points.

Source of vaiation	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 (T x R)	(s-1) (T x R)	8
Error	(r-1) (sTR-1)	22

S : Samples within tillage-residue interaction.
r : Replicate (Block).
T : Tillage.
R : Residue.
df : degree of freedom.

Appendix 2a : Some physical properties of Maru Soil at beginning of experiment.

Soil depth (cm)	θv at 0.1 bar (%)	θv at 0.3 bar (%)	θv at 1 bar (%)	θv at 15 bar (%)	bulk density (g/cm3)	Clay (%)	Silt (%)	Sand (%)
0-15	46.4	40.2	36.6	33.9	1.00	*49.8	*49.1	*1.1
15-30	51.5	45.7	41.8	38.6	1.26	53.1	45.7	1.2
30-60	52.7	45.3	40.2	37.6	1.22	52.1	47.0	0.9
60-90	52.4	46.8	41.1	37.8	1.25	52.9	45.9	1.2
90-120	54.2	46.7	40.7	38.7	1.26	52.4	46.6	1.0

* : Carbonate free.

Appendix 2b : Some Chemical properties of Maru soil at beginning of experiment.

Soil depth (cm)	NH_4^+ (ppm)	NO_3^- (ppm)	Available P (ppm)	Available K^+ (ppm)	Carbonate (%)	pH	EC (dS/m)
0-15	6.1	5.2	15	352	5.9	7.6	0.27
15-30	-	-	10	-	4.6	7.4	0.25
30-60	-	-	9	-	4.8	7.4	0.22
60-90	-	-	2	-	5.7	7.5	0.24
90-120	-	-	2	-	5.6	7.6	0.24

الرعي لمدة شهر بعد حصاد محصول القمح.

الصفحة غير موجودة من أصل المصدر

لقد أظهرت النتائج تبايناً مؤقتاً بين المعاملات المختلفة بالنسبة لمحتوى التربة الرطوبي الوزني. بينما كانت الكثافة الظاهرية لسطح التربة وقوة التربة معنوياً أعلى تحت معاملات المحراث الإزميلي مقروناً بالخلط المبكر أو المتأخر لبقايا النبات منهما في المعاملات الأخرى لمحصولي القمح والعدس.

لقد كانت سرعة رشح الماء الإبتدائية داخل التربة معنوياً أعلى تحت معاملة محراث السكة مقروناً بالخلط المبكر لبقايا النبات منه في المعاملات الأخرى. بينما لم تختلف سرعة الرشح الأساسي للماء داخل التربة معنوياً بين المعاملات المختلفة.

لقد أظهرت النتائج أن استعمال القيمة المناسبة للكثافة الظاهرية في حساب مقاييس محتوى التربة الرطوبي في أتربة الفيرتيزول أمر فرضي، وإلا فإن القيم المتحصل عليها ستكون أعلى من الحقيقية. لقد تم التوصل أيضاً إلى أن وجود الشقوق حول ماسورة القراءة تؤثر على قراءة جهاز المجس النيوتروني وتبعاً لذلك يجب تعديل القراءة اعتماداً على عرض وطول الشقوق.

أخيراً، أظهرت النتائج أن منحنى خصائص رطوبة التربة لم يتأثر بنوع المحصول، إنما وجد أن محتوى التربة الرطوبي الحجمي كان أقل معنوياً بعد الزراعة منه بعد الحصاد.