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DETERMINATION OF SUITABLE FIELD WORKDAYS FOR TILLAGE OPERATIONS AT SELECTED LOCATIONS OF KADUNA STATE, NIGERIA

Abdulsalam, M*., Isiaka, M., Gwarzo, M. A., Dalhat, M. K. and Dalha, I. B.
(*Agricultural Engineering Department, Faculty of Engineering, Ahmadu Bello University, Zaria, Nigeria)*
*Corresponding author, e-mail address: mabdulsalam@abu.edu.ng, Tel.: +234(0)8036052632

Abstract
Suitable field workdays for agricultural machine operations (ploughing, harrowing and ridging) of some selected areas of Kaduna State in Nigeria were determined using soil moisture level and rainfall criteria. These involved the development of soil moisture budget and establishment of tractability criteria for each soil types assessed. Thirty (30) years meteorological information of these areas were collected from the Institute for Agricultural Research ABU, Zaria and total of 200 soil samples were collected from 20 different farm lands and analyzed. The soil particle sizes, bulk densities, soil moistures level at field capacity and plastic limits were determined and the soil moisture limits were used to set the tractability criteria for each soil types. The information obtained was used to develop a computer based programme to monitor the variation in the moisture level. The estimated soil moisture levels and rainfall amount were compared with the tractability criteria to segregate the tractable and non-tractable soil moisture determining suitable and non-suitable workdays respectively. Out of the annual crop growing season of 214 days (from April to October) considered in this study, the sandy-clay-loam soils had the highest machinery suitable field workdays of 76 (35.51%) days for tillage operations (ploughing, harrowing and ridging). The clay soil had the least available machinery tillage workdays of 49 (23.00%) days. The sandy, sandy-loam, loam and clay-loam soils have 69 (32.24%), 63 (29.44%), 54 (25.23%) and 50 (23.36%) suitable workdays respectively.

Key Words: Tillage, workdays, tractability criteria, moisture level and rainfall

1. Introduction

The success of most agricultural operations depends on the weather. Weather is one of the major constraints for agricultural operations (USDA, 2009). For a particular crop, there is an optimum time period for tillage, planting, weeding and harvesting operations to ensure maximum crop yields at minimum cost of inputs. If a crop is planted at a time other than within the optimum period, reduced yield may occur and lead to losses. When the crop matures, and is not harvested within the optimum period, some of it may deteriorate in the field, leading to losses in production. These losses attract extra costs usually referred to as timeliness costs and are increased by unfavorable weather conditions (Edwards and Hannah, 2007). Accurate information on the days suitable for field operations is important in the design, development and selection of efficient machinery systems for crop production (Rotz and Harrigan, 2005). In addition, it may be a very useful tool for scheduling farm activities, such as tillage operations, planting, and harvesting operations. USDA (2009) reported that for efficient field operations and machinery selection, it is important to have a good knowledge of suitable field workdays for agricultural field machinery operations and this is determined by the amount of moisture in the soil. Once the number of days that are expected to operate a field machine have been determined, the minimum of daily machine capacity can be computed and used to select the suitable implement for the operation.

Weather patterns determine the number of days suitable for field work in a given time period each year. The procedure for determining workdays is based on weather condition, soil moisture and tractability criteria (Rounsevell, 1993). Many researchers have used computer simulation to model the relationships among the variables that determine the suitability of a day for field operations and estimation of suitable workdays were based on soil-moisture balance and tractability condition. Several models were developed and they were similar in that soil moisture was tracked and some critical soil moisture conditions were set to determine whether a given field operation could be performed on a given day (Griffin, 2009; Edward and Hannah, 2007; Rotz and Harrigan, 2005; and Gwarzo, 1990). Rotz and Harrigan (2005) reported that the approach for determining suitable workdays is the use of soil moisture limits and some critical soil moisture conditions set to determine whether a given field operation could be performed on a given day. The critical moisture levels were expressed in relation to the water-holding-capacity of the soil zone.

The suitable day's computer model was developed for use as a component of the integrated farm system model. This model follows the similar approach to that used in model developed in 1970s (Dyer and Bair, 1979). Gwarzo (1990) gave a report on suitable workdays in the Mokwa area of Niger state, Nigeria and the suitable days for field work were determined on a daily time step based on soil moisture, rainfall amount and tractability criteria. A BASIC computer programme developed was used to segregate the good and bad days for field work. The segregation was done taking into account information with respect to daily precipitation, existing weather conditions and soil moisture relationship. Hassan and Broughton (1975) used soil moisture as criterion to determine the suitability of field conditions for machine operations at MacDonald College Farm in the St-Lawrence low lands, United State of America. Soil moisture measurements were conducted and three different soil textures were considered-fine sandy loam, clay loam and clay. All three sites were sampled daily from June 7 to June 15 for soil moisture determinations. The measured soil moisture was averaged for six samples of the top zone.

Based on the above studies on suitable time for field operations it is obvious that weather conditions may place severe constraints on the time available for carrying out field operations during the agricultural production (Cevdet and Ibrahim, 2011). Specifically, in the selected areas of this study, frequent machinery breakdown and general poor utilization due to the weather and soil factors has been reported (Oyesiji, 2013). Determination of suitable workdays will allow farm managers to plan and optimize the machinery type, capacity and utilization. The objective of this study was to determine the available suitable workdays for tillage operations at Dogarawa, Giwa, Samaru and Shika areas of Kaduna State, Nigeria. The study will assist the farm managers and machinery owners in planning their field operations and selecting required machinery.

2. Methodology

The study of suitable field workdays for agricultural machinery tillage operations was carried out at selected areas in Kaduna with coordinate of 11^{o}11' N 7^{o}38' E on an altitude of about 686 m above sea level. The areas are situated in the northern Guinea Savannah ecological zone of Nigeria. The region have three distinct seasons; namely the hot dry season from March to May, the warm rainy season from June to October, and a cool dry season from November to February with an average relative humidity of 36.0 % during the dry season and 78.5 % for the wet season and average minimum temperature of 15 ^{o}C and maximum of 38.5 ^{o}C (NCAT, 2008).

Average climatic data and soil properties were taken as the constraining factors to determine the available workdays for tillage operations. For this purpose 30 years (1982-2012) Climatic data were obtained from meteorological unit of Institute for Agricultural Research (IAR), Ahmadu Bello University (ABU), Zaria, Nigeria. The data include rainfall, temperature, (minimum and maximum), relative humidity, vapour pressure, sunshine hours, wind speed and radiation. The climate data were used to develop a Suitable Field Workdays (SFWD) computer based programme to solve the constraint equations involving climate data analysis. It uses the data and soils information as the primary input to analyze the state of the specified soil on a specified day.

The programme secondary inputs data were specific day, location and soil type. The programme uses the secondary data to simulate the required climatic data from the primary data located at the database. The simulated climatic data were used for estimating the rainfall amount, potential evapotranspiration, runoff and deep percolation by following the predefined algorithm to estimate the soil moisture storage using the soil moisture budgeting equations.

2.1 Soil Moisture Budgeting

Daily soil moisture balancing for the period April to October (a total of 214 days) for whole year was estimated. For each of the soil assessed, on the day of initialization the soil moisture (SM_{nd-1}) on the previous day (31^{st}, March) was assumed zero. Soil moistures level was determined using Equation (1). The components (rainfall, runoff, deep percolation etc.) which constituted the soil moisture balance equation were determined using the simulated weather data and the programmed equations. The estimated rainfall amount, runoff, deep percolation and initial soil moisture, SMn-1 were fitted into equation 1 to give the daily soil moisture change on a particular day;

$$\pm DSM_n = P_n - ET_n - RO_n - (D_n) \pm SM_{n-1} \quad (1)$$

where:

DSM_n = daily soil moisture, mm, P_n= rainfall amount, mm, ETn= potential evapotranspiration, mm/day, RO_n= runoff, mm,

D_n =Deep percolation, mm, SM_{n-1}= initial soil moisture, mm

The actual moisture in the soil is the cumulative sum of the daily soil moisture level change. This is also the soil moisture storage in mm. The estimated soil moisture for each day was summed cumulatively from the day of initialization to give the soil moisture level on the specified *n* day. The cumulative soil moisture was estimated using Equation (2)

$$SM_n = \sum_{i=1}^{n} DSM_n \quad (2)$$

where;

SM_n= stored soil moisture, mm, DSM_n=daily soil moisture, mm

Basically, the primary data used to determine the components of the soil moisture budgeting constitute the climatic data, soil types, moisture levels at field capacities and plastic limits, z-*table* and the mathematical equations scripted to analyze the specified task. The components of the soil moisture budgeting equation were modeled as follows;

2.1.1 Rainfall Amount:

The rainfall amount was determined using the Rainfall Normal Distribution Model equation 3. This model involves taking the average sum of the rainfall amount, the standard deviation and the corresponding z value defined by the probability of rainfall Occurrence. Usman (2011) reported that rainfall normal distribution model gives more accurate rainfall amount of the study areas compared to other models;

$$P_n = \mu_{P_n} + z\sigma_{P_n} \tag{3}$$

where:

P_n= estimated rainfall amount, mm, μ = rainfall mean value, mm, σ= deviated rainfall value, mm, z = z value read from normal distributed table,
n= specified day

2.1.2 Potential Evapotranspiration, Et_o

Penmann-Monteith Model (equation 4) as reported by Richard et al. (1998) was used to calculate the potential evapotranspiration. The potential evapotranspiration of the study areas were determined using the 30 years meteorological data collected from IAR meteorological unit.

$$ET_{o_n} = \frac{0.408\Delta_n(R_n - G) + \gamma\frac{900}{T_n+273}u_n(e_{sn} - e_{an})}{\Delta_n + \gamma(1 + 0.34u_n)} \tag{4}$$

where;

R= net radiation, $MJm^{-2}day^{-1}$, G= soil heat flux, $MJm^{-2}day^{-1}$, T= air mean temperature, ^oC, U= wind speed, ms^{-1}, e_s=saturation vapour pressure, kPa, e_a= actual vapour pressure, kPa, Δ= slope vapour pressure curve, $kPaoC^{-1}$, γ= psychometric constant, kPa^oC^{-1}, Specified number of day

2.1.3 Determination of runoff RO;

The surface runoff was assumed to occur when precipitation exceeds a threshold limit defined by Equation (5) (Suresh, 1997):

$$RO_n = \frac{(P_n - 0.2\times S)^2}{P_n + 0.8\times S} \quad \text{if } P_n > 0.2\times S \tag{5}$$

Runoff, RO = 0 if $P_n \leq 0.2\times S$

where;

S= surface retention capacity, mm, CN= curve number, P_n= rainfall amount, mm

2.1.4 Deep-percolation, D_n

Deep percolation occurred only after the soil pores have been filled with water to field capacity (Igbadun, 2006). Any water which passes beyond the bottom layer (300mm) is assumed to be lost to deep percolation. In this study, deep percolation was considered zero if $DSM_{n-1} \leq Fc$. The level of deep percolation was determined using Equation (6):

$$D_{nd} = (DSM_{n-1} - Fc) \quad (6)$$

where:
DSM= previous soil moisture storage, mm, FC= field capacity, mm

2.2 Determination of Tractability Conditions for the Collected Soil Samples

The study areas have same climatic conditions so the tractability of agricultural machinery was based on the soils types and its properties. A 30 cm depth of the soil thickness was considered adequate to support agricultural machine operations (Gwarzo, 1990). Amount of soil moisture levels within the top 30 cm of the soil layer and limits of daily rainfall were used as the tractability criteria. The product of the soil depth, 30 cm, the bulk density of the soil and the moisture level at that limit gives the amount of soil moisture. The tractability conditions involve the soil textural class, soil moisture level at field capacity and plastic limit of each soil type, the soil bulk density and the soil depth (300mm) in this study. These information were used to establish the upper and lower limits of soil moisture level for good traction as indicated in the Equations (7) and (8) respectively (Gwarzo, 1990).

$$Tractability\ upper\ limit, TUL = 95\% \times \frac{F_c \times D \times BD}{100} \quad (7)$$

$$Tractability\ lower\ limit, TLL = \frac{P_l \times D \times BD}{100} \quad (8)$$

where;
P_l= plastic limit, mm, BD= bulk density, g/cc, D = soil depth, mm, TUL= Tractable Upper Limit, mm, TLL= Tractable Lower Limit, mm

Twenty (20) different farms were visited in the study areas and ten (10) soil samples were collected from each of the farms using an auger excavator. The samples collected were analyzed in the Civil Engineering Department soil testing laboratory, Ahmadu Bello University, Zaria. The constituted clay, silt and sand in percentage were recorded and grouped based on the USDA textural class. Also, soil moisture at field capacity of each soil sample was determined with a pressure plate apparatus at 33.33 kPa and recorded. The moisture levels at plastic limits of the soil types were determined. The soil bulk densities **w**ere determined using an un-compacted soil samples extracted with an auger. The bulk density of a soil mass is the dry weight per unit bulk volume (Musa, 2010).

$$BD = \frac{W_b}{Vc} \quad (9)$$

where;
BD = Bulk density, g/cc, W_b= weight of dried soil, g, V_c = bulk volume, cm^3
The results of the soil analysis, soil moisture level at field capacity, plastic limit, bulk densities and soil depth were recorded and used to establish the tractability condition using equations 7 and 8.

3. Results and Discussion

3.1 Soil Types and Characteristics of the Study Areas

The results of the particle soil analysis test are presented in Table 1. The results indicated that most of the farm land in Samaru had sandy, sand-loam and sandy-clay-loam soil. Shika farm land had sandy-loam, loam and sandy-clay-loam soil. Loamy and clay soil were most present in Giwa farm land. The Dogarawa farm land soil types were mostly characterized by sandy-loam, clay-loam and clay soil. The sandy soil had the highest bulk density of 1.75 g/cc and the least field capacity of 12.5 %. The clay soil had the highest field capacity of 42% and the least bulk density of 1.27 g/cc. This may be attributed to the textural properties of the soils. The light textured soils (sandy and sandy-loam) are coarser and contained more voids; therefore, the moisture retention will be low but higher specific weight in particles. Heavy textured soils (clay and clay loam) retained more moisture but less specific weight. This is because heavy textured soils are less coarse and have fewer voids spaces compared with light textured soils. The soil textural properties greatly influence the moisture retention, drainage characteristic of soil and tractability of the soil. The clay soil had the highest upper limit of tractable soil moisture of 149.63 mm while the sandy soil had the least tractable upper soil moisture with 62.34 mm. The soils with fine particles sizes have higher bulk density.

The moisture level at plastic limits for each soil types are as shown in Table 2. The plastic limits of the soils were used to establish the lower limit of tractable moisture levels. The clay soil had the highest moisture level at plastic limit with 24.80 mm and sandy soil had the least with 8.35 mm. Soil moisture level less than 24.80 mm in the clay soil are considered non tractable soil moisture. This may be attributed to the soil cohesiveness at that state. Also, it is observed that more coarse soils are easily friable and less cohesive. A 8.35 mm soil moisture sandy soil is tractable. This is because soil particles are less cohesive and it can easily get drained.

Table 1: Soil analysis showing the upper limit of tractable soil moisture level for each soil type

Locations	Depth, mm	Bulk density g/cc	Field capacity oven dry %	Moisture held at *fc* in 300mm	Tractable SM upper limit, mm	Texture class			Soil type
						Clay %	Silt %	Sand %	
Samaru	0-150	1.70	12.5	65.63	62.34	10	17	73	*SANDY*
	150-300	1.75				9	16	75	
		1.52	18.0	84.78	80.54	15	40	45	*SAND-*
		1.57				15	39	46	*LOAM*
		1.50	27.0	124.74	118.50	34	31	35	*SANDY-CLAY*
		1.54				33	31	36	*LOAM*
Dogarawa	0-150	1.27	42.0	157.50	149.63	68	17	15	*CLAY*
	150-300	1.25				70	16	14	
		1.52	18.0	84.78	80.54	15	40	45	*SAND-*
		1.57				15	39	46	*LOAM*
		1.35	36.0	144.72	137.48	41	30	29	*CLAY-*
		1.34				42	29	29	*LOAM*
Giwa	0-150	1.49	28.0	125.16	118.90	29	40	31	*LOAM*
	150-300	1.41				30	40	30	
		1.27	42.0	157.50	149.63	68	17	15	*CLAY*
		1.25				70	16	14	
Shika	0-150	1.49	28.0	125.16	118.90	29	40	31	*LOAM*
	150-300	1.41				30	40	30	
		1.52	18.0	84.78	80.54	15	40	45	*SAND-*
		1.57				15	39	46	*LOAM*
		1.50	27.0	124.74	118.50	34	31	35	*SANDY-CLAY*
		1.54				33	31	36	*LOAM*

Table 2: Plastic limits showing the lower limit of tractable soil moisture for each soil type

Locations	**Average Moisture, %**	**Tractable Soil Moisture level, Lower Limit, mm**	**Soil Type**
Samaru	2.783	8.35	*Sandy*
	2.967	8.90	*Sandy-Loam*
	3.950	11.85	*Sandy-Clay-Loam*
Dogarawa	2.967	8.90	*Sandy-Loam*
	8.267	24.80	*Clay*
	6.367	19.10	*Clay-Loam*
Shika	3.550	10.65	*Loam*
	6.367	8.90	*Sandy-Loam*
	3.950	11.85	*Sandy-Clay-Loam*
Giwa	8.267	24.80	*Clay*
	3.550	10.65	*Loam*

3.2 Tractability Conditions for the Soil Types in the Study Areas

The established tractability conditions shown in Table 3 were used to establish if the estimated soil moistures levels were within the limits bound of tractable soil moisture. This was the major technique used to segregate between the good and bad field workdays. The clay soil (heavy textured) was observed to have the highest tractable soil moisture limit with 149.63 mm and the lower tractable soil moisture limit was 24.80 mm. This may be attributed to moisture retention capacity and poor rate moisture draining of the soil. Sandy soil had the least tractable soil moisture. While the sandy soil had the least upper tractable soil moisture among the soil types considered in this study. The upper limit of tractable soil moisture level was 62.34 mm and the lowest limit was 8.35 mm. This means that at a less soil moisture, the sandy soil was suitable for tillage operations unlike the heavy textured (clay) soil. Also, the rainfall criteria involve setting limits for the immediate previous rainfall amount and the present rainfall amount. For a day to be considered suitable for tillage operations, the rainfall yesterday and today must not exceed 14 mm and 7 mm respectively, as established in tractability condition shown in the Table 3.

Table 3: Parameters defining field conditions for tractability in the studied areas

Parameter	Tractability Criteria	Limits of soil Moisture level for each soil type, mm					
		Sandy Soil	*Sandy-loam*	*Loam Soil*	*Sandy – clay-Loam*	*Clay Soil*	*Clay loam*
1. Tractable or good workday	Moisture level in the top 30 cm of soil profile ***not exceeds*** 95 % of field capacity.	≤62.34	≤80.54	≤118.90	≤118.50	≤149.63	≤137.48
	Maximum rainfall yesterday (14 mm). (heavy, medium and light textured soils)	≤14	≤14	≤14	≤14	≤14	≤14
	Maximum rainfall today (7 mm). (heavy, medium and light textured soils)	≤7	≤7	≤7	≤7	≤7	≤7
	Moisture level in the top 30cm of soil profile not to be less than lower plastic value.	≥8.35	≥8.90	≥10.65	≥11.85	≥24.80	≥19.10
2. Non-tractable or non-good workday	Moisture level in the top 30cm of soil profile ***exceed*** 95 % of field capacity (light to medium textured soils)	≥62.34	≥80.54	≥118.9	≥118.5	≥149.63	≥137.48
	Maximum rainfall yesterday exceeds (14 mm). (heavy, medium and light textured soils)	≥14	≥14	≥14	≥14	≥14	≥14
	Maximum rainfall today exceeds (7 mm). (heavy, medium and light textured soils)	≥7	≥7	≥7	≥7	≥7	≥7
	Moisture level in the top 30cm of soil profile less than lower plastic limit value.	<8.35	<8.90	<10.65	<11.85	<24.80	<19.10
3. Best conditions for tillage	Moisture level in the top 30cm of soil profile between lower plastic limit to upper plastic limit. (heavy, medium and light textured soils)	From 8.5 to 62.34	From 8.9 to 80.54	From 10.65 to 118.90	From 11.85 to 118.50	From 24.8 to 149.63	From 19.1 to 137.48
	Maximum rainfall yesterday (14 mm)	14	14	14	14	14	14
	Maximum rainfall today (7 mm)	7	7	7	7	7	7

3.3 Suitable Workdays for Tillage Operations (ploughing, harrowing and ridging)

Out of the 214 days working season duration for each soil type assessed for tractability conditions, the sandy-clay-loam soil had the highest suitable workdays with 35.51 % of the total time as suitable for field work while the clay soil have the lowest estimated number of suitable workdays with 23.00 % of the total time as suitable for field work. From April to May the light textured soil had more suitable workdays. Both sandy and sandy-loam soil had 9 and 7 suitable workdays in the month of April and May respectively. The heavy textured soils (clay and clay-loam) both had 0 and 1 suitable workday in the month of April and May respectively. This may be strongly attributed to the textural properties of the soils. In this period, the soil moisture is low and that the cohesive soils (heavy textured soil) are still very hard and not workable. In this period, the pre-rainy season prevails and the amount of evapotranspiration is more than the moisture going into the soil. In the month of June, the soil moisture is optimum for tillage operations. The clay-loam soil had the highest available workdays, the whole of this month was considered suitable for tillage operations. The sandy soil had the lowest available suitable workdays with 21 days found to be suitable for tillage operations. The sandy-loam, loam, sandy-clay-loam and clay had equal number of available suitable tillage workdays which was found to be 28 days. In the month of July, maximum suitable field workdays are recorded for clay soil types. This may be attributed to the moisture retention property of the clay soil and that it required more soil moisture to ensure penetration and pulverization during tillage operations compare with the light and medium textured soil. Only 2 days found suitable for tilling the light soil textured soils (sandy and sandy-loam soil) in the month of July. In the month of August and September, the rainfall intensities were at peak, the soil moisture level exceeds the upper limit of tractable soil moisture. The clay, clay-loam, sandy-loam and loam soil had no suitable day for tillage operations. Only the sandy and sandy-clay-loam had 1 day suitable for tillage operation in the month of August. These soils are coarser, so moisture level can easily be drained to reduce the soil water level. In the month of September, rainfall occurrence and its intensity started reducing in the third week of the month. The coarse soils (sandy and sandy-loam) had 11 and 8 suitable workdays respectively. The clay, clay-loam and sandy-clay-loam had 0, 0 and 7 suitable workdays respectively. This was because the heavy textured soils have more moisture retention capacity compared with the light textured soil. The moisture level in the light textured soils was easily drained to obtain tractable soil moisture. The stored moisture level in the soils was further drained in the month of October. In this month, 18, 14, 9, 0, 0, and 0 tillage workdays were recorded suitable for sandy, sandy-clay-loam, sandy-loam, clay-loam, loam and clay soil respectively. Due to the retention capacity of the heavy textured soils (clay and clay-loam), the moisture level was still above the upper limit of tractable soil moisture. The percentage of available suitable days for tillage operations are 29.44%, 32.24%, 25.23%, 35.51% 23.00% and 23.36% for sandy-loam, sandy, loam, sandy-clay-loam, clay and clay-loam soils respectively as shown in Table 4.

Table 4: Estimated machinery good field workdays for tillage operations (ploughing, harrowing and ridging) for each of the soil types considered in the study areas

	Soil types					
Month	Sandy soil	Sandy-loam soil	Loam soil	Sandy-clay-loam	Clay	Clay-loam
April	9	9	6	6	0	1
May	7	7	6	5	0	1
June	21	28	28	28	28	30
July	2	2	14	15	21	18
August	1	0	0	1	0	0
September	11	8	0	7	0	0
October	18	9	0	14	0	0
Total	69	63	54	76	49	50
Percentage SWD	32.24 %	29.44 %	25.23 %	35.51 %	23.0 %	23.36 %

4. Conclusions

The available suitable field workdays for tillage operations in the selected locations (Dogarawa, Giwa, Samaru and Shika) were determined using the moisture level stored in the soil and rainfall as criteria. Out of the 214 days of the total working season, the percentage of available suitable days for tillage operations were 35.51%, 32.24%,29.44%, 25.23%, 23.36% and 23.00% for sandy-clay-loam, sandy-loam, sandy, loam, clay-loam and clay soil respectively. The availability of information on suitable workdays for tillage operations of the study areas will improve utilization of tillage equipment and general machinery management. Also, it will guide the farmers in machinery selection and scheduling of field operations.

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