

Soil Moisture Content as a Determining Factor for Machinery Selection

II. Determination of soil workability for tillage operations as a function of soil moisture content

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ABSTRACT

Experiments were conducted at the Seed Propagation Farm of the Rahad Scheme (280km south of Khartoum) to determine the soil workability criterion of the clay soil, which is the dominant type of soil in the region of rainfed agriculture in the Sudan. The parameters used were the soil bulk density, shear strength, draft, wheel slip and particle size distribution. It was found that the suitable range of SMC for plowing lies between 0.17FC and 0.80FC (14%-29.9% of the available moisture content).

INTRODUCTION

Soil moisture content has a major influence on soil strength and consistency, and thus on how the soil will react to a certain type of pressure (Krause and Lorenz, 1984). Moreover, the soil moisture content, which is highly affected by climate and weather conditions, has a considerable effect not only on the cultivation practices but also on agricultural production.

The major problem in all arid regions is the short time available for tillage, and under these conditions all cultivation operations should, be aimed at making optimum use of frequent precipitation (Krause and Lorenz, 1984). The maximum amount of water can be absorbed only if the soil surface is neither crusty nor compact.

Crusty soils can be best plowed when they are in an intermediate soil moisture condition, since when they are too wet they puddle, and when they are too dry they break up into big chunks and powder (Allman and Knoke, 1947). At the intermediate moisture content soils are friable and ready to break up into clods of desired size range with the least amount of effort. The precise moisture range of "optimal wetness" has to be determined specifically for each type of soil.

Farmers disagree on how dry the soil should be for field work. Moreover, researchers have not established standards for determining the threshold moisture to begin field operations (Notle *et al.*, 1983).

Agronomists describe the proper soil moisture for planting as that which gives good seed-soil contact. On the other hand, farmers refer to plow "scouring" where the soil does not stick to the plow if the soil moisture content is satisfactory, or they say the soil is turning up "slick" if it is too wet.

In practice, the farmers test whether the soil has dried sufficiently to be tilled subjectively by kneading and rolling a punch of the wet topsoil in the palm of the hand and then casting it on the ground. If it breaks into pieces the soil is workable, otherwise it is too wet to be worked (Voorhees and Walker, 1977). In this way and through practical experience, a farmer can get an idea about the effect of any tillage machine on the soil.

A more objective assessment of soil workability should be provided from actual field records through estimating the probability distribution of the days in which farmers can get in the field to accomplish specific tasks (Rosenberge *et al.*, 1982).

Simalenga (1989) indicated that a soil is considered workable under the following conditions:

1. It has sufficient shear strength to withstand the weight of the tractor.
2. It has sufficient shear strength to meet the traction requirement with acceptable wheel slip.
3. A suitable soil tilth can be produced.

The quantitative description of soil behaviour in response to its workability and vehicular traffic have been investigated and reported by many researchers (Knight and Freitag, 1982; Batesman, 1963; Hassan and Broughton, 1975; Voorhees and Walker, 1977). In order to predict such behaviour, it was necessary to identify the relevant soil strength parameters and relate them in terms of well-known physical properties such as bulk density and soil moisture content.

Previous researchers (Simalenga, 1989; Rounsevell, 1993) have dealt with the estimation of suitable working days and used the soil moisture content above which it is postulated to be impossible to perform field operations as a criterion for defining the working days. Moreover, many scientists found that it is convenient to express the soil workability criteria as a percentage of field capacity; while (Shaw, 1965) argued that soil workability criteria should be expressed as millimeters of available water capacity. Allman and Knoke (1947) have reported that a soil is tractable when the soil moisture content is near field capacity.

Selirio and Brown (1972), Witney and Oskoui (1982), and Tulu *et al* (1974). used the soil moisture content as a function of field capacity in the prediction of working days. They showed that cultivation was possible when the soil moisture content was below 95% of the field capacity. However, Wintey and Oskoui (1982) defined 110% of the field capacity as the maximum condition in determining suitable field days in arable farms.

The main objective of this research work was to determine soil workability criteria based on soil physical properties and moisture content for tillage operations in the field.

MATERIALS AND METHODS

Experimental site

The experimental work to determine the effect of soil moisture content on slip, draft and soil physical properties was carried out within the Rahad Scheme, which lies some 280km south-east of Khartoum. The Scheme lies in the central clay plains of the Sudan. The soil is Vertisol with about 70% montmorillonite clay of low water permeability, high water holding capacity, and with very low nitrogen and organic matter content.

Materials

For the draft measurement, a spring-type dynamometer was used. An International 1086, 2WD tractor and a trailed 770 International Offset disk harrow were used for tillage operations, because disk harrows are the most used tillage implements. The dynamometer was inserted between the tractor and the implement. Throughout the experimental work, the speed and depth of harrowing were kept constant at 7km/h and 200mm, respectively.

During the experimental work, the other soil parameters, which were measured and recorded, were soil moisture content, soil bulk density, initial and final shear strength, particle size distribution, as well the tractor wheel slip. Soil tilth was subjectively evaluated.

Experimental procedures

(a) Particle size distribution

Six soil samples were taken at depths of 0-10cm, 10-20cm and 20-30cm after the harrowing operation. The standard hydrometer test method was used to determine the particle size distribution. The particle size distribution was expressed in terms of gravimetric percentage of clay (<0.002mm), silt (0.002-0.06mm) and sand (0.06-2.0mm).

(b) Bulk density

Soil bulk density was determined using a core sampler. A 1000cm sampler was inserted into the soil to take the soil sample. The soil sample was oven-dried and weighed. The weight of the dry soil was then divided by the volume of core sampler to obtain the bulk density in g/cm^3 . This procedure was replicated three times.

(c) Field capacity and permanent wilting point

The field capacity and the permanent wilting point of the soil were determined by measuring the soil moisture content at 1/3 bar, and 15 bar, respectively. The standard pressure-plate and pressure-membrane apparatus was used to determine the field capacity and permanent wilting point. These measurements were replicated three times. The difference between the field capacity and the permanent wilting point was the available moisture content. The soil workability was then expressed as a function of field capacity and the available moisture content.

(d) Shear strength

The soil shear strength was measured using a vane shear meter. Three measurements were made each time at depths of 0-1.0cm and 10-20cm before and after one harrowing operation.

(e) Particle size distribution

Particle size distribution was determined using two sieves one having 5x 5cm openings, and the other having 1 x 1cm openings. The plowed soil was sieved on a polyethylene mat, and the weight of each particle size was determined. The procedure was replicated six times. The particle size distribution was then expressed as course > 5 cm, medium 1-5 cm and fine < 1cm.

(f) Soil tilth

The quality of soil tilth after the harrowing experiment was determined by three assessors: The farmer, the driver and the researcher. The parameters used for evaluation were fineness of the tilth, field leveling, harrowing depth and residue management. They gave their judgment of soil tilth as good, medium and fine.

(g) Wheel slip

The tractor wheel slip was determined by measuring the distance traveled in ten revolutions of the rear wheel when pulling the implement ((D_1)) and the distance traveled with no load ((D_2)). This procedure was replicated three times. The percent slip was determined by the following equation (Culpin, 1967):

$$\% \text{Slip} = \{(D_2 - D_1) / D_1\} 100$$

RESULTS AND DISCUSSION

Results from the soil mechanical analysis are shown in Table 1. Accordingly, the soil was classified as a clay soil, and this result reflects the main characteristics of the soil in the central clay plains of the Sudan.

Table 1. Mechanical analysis of soil.

Depth (cm)	Course sand%	Fine sand%	Silt%	Clay%	Soil type
0-10	6	4	36	54	Clay
10-20	5	4	37	54	Clay
20-30	4	3	36	57	Clay
Mean	5	4	36	55	Clay

The water retention characteristics of the soil are shown in Table 2. The average field capacity (FC) and the permanent wilting point (PWP) were found to be 39.95% and 20%, respectively, while the available moisture content (AWC) was 19.95%. These results coincide with those of Farbrother (1969) in which the field capacity was 36%, the permanent wilting point was 18% and the available water content was 18%. The average bulk density was found to be 1.16g/cm³ (Table 2).

Table 2. Soil water retention characteristics

Depth(cm)	FC (%)	PWP (%)	Available water%	Bulk density(g/cm ³)
0-10	36.8	18.4	18.40	1.12
10-20	39.5	19.4	19.70	1.16
20-30	40.7	20.4	20.30	1.18
30-40	42.8	21.4	21.40	1.19
Mean	39.95	20.0	19.95	1.16

Effect of soil moisture content on slip and draft

The effects of soil moisture content on slip and draft are shown in Table 3. It was observed that the wheel slip and draft were directly proportional to the soil moisture contents until up to the SMC of 30.7% above which it became impractical to perform the harrowing operation due to the excessive wheel slip. On the other hand, at 6.63% moisture content the quality of the soil tilth was found to be poor although both slip and draft were the lowest. The correlation coefficient SMC on wheel slip and draft were high and significant (0.91 and 0.9, respectively).

Table 3. Effect of SMC on slip and draft

Moisture content%	Slip%	Draft(kN)[
30.70	17.10	20.00
29.90	17.00	19.50
28.60	16.70	19.00
26.40	14.70	18.50
16.93	12.70	17.50
14.03	11.29	16.00
6.63	9.63	15.00

Effect of soil moisture content on bulk density

The effect of SMC on bulk density is shown in Table 4. It was found that at 6.63 moisture content the bulk density was higher and decreased as the SMC increased.

Effect of soil moisture content on shear strength

The effect of 6MC on shear strength is shown in Table 4. It was also found that at 6.63% moisture content shear strength was highest and decreased as the SMC increased. For shear strength, the analysis resulted in a correlation coefficient of -0.45.

Effect of soil moisture content on particle size distribution

The results of the effect of SMC on particle size distribution are shown in Table 4. It was observed that the amount of course clods decreased with the increase in SMC up to a level of 28.6% and then increased with the increase in SMC. The increase in the amount of clods improves aeration and water infiltration rate, and this constitutes one of the major objectives of soil tillage, i.e. the increase in the amount of course clods improves the soil structure (Gill and Vanden Berge, 1967).

Table 4. Effect of SMC on soil parameters and tilth.

MC %	Shear strength (kN/m ²)		Bulk density (g/cm ³)		Clods size distribution			Soil tilth
	1	F	1	F	C	M	F	M
30.70	5.04	2.17	1.04	0.87	52.10	29.35	20.55	G
29.90	7.40	3.70	0.85	0.82	35.88	20.06	44.06	G
28.60	4.10	2.20	0.99	0.81	13.57	31	55.11	G
26.40	4.60	2.20	1.11	0.98	26.52	41.31	26.17	G
19.90	5.30	2.10	0.91	0.87	30.61	36.85	32.81	G
14.03	5.25	2.62	0.85	0.81	34.90	27.57	37.57	G
6.63	9.00	4.20	0.95	1.16	41.28	29.35	30.79	P

Key; 1=Initial. C=Course, G=Good, f= Final, M= Medium, P = Poor and F= Fine

CONCLUSION

From the results of this research work, the following conclusions could be made:

- 1- SMC significantly affects the final soil condition and tilth quality.
- 2 - The bulk density and shear strength decrease with increased SMC.
- 3- The optimum range of SMC for workability lies between 14% and 29.9%.

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