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A NEW SOIL COMPACTOR FOR INCREASING WATER HOLDING CAPACITY OF LOAMY SAND SOIL

Khiery M. Ismail[1] and I. S. Al-Salamah[2]

[1] *Dept. of Agricultural Engineering, Faculty of Agriculture, University of Alexandria, Egypt*
[2] *Dept. of Civil Engineering, Faculty of Engineering, Qassim University, Saudi Arabia.*

ABSTRACT

Because the most soils in Saudi Arabia can not maintain water being sandy soils. This soil characteristic leads to the loss of water by gravity. In addition, the high degree of temperature also can cause high evaporation rate for water after irrigation especially in summer. A thought was developed toward a method to increase soil bulk density that leads to raise the capability of water to maintain water. This was achieved by designing and constructing a machine for compacting and making holes in soil. These holes will act as small water tanks in soil and save water to growing seeds. This machine consisted of 44 cm diameter cylinder with 245 cm width to make 8 rows of holes on the ground with 30 cm apart. The cylinder has 5 groups of metal cones (10 cm diameter with 10 cm height) welded on the cylinder circumference. Thus, lay out holes on the ground have a distance of 30 cm apart and 40 cm apart in the other direction. Mainly two field treatments were carried out, one with holes and one without holes. Variables such as soil moisture content and soil bulk density of soil were measured at different depths and times. The other variables such soil penetration resistance and organic matter as well as the clay percent were determined after the 4th irrigation for both treatments. The results showed that soil moisture content was higher in hole soil treatment than soil without treatment due to the collection of clay particles and organic matter by water droplets during irrigation. The collection of clay and organic matter in these holes made the holes very well sealed and increased the soil storage for water. It is obvious that the developed machine decreased the soil hydraulic conductivity that leads to an increase in soil water content.

تعتبر معظم أراضي المملكة العربية السعودية أراضى رملية أو لومية وتتميز بقدرتها المنخفضة في الاحتفـاظ بالمـاء حيث تفقد المياه بفعل الجاذبية الأرضية هذا بالإضافة إلى ارتفاع درجة الحرارة والذي يـسبب فقـد الميـاه بـالتبخر وخصوصا بالصيف. لهذا فلقد نشأت فكرة كبس التربة لتقليل مسامها وزيادة قدرتها للاحتفاظ بمياه الري وذلك بتصميم آلة كبس خاصة تقوم بعمل جور بالتربة للزراعة حيث تقوم الآلة بكبس التربة وعمل جور لتجميع المياه وحفظها لفترة تمكن البذور من امتصاصها. صممت الآلة من اسطوانة قطرها ٤٤سم وعرضها ٢٤٥سم ويثبت على طولها باللحام ٨ صفوف من البروزات المخروطية التي تتباعد عن بعضها في الصف الواحد ٣٠ سم. ولقد تم عمل ٥ بروزات في كل صف من الصفوف الثمانية (بقطر ١٠سم وارتفاع ١٠سم لكل بروز) لتعطي مسافة ٤٠ سم علـى الأرض. صـممت الأسطوانة بحيث يتم تعليقها بالجهاز الهيدروليكي للجرار. سمح التصميم أيضا بعمل إطار علوي لإضافة أوزان لإعطاء الكبس المطلوب فيه.

تم اختبار أداء الآلة حقليا" طبقا لتصميم إحصائي لمقارنة معاملات إعداد التربة للزراعـة بجـور والزراعـة بـدون بجور.كانت المتغيرات التي قيست في الحقل لمقارنة المعاملتين السابقتين هي: ١-المحتوى الرطوبي في التربة ٢-كثافة التربة في أعماق مختلفة وأوقات مختلفة بعد الري ٣-مقاومة اختراق التربة ٤-محتوى المواد العـضوية بـالجور ٥-نسبة الطين في الجور.

أظهرت النتائج أن المحتوى الرطوبي والكثافة الظاهرية في معاملات الجور أعلى منه في معاملات بدون جور. كمـا أظهرت النتائج أن تربة الجور احتوت على مادة عضوية ونسبة طين أعلى مما في التربة التي لم يعمل بها جور وذلك بسبب جرف مياه الري لهذه المواد إلى الجور وهذا أدى إلى تكوين طبقة عازلة من الطمي أدت إلى تقليل فقـد الميـاه بالجاذبية كما انه لكون الجور عمق ١٠ سم وقطر ١٠ سم أدى إلى تواجد ظلال في الجورة عند سطوع الشمس عليها مما أدى إلى تقليل التبخر بدرجة الحرارة وبالتالي إلى الاحتفاظ بقدر اكبر من الرطوبة في الجور بالمقارنة مع التربـة التي لم تعامل بالجور. أظهرت النتائج أيضا أن مقاومة الاختراق للتربة كانت أعلى في تربة الجور وهى نتيجة طبيعية بسبب تكون الجورة التي تؤدى إلى زيادة كثافة التربة في الجورة نفسها عن السطح المجاور لها.

مما سبق فأنه يمكن القول أن استعمال هذه الآلة كان ناجحا" في زيادة قدرة التربة على الاحتفاظ بمياه الري.

1. INTRODUCTION

The main soil texture in Saudi Arabia is sandy or sandy loam. This type of soil does not maintain water. Many methods can be used to overcome this problem but they are very much costly. A slight level of soil compaction may be applied to this type of soils to reduce pore spaces between soil particles and thus a better contact between soil particles is obtained leading to an improved water holding capacity. However, heavily compacted soils contain few large pores and have a reduced rate of both water infiltration and drainage from the compacted layer. This occurs because large pores are the most effective in water transport through the soil when it is saturated (Rapper, R. L. and Kirby, M. J. 2006, and Radford and Nielson, 1985.

Soil compaction can have both desirable and undesirable effects on plant growth. Slightly compacted soil can speed up the rate of seed germination because it promotes good contact between the seed and soil. In addition, moderate compaction may reduce water loss from the soil due to deep penetration and, therefore, prevent the soil around the growing seed from drying out because of an improved seed-soil contact, and hence better germination and growth of the seedling and subsequently improved crop yields during extremely dry years (Rapper and Kirby 2006; and Radford and Nielson, 1985; and Raghavan et al., 1979). In addition, O'Sullivan and Simota, 1995 and Nadian et al., 1996 reported that slight soil compaction may also improve soil structure, reduce soil erosion and provide a more suitable medium for seed growth. However; high levels of compaction adversely affect soil root growth, resulting in decreased oxygen and nutrient uptake.

Soil organic matter (SOM) is one of the primary soil constituents that promote good soil aggregation or stable aggregates. The form of SOM that binds soil particles together into aggregates is called *humus*. Humus consists of highly decomposed organic material. It can increase a soil's available water holding capacity, serve as a slow-release fertilizer, promote the formation and stability of aggregates, increase water infiltration, and enhance soil tilth, all of which contribute to decreasing soil erosion and increasing yields and plant health. Mulch protects the soil against the bad effects of raindrop impact and severe compaction. An added benefit of mulch is that it reduces water loss to evaporation and so extends the period of time between irrigation events. In addition, mulching is an effective weed suppressant practice and can reduce herbicide usage. Mulch is best suited for sprinkler- or drip-irrigated systems (Prichard et al., 1989; Raper and Kirby, 2006 and Hudson 1994; and O'Geen et al, 2006). Pidwirny (2008) reported that an adequate level of humus provides soil with a number of benefits:

- Increases the ability to hold and store moisture
- Helps maintain porosity in fine textured soils
- Reduces leaching of soluble nutrients to lower soil layers
- Supply soil with carbon and nitrogen for plants
- Improves soil structure for plant growth
- Decreases erosion losses

The capability of soil to hold water is affected by its bulk density. Burak (2005) reported that the relationship between soil moisture content and soil bulk density is not linear. Increasing soil bulk density increases the capacity of soil for moisture up to an optimum level of moisture content. Increasing soil bulk density behind that optimum level decreases the capacity of soil to hold moisture. He also reported that optimum levels of soil moisture were 4-8%, 10-20%, and 12-24% for sand, silt, and clay, respectively. Neibling and Falk (1997) reported also that the optimum levels of soil moisture content were 8-10% at soil bulk density of 1.88-1.92 kg/cm^3 (126-129 Ib/ft^3) for fine sand or fine silty sand, and about 18% at 1.49 kg/cm^3 (100 Ib/ft^3) for sandy silt or silty loam soil. In addition, Fritz et al., (2008) and Holtz and Kovacs (1981) reported that the optimum water content is defined as the corresponding water content at which the dry density is maximized and is dependent on both the soil type and the compaction energy used. They found that the optimum level of moisture content was about 20% when soil was compacted to a bulk density of 1.98 for silty clay soil.

In this research, a new method is used to prepare soil for planting where water is saved in holes besides seeds. This method required to design a hole digger for making holes in previously compacted soils. Theses holes will act as small water tanks at the irrigation time. Thus water becomes available for planted seeds for longer time in this kind of soils. Soil compaction of such light soil can be achieved by the same developed machine where weight is added to the cylinder frame. This also helps for obtaining a firm shape for such holes. Thus, this process increases the soil hydraulic conductivity of soil related to maintaining water. Therefore, the objectives of this paper were to:

1- Design a machine that makes holes in soil.
2- Test the performance of the new method which includes soil moisture of holes and its bulk density.
3- Test the penetration resistance of soil around the holes.
4- Determine the clay and organic matter percentages collected in the holes after irrigation.

2. MACHINE DEVELOPMENT

It is known that the common area specified for seed for the most crops in the Experimental Farm Station of Agricultural Faculty, Qassim University, is 1200 cm^2 (40 cm in rows and 30 cm between seeds). Therefore, these dimensions were taken in the consideration when the machine was developed to make the holes in soil on 40 cm a part in one longitudinal direction and 30 cm in the other perpendicular direction. The machine consists of 44 cm diameter cylinder with 245 cm width. It is designed to be mounted and rotated on an axial shaft of 6 cm diameter. This shaft was carried on both sides with a frame which is connected to a three point hitch system. The configuration of this design is shown in Fig. 1. The cones were also mounted by welding in 5 groups on the cylindrical circumference at which 40 cm is obtained on the ground apart. The machine cylinder has 8 rows of cones mounted on its circumference in which 30 cm apart for each group is obtained. This makes the machine width to be 220 cm. A frame as shown as in Figs. 2 and 3 was designed to carry the cylinder and to load a weight of 200kg to improve the cone penetration in soil and to obtain the proper soil compaction that gives better soil characteristics for maintaining water.

3 EXPERIMENTAL DESIGN

To evaluate the performance of the developed machine, mainly two treatments were tested as follows:

1- chiselling + leveling followed by planting (normal plots)

2- chiselling + leveling followed by conning operation and planting (hole plots).

Figure 4 shows the both plots with and without holes. Each plot is 50 meter long and 2.2 meter wide.

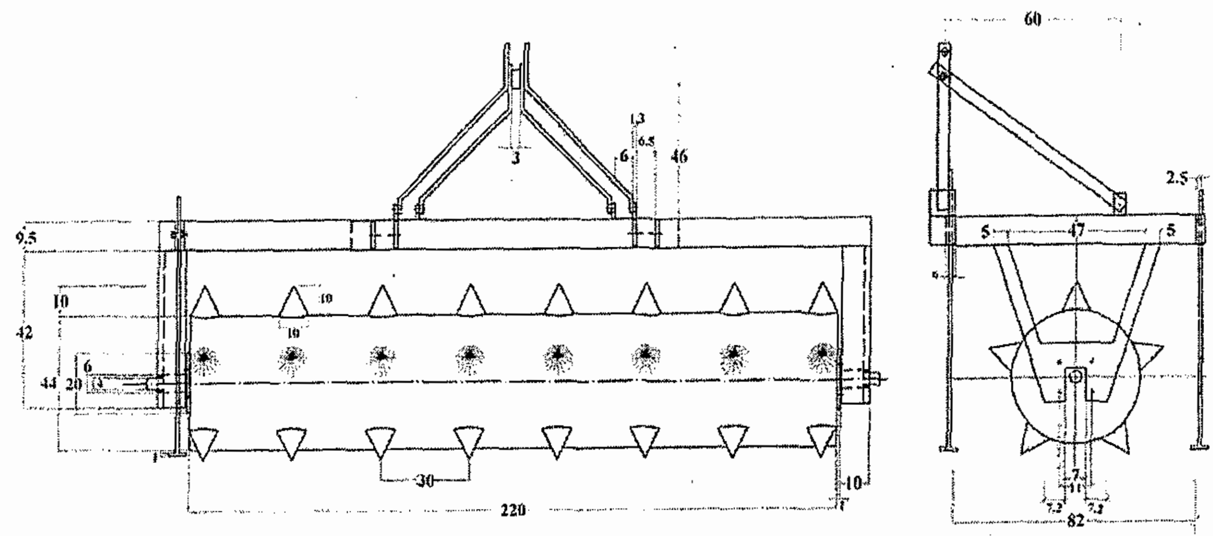

Fig. 1 An elevation and side views of the developed machine for making holes in soil (Dimensions in cm.).

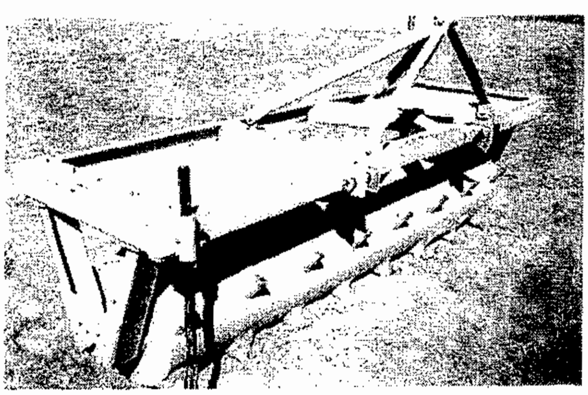

Fig. 2 A photograph of the designed machine for making holes in soil.

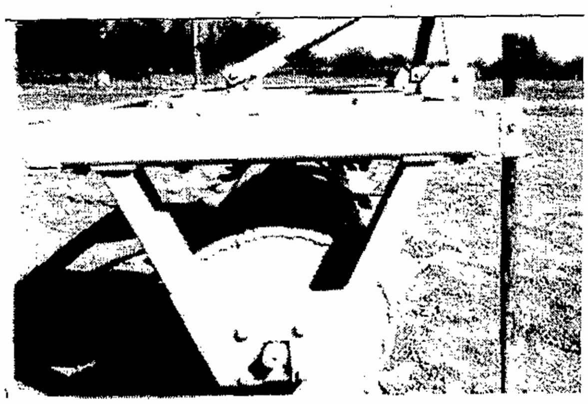

Fig. 3 A side photograph of the design machine for making holes in soil.

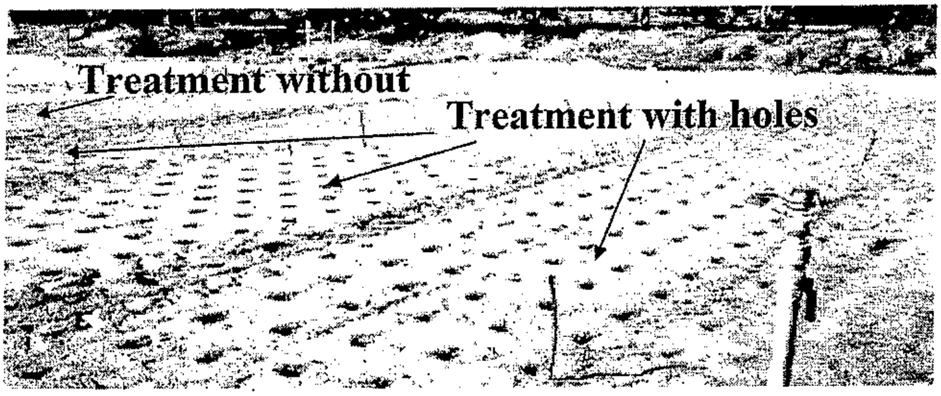

Fig. 4 The layout of soil treatments in field.

4. PROCEDURE

The variables to be measured in both treatments (normal and hole plots) were:

1- moisture content of soil
2- soil bulk density
3- soil penetration resistance
4- clay and organic matter percentages

Figure 5 shows the layout of soil holes carried by the developed machine where the distance of 40 cm was considered as x direction while the perpendicular distance of 30 cm (between holes) was considered as y direction.

4.1. Measurements of Soil Moisture Content

The measurements of moisture content were taken at each 8 cm between the two holes in x direction as shown in Fig. 5 where it shows the locations sampling cups (each 8 cm apart). In y-direction, moisture samples were taken each 10 cm where 4 samples were collected between the two holes. Moisture samples were taken at depths of 1, 2, 3.5 and 7 cm from the soil surface. These samples were also collected directly one day and two days after the irrigation. Soil moisture content was determined according the standard methods.

4.2 Measurements of Soil Bulk Density

The field measurements of the dry soil bulk density were determined for soil depths of 3.5 and 7 cm in both x and y directions. Volume and weight for each filled cup were determined. Soil moisture content was then determined by oven method. Bulk density was also determined knowing the soil mass and its volume in each cup.

4.3. Measurements of Organic Matter of the Hole Soil

The organic matter content of holes were also determined according to the Walkely and Black method (Nelson and Sommers, 1982) by the end of 4th irrigation. It was also determined for normal plots.

4.4. Soil Penetration Resistance

The penetration resistance of soil was determined by soil proctometer shown in Fig. 6. This proctometer was capable to measure a soil resistance up to 500 psi with an accuracy of 2 psi at the proper spring. Measurements of soil penetration resistance was taken at different levels of soil moisture content for the above soils.

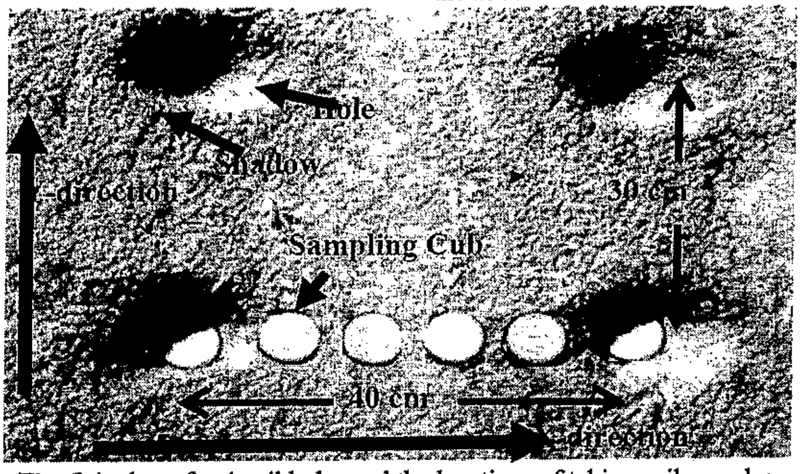

Fig. 5 A photo for 4 soil holes and the locations of taking soil samples for soil bulk density and moisture determination.

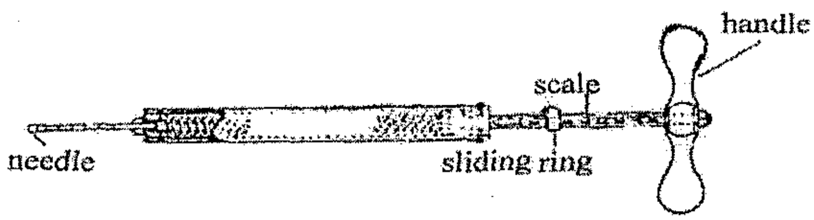

Fig. 6 The proctometer used for determining the soil penetration resistance.

5. RESULTS AND DISSCUTIONS

5.1. Moisture Distribution

Figure 7 shows the moisture content levels in hole plots at depths of 1, and 2 cm immediately after the irrigation while Fig. 8 shows the moisture content of soil immediately after irrigation and one day after irrigation at soil depth of 3.5 cm. The moisture distribution 2 days after irrigation at soil depths of 0-1 and 0-2 cm are shown in Fig. 9. Obviously, the moisture content was much higher in the bottom of hole than between any two holes at any soil depth. This result could be explained by the fact that the constructed holes by the developed machine collects fine clay particles and organic matter leached by water droplets during irrigation. This makes the hole walls very well sealed and thus the water lost by gravity is reduced.

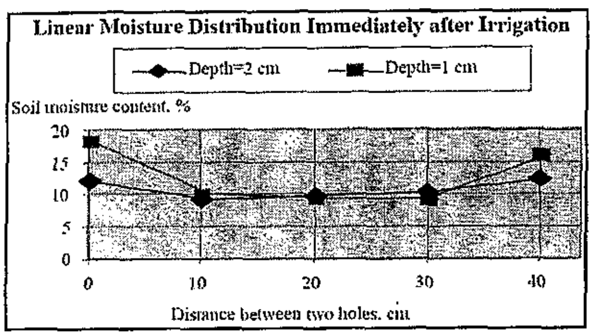

Fig.7 The Distribution of soil moisture content between two holes at 1 and 2 cm from soil surface directly after irrigation.

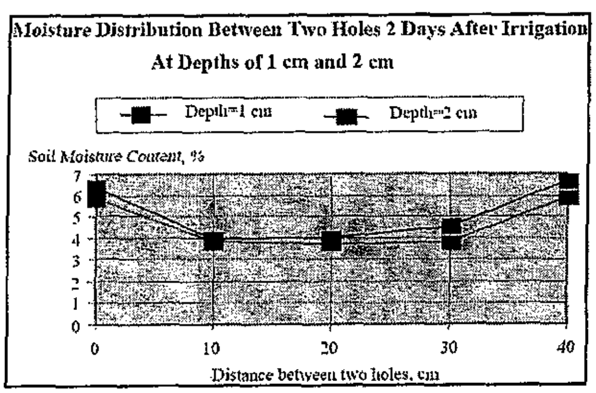

Fig. 8 The distribution of soil moisture content between two holes at soil depth of 1, and 2 cm from soil surface and 2 days after irrigation

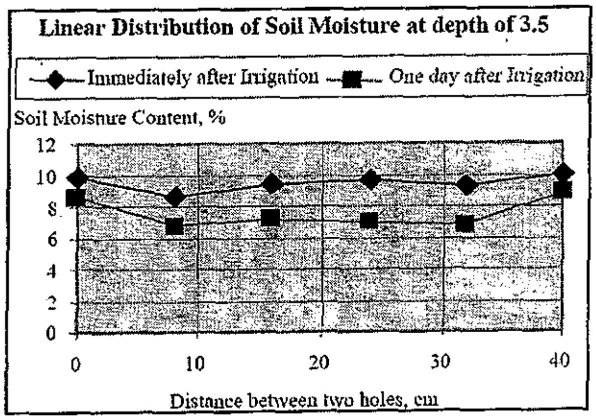

Fig. 9 The distribution of soil moisture between two holes at soil depth of 3.5 cm from soil surface directly after irrigation and one day after irrigation.

The moisture content data were also utilized to graph the response surface (3D-graph) for different cases. Figure 10 shows the response of moisture content at soil depth of 0-1 cm one day after irrigation while Fig. 11 shows the response surface for soil depth of 1-2.5 cm. Figure 12 shows the response surface of moisture content at soil depth of 0-7 cm after irrigation. Again, moisture content was much higher in the hole bottom than in any other location.

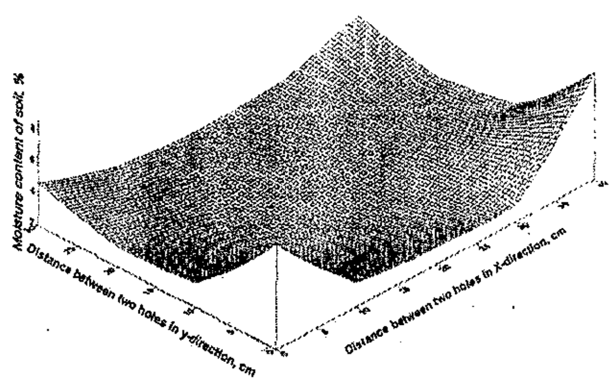

Fig. 10 Distribution of soil moisture content of 0-1 cm depth after a day from irrigation.

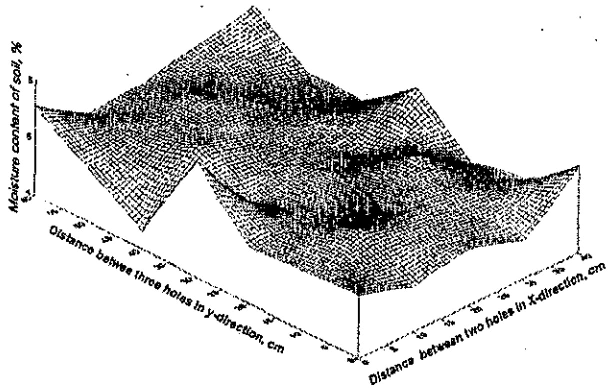

Fig. 11 Distribution of soil moisture content for a depth of 0-3.5 cm, a day after irrigation

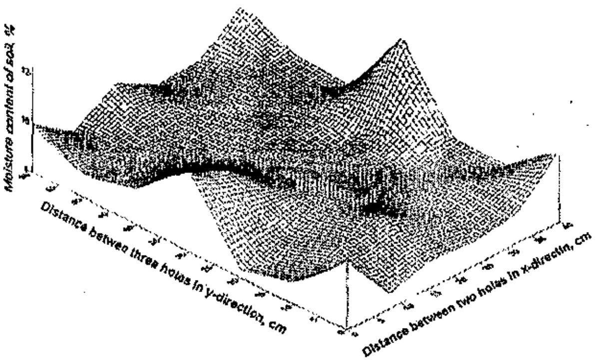

Fig. 12 Distribution of moisture content at a 7 cm depth from soil surface after irrigation.

5.2 Distribution of Soil Bulk Density

It was found that the average soil bulk density was about 1.35 for soil depth of 0-7cm for the non-treated soil with holes while Fig. 13 shows the distribution of dry bulk density for soil treated with holes at the same depth. It is obvious that the hole soil is higher dense than in soil between any two holes or than soil is not treated with holes. This is explained by the fact that the soil moves aside and lower when machine cones penetrate the soil vertically resulting a higher dense soil in the holel than in soil between the holes. In addition, using the developed machine over soil previously leveled raises the soil compaction to new levels like what shown in Fig. 13. This was good for this kind of soil to decrease the loss of water by gravity.

5.3 Soil Penetration Resistance

The results of soil penetration resistance are shown in Fig. 14 for three location of soils; normal treatment soil, surface soil between hole, and bottom hole soil. Basically, the penetration resistance of soil decreases with increasing soil moisture content. This was true for all three locations under the test. The soil penetration resistance ranged from about 60 to 100 psi for moisture content of 2 to 7.5% for normal treatment soil. However, the penetration resistance ranged from 300 to 450 psi and from 250 to 350 psi for hole bottom soil and soil between holes, respectively.

As shown as in Fig. 14, the treated soil (both in hole bottom and between holes) with the developed machine, are capable to maintain more moisture than soil in normal treatment (without holes). As a matter of fact, the hole soil maintained moisture from about 5 to 10% while the non-hole soil (normal treatment) maintained moisture only from 2.5 to 6.5% . Because penetration resistance of soil reflects the level of bulk density of soil, this becomes an important parameter taken in the consideration for improving the light soil characteristics for maintaining water.

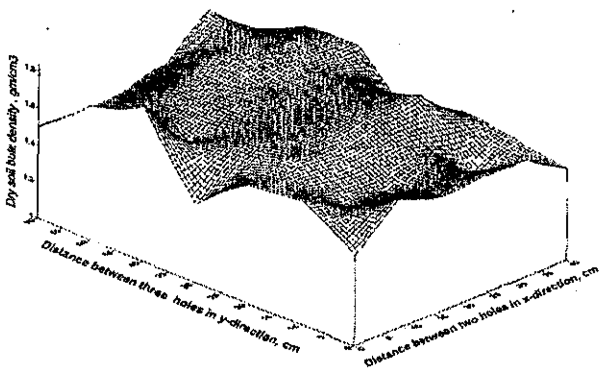

Fig. 13 Distribution of the dry bulk density for soil depth of 0-7 cms, immediately after irrigation.

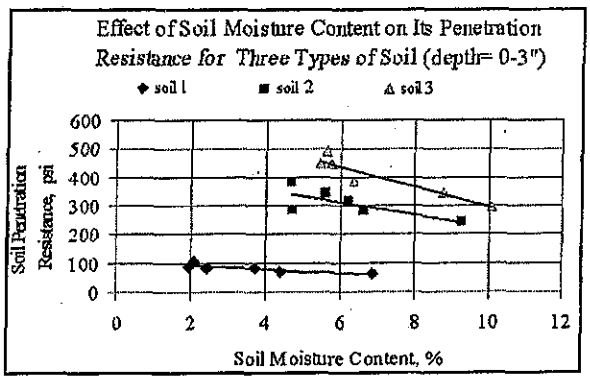

Fig. 14 Effect of moisture content on the soil penetration resistance for different soils (Soil 1: soil with no compaction, Soil 2: soil surface in treatment with compaction, Soil 3: soil in holes in treatment with compaction).

5.5 Organic Matter

Table 1 shows the percentages of organic matter for soils with holes and without holes. Obviously, the hole soil contained higher percentage of organic matter than soil left without holes (normal treatment). This can be explained by the fact that water droplets during irrigation moves the organic materials from the soil surface to the holes causing an increasing in the organic matter in the holes.

Table 1: The Organic matter and soil components for *Soil with holes and without holes.*

Soil Characteristics	Soil with holes	Soil without holes
Organic matter, g/100 g soil	3.52	2.09
Sand percentage	82.23	85.74
Silt percentage	05.27	09.99
Clay percentage	12.5	04.27
Soil type	Loamy sand	Loamy sand

5.6 Mechanical Analysis of Soils

Table 1 also shows the soil particle analysis for the two kinds of soils (hole soils and soil without holes) As shown the clay percentage in the hole soil was higher 12.5%) while it was lower (4.27%) in soil without holes. This also can be explained by the fact that water droplets move the fine particles during irrigation causing an increase in the clay percentages of hole soils. Table 1 shows the original distribution of soil particles. As shown, the soil components were 85.74, 9.99, and 4.27% for sand, silt, and clay, respectively in soil without holes while they were 82.23, 5.27, and 12.5% in soil with hole, respectively.

6. CONCULUTION

It can be concluded that the new method of planting causes the followings:

1- higher moisture content in soil treated with the developed machine (*hole treatments*).
2- more movement for clay or silt particles and organic matter with water movement to the holes.
3- less evaporation rate in the hole soil due to the shadow and sealed walls by clay layers.
4- more saving for water due to increasing soil bulk density and soil penetration resistance.

Thus, the developed machine for making holes can achieve a promising future for agriculture in Saudi Arabia.

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