Soil bulk density and some related soil physical properties in relation to soil moisture content under New Hamdab conditions, northern Sudan

Abbas Mohammed Ali Mustafa[1] and Hisham Mousa Mohammed Ahmed [2]

[1] Agricultural Research Corporation, New Hamdab Research Station, Northern State, Sudan.
[2] University of Gezira, Faculty of Agricultural Sciences, Wad Medani, Sudan.

ABSTRACT

This study was carried out during 2009/10, in New Hamdab Research Station Farm, Northern State, Sudan. Soil bulk density was determined with its corresponding soil moisture contents for depths 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm from a soil profile of 120 cm deep using the core method. Correlation between soil bulk density *versus* each of soil depths (D) and soil moisture contents were made, nevertheless, the bulk density related soil physical properties values in relation to moisture content were also estimated. The results indicated that soil bulk density had a significant linear positive relationship ($P \leq 0.001$) with soil depth (r^2=0.89), and negatively related to soil moisture content for all the tested depths(r^2= 0.99, 0.98, 0.97, 0.58 and 0.98). The values of all related soil physical properties to soil bulk density increased with increasing gravimetric soil moisture content for all depths except for the air filled porosity which decreased. A calculated amount of irrigation water of 1693 m^3/ha is needed to irrigate an air dry soil that contains about 5% moisture.

INTRODUCTION

Soil bulk density is an important soil physics property. Changes in soil bulk density affect available water, air capacity, permeability, internal soil drainage, trafficability and penetration by plant roots (Muhammed, 2002). The water content of soil is an important factor that controls the behavior of bulk density. As a quantitative measure of wetness of soil mass, water content affects the level of compaction of soil, which is indicated by its bulk density (Agodz and Adam, 2003). As water content increases, air porosity decreases and total soil porosity decreases with an increase in soil bulk density (compaction).However, severe compaction (increase in soil bulk density beyond a certain level) results in a decrease in soil moisture content (Hill and Sumner,1966). As soil bulk density is related to the combined volumes of the solids and pore space, any factor that influences soil pore space will affect soil bulk density (Baver and Farnsworth,1940).

Crop water requirements (CWR) varies during the growing period, mainly due to variation in crop canopy and climatic conditions, and is governed by crop evapotranspiration (ET) . Thus, an accurate estimation of crop ET is an important factor for efficient water management (Tyagi, *et al*, 2000). Adam (2005) reported that CWR is important in planning of cropped area and operation of irrigation network. Determination of CWR is based on the calculation of reference evapotranspiration (ET_o) and the crop coefficient (K_c). So, determination of a crop coefficient and consequently the potential evapotranspiration are important for irrigation scheduling and management in order to reduce irrigation water losses, such as deep percolation and runoff (Costello, *et al*,2000)

For the determination of a crop coefficient, firstly, calculate the crop evapotranspiration, which is calculated from soil moisture depletion by the gravimetric method. But the gravimetric soil moisture content (MC) is calculated as a percentage on dry weight basis (w/w). So there is a need to convert the percentage soil moisture to volumetric moisture content (v/v) and this can be done by multiplying MC% by air dry soil bulk density. In order to estimate the volumetric moisture content in each soil depth, it is imperative that soil bulk density has to be measured for each depth. However, measurement of soil bulk density before and after every irrigation during the season is laborious, time consuming, and expensive.
So this study was undertaken to avoid such problems and furnish data for water management especially that of CWR in this area.

MATERIALS AND METHODS

This study was carried out in season 2009/10 in New Hamdab Research Station Farm, in New Hamdab Agricultural Scheme in Northern State, Sudan. The area is located in the semi desert plain between longitude 31° 06\ 08\\ E and 31° 13\ 31\\ E and latitudes 17° 55\ 11\\ N and 17° 58\ 11\\ N. The soil of the farm is classified as typic Haplocambids, fine loamy, mixed, hyperthermic and correlated to Kelly soil series. The soil is non- saline, non- sodic and characterized by low fertility and light texture (Table 1).

Table 1: Some physical and chemical properties of the soil of the study area.

Properties	Depth (cm)				
	0 – 20	20 - 40	40 - 45	45 - 85	85 - 125
CS (%)	52	52	55	55	52
SS (%)	14	13	14	15	12
Si (%)	18	12	15	08	13
C %	16	13	16	22	23
pH (paste)	7.9	7.9	7.8	8	7.6
$CaCo_3$ (%)	2.4	2.4	2.0	6.6	19.2
Total N (%)	0.028	0.027	0.024	0.022	0.015
O.C (%)	0.094	0.094	0.078	0.078	0.156
EC(dsm^{-1})	0.45	0.86	0.55	1.08	1.47

CS= coarse sand SS= sand silt Si= silt C= clay

Soil bulk density was determined with its corresponding soil moisture content for each of the following soil depths: 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm, and 80-100 cm from a soil profile 120 cm deep using the core method. The volume of the core was 100 cm³ (5cm internal diameter and5cm height). The profile was filled with water to saturation point; then
three samples per depth were taken. The samples were weighed \immediately, then oven dried at 105ºC for 24 hr. After that soil bulk density was determined as follows:
Soil bulk density = air dry weight of the soil/ volume of core …………(1)
The corresponding soil moisture content θg or MC% (w/w) was also determined as follows:
MC% (w/w) = (Ww – Dw / Dw) * 100 ……………………………………(2)
where; Ww is the weight of the soil before oven drying and Dw is the dry weight of the soil.

The samples were taken every day until the profile was air dry, then filled with water again and taking samples was continued. This operation was repeated until the number of samples reached 90 samples per depth. This was done in order to determine soil bulk density at different soil moisture contents. To reduce variability, all moisture contents and soil bulk density data were arranged in an ascending order and the mean values for the two parameters were taken at an interval of 5 percent gravimetric moisture content.

A curve of soil bulk density *versus* its corresponding soil moisture content was made to find out the correlation between them. The other soil physical properties which are related to soil bulk density (total soil porosity (f), air-filled porosity (a), void ratio (e), percent saturation (s) and the volumetric moisture content θv) were calculated as follows:
f = 1-bulk density/2.65 …………………….…………………..………… (3)
e = f /(1-f) ……………………………………………………….……..……. (4)
s = θv/f ……………………………………………………...……….... (5)
a = f- θv or f(1-s) …………………………………..…………... (6)
θv = θg*bulk density ……………………………………..………... (7)
The air filled porosity in relation to moisture content was converted to (m³/ha).

RESULTS AND DISCUSSION

There was a highly significant ($p \leq 0.001$) positive relationship between the soil depth and the soil bulk density, Fig.1. So the regression equation appropriate for the bulk density fitting curve was as follows:

Bulk density = 0.002*D + 1.523,

where D is the soil depth (cm).

Figures 2,3,4,5 and 6 showed a highly significant ($P \leq 0.001$) negative relationships between the gravimetric soil moisture content and the soil bulk density for all depths, and that r^2 values for the depths 0-20 cm, 20-40 cm, 40-60 cm, 60-80 cm and 80-100 cm were 0.99, 0.98, 0.97, 0.58, and 0.98, respectively. There were high confidence levels as revealed by these high values of r^2 and that the linear regression equations presented in these figures were accepted as appropriate for the soil bulk density fitting curves. Thus the average regression equations between soil bulk density and each of the tested soil depths were as follows:

Soil bulk density = 1.645 - 0.007 *θg, r^2=0.99 for the depth 0-20 cm
Soil bulk density = 1.785 - 0.013 *θg , r^2=0.98 for the depth 20-40 cm
Soil bulk density = 1.735 - 0.003 *θg, r^2=0.97 for the depth 40-60 cm
Soil bulk density = 1.760 - 0.003 *θg , r^2=0.58 for the depth 60-80 cm
Soil bulk density = 1.755 - 0.002 *θg , r^2=0.98 for the depth 80-100 cm

where θg is the gravimetric soil moisture content.

Tables 2, 3, 4 and 6 show the values of the percent volumetric wetness, porosity, void ratio, percent saturation and air filled porosity in relation to the gravimetric soil moisture content. Generally, the values of all these soil physical prosperities, which are related to soil bulk density, increased with increasing gravimetric soil moisture content for all the depths tested except for the air filled porosity which decreased.

The result of the air filled porosity values (m^3/ha) in relation to the moisture content for the depth 0 – 60 cm (Fig.7) showed that when the soil is air dry, it contained about 5% soil moisture. At the planting time, the volume occupied by air was 1693 m^3/ha. This finding may explain the need for a high amount of irrigation water for the first irrigation. This 1693 m^3/ha represents the total available of the air dry soil. On the other hand, when soil moisture is about 20% the volume occupied by air was only 565 m^3/ha showing that about 67% of the porosity was filled with this 20% of soil moisture. Therefore, less water is required for the subsequent irrigation.

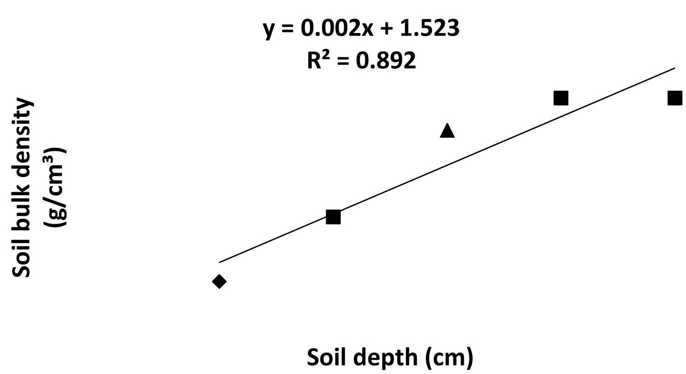

Fig.1. Soil bulk density (g/cm³) as a function of soil depth (cm).
in relation to gravimetric soil moisture content
(%) at depth 0 - 20 cm.

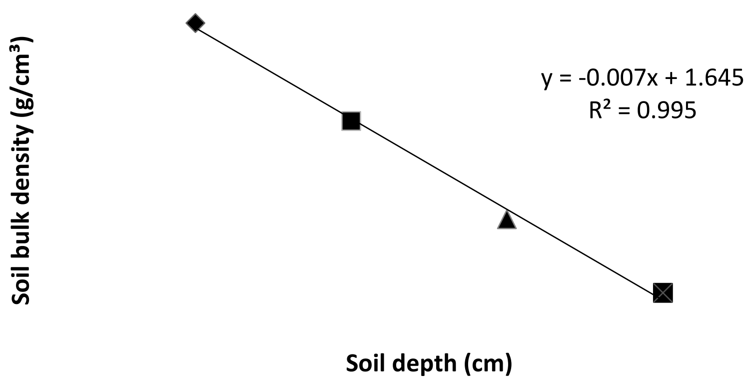

Fig.2. Soil bulk density (g/ cm³) in relation to gravimetric soil moisture content
(%) at depth 0 - 20 cm.

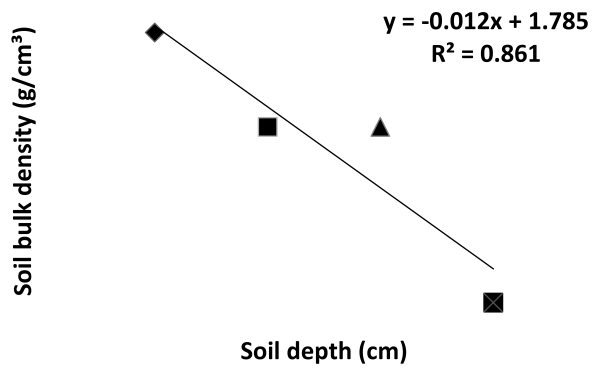

Fig.3. Soil bulk density (g/cm³) in relation to gravimetric soil moisture content
(%) at 20 - 40 cm.

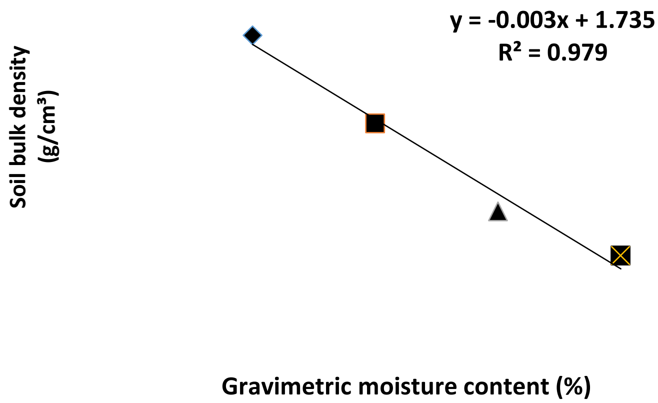

Fig.4. Soil bulk density (g/cm³) in relation to gravimetric soil moisture content

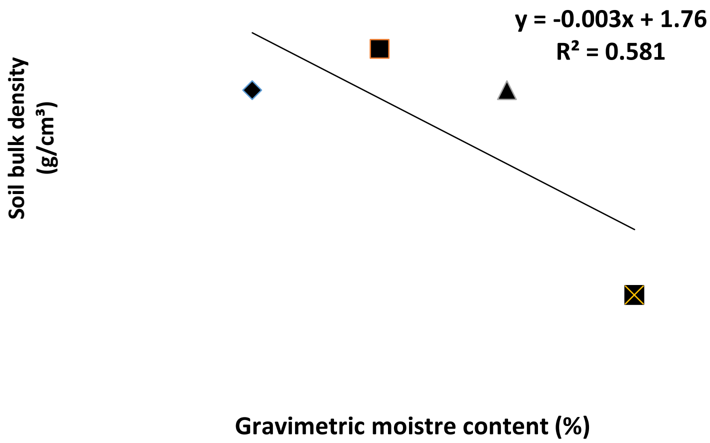

Fig.5. Soil bulk density (g/cm³) in relation to soil gravimetric moisture content (%) at depth 60 - 80 cm.

Fig.6. Soil bulk density (g/cm³) in relation to gravimetric soil moisture content (%)at depth 80 - 100 cm.

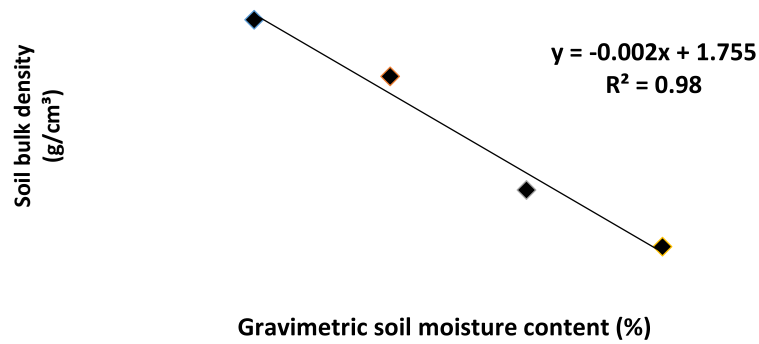

Table 2. Percent volumetric wetness, porosity void ratio, percent saturation and air filled porosity in relation to moisture content of 0 – 20 cm depth.

% θg	θv	f	E	%s	fa
5	8.05	0.39	0.65	20.51	0.31
10	15.75	0.41	0.69	38.65	0.25
15	23.1	0.42	0.73	54.66	0.19
20	30.1	0.43	0.77	69.36	0.13

Table 3. Percent volumetric wetness, porosity void ratio, percent saturation and air filled porosity in relation to moisture content of 20 – 40 cm depth.

% θg	θv	f	E	%s	fa
5	8.6	0.35	0.54	24.51	0.26
10	16.55	0.38	0.61	43.86	0.21
15	23.85	0.41	0.7	57.98	0.17
20	30.5	0.43	0.74	71.53	0.12

Table 4. Percent volumetric wetness, porosity void ratio, percent saturation and air filled porosity in relation to moisture content of 40 – 60 cm depth.

% θg	θv	f	E	%s	fa
5	8.6	0.35	0.54	24.51	0.27
10	17.05	0.36	0.56	47.56	0.19
15	25.35	0.37	0.58	69.26	0.11
20	33.5	0.37	0.59	90.59	0.03

Table 5. Percent volumetric wetness, porosity void ratio, percent saturation and air filled porosity in relation to moisture content of 60 – 80 cm depth.

% θg	θv	f	E	%s	fa
5	8.73	0.35	0.53	25.13	0.26
10	17.3	0.34	0.52	50.38	0.17
15	25.73	0.35	0.53	74.1	0.09
20	34	0.37	0.58	92.89	0.03

Table 6. Percent volumetric wetness, porosity void ratio, percent saturation and air filled porosity in relation to moisture content of 80–100 cm depth.

% θg	θv	f	E	%s	fa
5	8.73	0.34	0.52	25.41	0.26
10	17.35	0.35	0.53	49.98	0.17
15	25.87	0.35	0.55	72.95	0.1
20	34.3	0.36	0.56	95.68	0.02

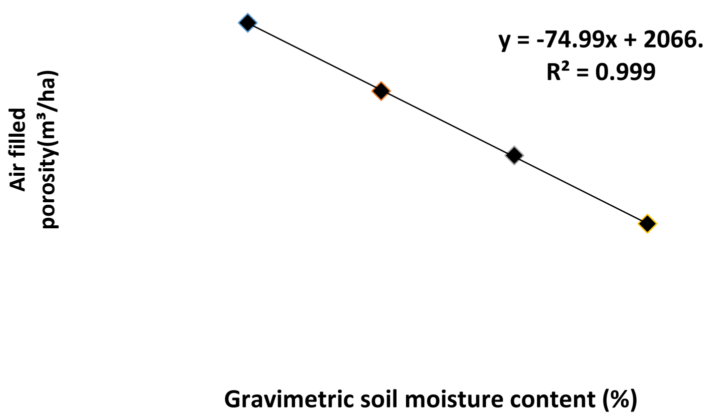

Fig 7. Air filled porosity in relation to gravimetric soil moisture content for the depth 0 - 60 cm.

CONCLUSION

Soil bulk density had a significant ($P \leq 0.001$) positive relationship with soil depth. There was a highly significant ($P \leq 0.001$) negative relationship between the gravimetric soil moisture content and the soil bulk density for all depths tested. The value of each of the other soil physical properties increased with increasing gravimetric soil moisture content for all depths tested except for the air filled porosity which decreased. A high amount of irrigation water (1693 m^3/ha) is needed to irrigate this soil at the time of planting when the soil moisture is about 5%.

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الكثافة الظاهرية للتربة وبعض خصائص التربة الفيزيائية ذات الصلة وعلاقتها مع محتوى الماء تحت ظروف منطقة الحامداب الجديدة، شمال السودان

عباس محمد على مصطفى[1] وهشام موسى محمد أحمد[2]

[1]هيئة البحوث الزراعية ، محطة بحوث الحامداب الجديدة ,الولاية الشمالية, السودان.

[2]جامعة الجزيرة , كلية العلوم الزراعية , قسم الهندسة الزراعية , مدنى , السودان.

الخلاصة

أجريت هذه التجربة في موسم 10/2009 في مزرعة محطة بحوث الحامداب الجديدة، مشروع الحامداب الجديدة الزراعي في شمال السودان. تم تحديد الكثافة الظاهرية للتربة مع محتوي الماء عند أعماق 0- 20 سم ،20-40 سم ، 40-60 سم، 60-80 سم و 80- 100 سم من قطاع أرضى بعمق120سم مستخدمين طريقة (Core method). وقد تم إجراء اختبار لعلاقة الارتباط بين الكثافة الظاهرية للتربة و العمق، وكذلك بين الكثافة الظاهرية للتربة ومحتوي الماء. كما تم اختبار علاقة قيم خصائص التربة الفيزيائية ذات الصلة بالكثافة الظاهرية للتربة والمحتوي المائي. وقد أوضحت النتائج أن للكثافة الظاهرية للتربة علاقة معنوية ايجابية ($p \leq 0.001$) مع عمق التربة ($r^2 = 0.99$)، وعلاقة معنوية عكسية مع محتوى الماء عند كل الأعماق أعلاه حيث كان معامل التحديد (Coefficient of determination) يساوى 0,99 ، 0,98، 0,97 و 0,57 على التوالي. ولذلك فمعادلات الانحدار كانت مناسبة لمنحنى الكثافة الظاهرية للتربة لكل الأعماق. كذلك ازدادت قيم كل خصائص التربة الفيزيائية ذات الصلة بالكثافة الظاهرية بزيادة محتوى الماء في التربة ماعدا مسامية هواء التربة والتي تناقصت بزيادة محتوى الماء في التربة. كما أبانت الدراسة أن كمية مياه الري المطلوبة لري هذه التربة عند درجة محتوى ماء 5% تساوى 1693 مترا مكعبا لكل هكتار وهذه الكمية التي تحتاجها هذه التربة عند الزراعة.