PREDICTING SUITABLE FIELD WORKDAYS FOR SOIL TILLAGE IN NORTH CENTRAL NIGERIA.

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ABSTRACT

A simulation model was developed to predict suitable field workdays for tillage operations in North Central Nigeria. Predictions were made from a computer model which simulates daily soil moisture in the top 30 cm of soil depth using 6 years of daily meteorological records. The model was tested and validated by comparing its output with the observed workdays during the 1996 farming season on two soil types. Results show that there was good agreement between the observed and predicted values using established tractability criteria.

KEYWORDS: Suitable field workdays, tillage, agro –meteorology, tractability.

1. INTRODUCTION

The success of most agricultural operations depend on weather. For a particular crop, there is an optimum time period for tillage, planting, weeding and harvesting to ensure maximum crop yields at minimum cost of inputs (labour, planting materials, machinery, soil etc.) If a crop is planted at a time other than within the optimum period, reduced yield can occur leading 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. These losses attract extra costs usually referred to as timeliness costs [1] and are increased by unfavorable weather conditions.

The optimum time spectrum for each farm operation is further reduced in practice because some days within the period will not be good for field work. The time spectrum for planting maize may be up to three months but the actual good working days may be limited to one month since for some days, the soil will be too wet, too dry or there will be rain. If the soil moisture is too high, working the soil will lead to puddling compaction, soil deterioration and reduction in soil quality. For motorized operations, this will lead to increased wheel slip, impaired traction and general increase in time spent for field work. If the soil moisture is too low, ploughing may lead to the formation of large clods, excessive energy demand and poor quality of work. These unfavourable soil conditions, will eventually lead to non-sustainable agricultural production.

The summation of all the days that are suitable for field work for a particular operation is referred to as Suitable Field Workdays (SFW).

Information on SFW for different operations, crops and agro-ecological zones are useful to agricultural administrators, managers and farmers for planning purposes. Knowing the SFW for planting for example, a farm manager can decide in advance to increase or decrease labour and machinery. Such information will be useful to agencies such as Agricultural Development Projects (ADP), and Tractor and Equipment Hiring Units (TEHU) in developing farm calendar and extension documents for farmers. In the United States, SFW is given as part of American Society of Agricultural Engineers (ASAE) Standards D230.4 for different regions of the country. Similar standards are yet to be developed for Nigeria because of lack of data.

The prediction of SFW can be achieved by estimating the soil moisture content based on the moisture budgeting technique, combined with probability analysis [2]. The moisture is then compared to some established tractability criteria. If the soil moisture status meets the criteria, the day is considered a SFW. When this is evaluated over a period of time, the SFW for that operation is established. Several researchers have used this approach [3 – 16]. Although the models use a similar approach, the calculation of the components of the models is different since they are site specific.

In Nigeria, not much has been reported on determination of SFW, except the work of Gwarzo et al.,[17] for parts of the North Western Nigeria. At the National Centre for Agricultural Mechanization (NCAM), Ilorin, an Agro-meteorological Station has been established and agro-meteorological information is being generated and collated on a continuous basis. The data being generated will in the long run be useful in management of agricultural operations in the Niger Basin in particular and North Central Nigeria in general.

This paper describes a computer-based simulation model used to predict the effect of soil moisture on SFW for tillage operations in Ilorin, North Central Nigeria based on meteorological and other related data. It also reports the results obtained and highlights how the information can be used for agricultural watershed management.

2. METHODOLOGY

The approach used in this study was to study agro-meteorological data obtained from NCAM Meteorological Station and discuss the usefulness of these in agricultural watershed management. In particular, the problem of predicting suitable field workdays (SFW) was addressed. A model was developed for this purpose based on soil moisture budgeting and established tractability criteria. The model was applied to the watershed under study using agro-meteorological and other data for a period of time. The predicted results were compared with actual observed data on SFW. Details of this procedure are presented subsequently.

2.1 Agro-meteorological and Other Observations

The determination of SFW requires agro-meteorological and hydrological data which must be obtained on a daily basis over a period of time. Some data were obtained from the meteorological station at the National Centre for Agricultural Mechanization (NCAM) while others were obtained by direct measurements.

Since the meteorological station at NCAM became operational (in 1991), agro-meteorological data have been recorded on a continuous basis. These include time, amount and duration of rainfall, wind speed and direction, sunshine hours, open pan evaporation, air temperature and soil temperature.

Other measurements include runoff, soil moisture, field capacity, permanent wilting point and actual available field workdays. Runoff at various seasons was obtained from standard runoff plots under conventional tillage practice for the area. Daily soil moisture was obtained by sampling from NCAM experimental farm. The moisture content was determined by the gravimetric method. Actual observed SFW were obtained by following the activities of the Farm Management Unit of NCAM. Days in which field work could not be done due to rain, too high moisture or too low moisture were recorded. These observations started in August 1995 and is on a continuous basis in order to generate a long term data.

2.2 The Water Balance Model

A model was developed based on the concept that the available soil moisture is a function of previous precipitation, irrigation, drainage, evapotranspiration and surface runoff. The soil moisture content on any particular day is the difference between what it was the previous day plus any addition through precipitation or irrigation and the losses through runoff, drainage, and evapotranspiration. Thus, daily soil moisture was estimated as:

$$M_i = M_{i-1} + P_i + I_i - R_i - D_i - E_i \qquad (1)$$

where

M_i = Soil moisture content on day i, mm.

M_{i-1} = Soil moisture content on day i –1,mm.

P_i = Precipitation on day i, mm.

I_i = Irrigation on day i, mm.

R_i = Runoff on day i, mm.

D_i = Drainage on day i, mm.

E_i = Evapotranspiration on day i, mm.

Based on data from a related experiment, Runoff (R_i) was modelled as (Ahaneku, 1997):

$$R_i = 8.1P_i - 17.6 \qquad (2)$$

when $P_i > 4$mm

A drainage quantity was computed for use in the water balance equation of the following day provided the soil moisture was greater than field capacity.

Drainage was estimated according to Babeir et al., (1986):

$$D_i = (M_{i-1} - FC) * DC \qquad (3)$$

where FC = Field Capacity

DC = Drainage Coefficient

Actual evapotranspiration was estimated as:

$$ET_a = ET_p * K_c \qquad (4)$$

where

ET_a = Actual evapotranspiration (E_i)

ET_p = Potential evapotranspiration given as (Doroombos and Pruitt, 1975):

$$ET_p = 0.7E_{pan} \qquad (5)$$

where E_{pan} is pan evaporation obtained from meteorological observations. K_c is crop coefficient which varies with crop and season. Using soybean as the reference crop, and an average for the various seasons, a value of K_c = 0.95 was used as obtained from a field experiment [18].

Once soil moisture was computed, a set of criteria was used to establish if the soil was suitable for field operations.

2.3 Soil Tractability Criteria

Soil tractability is the ability of a farm land to permit a machine to operate and perform its function efficiently without damaging the soil. For operations that involve soil engaging, such as tillage and planting, the soil is tractable if it has sufficient bearing strength to support the weight of the machine, can develop adequate shear resistance to avoid slip and soil damage and can produce a good soil tilth without the formation of large clods. This soil behaviour varies with soil types and the operation being carried out. It is also dependent on the soil moisture status. Based on literature and actual field observation of machinery operations at NCAM, the following criteria were used for deciding when soil is tractable:

a) moisture content in the top 30 cm of soil depth not more than 95% of field capacity [16].

b) moisture content in the top 30 cm of soil depth not less than permanent wilting point.

c) if the previous day was a workday and today's precipitation was no more than 5mm.

Any day in which the soil is tractable using the above criteria is regarded as a suitable or available workday.

2.4 Computer Implementation

A computer programme was developed in Quick Basic for the model. In general, the model estimates the soil moisture content on a particular day, compares it with the tractability criteria and takes a decision on whether the soil is tractable and hence the day a workday.

The flow chart for the programme is shown in Fig. 1. It starts by initializing control parameters namely the starting date for the simulation, moisture content on the starting date, and time frame for the simulation. The meteorological data of interest are then read from a data file. These include rainfall, pan evaporation, relative humidity, maximum and minimum temperature, soil temperature. The tractability conditions are set as described earlier.

The next stage in the programme is to estimate daily soil moisture. First, the moisture content of the soil on the previous day is established. This is followed by establishing the precipitation for the present day from the values already read. Runoff is next determined using equation (2), followed by drainage [equation (3)]. Having calculated all the components, the moisture content of the soil on that day is calculated using equation (1).

The tractability condition is applied by checking the estimated moisture with that in the criteria. If the condition for a workday is satisfied, a counter for SFW is incremented. The programme then checks if the last day in the time window selected has been analysed. If the answer is negative, the process is repeated with data for the next day. When all the days have been analysed, results are summarized and presented to the user.

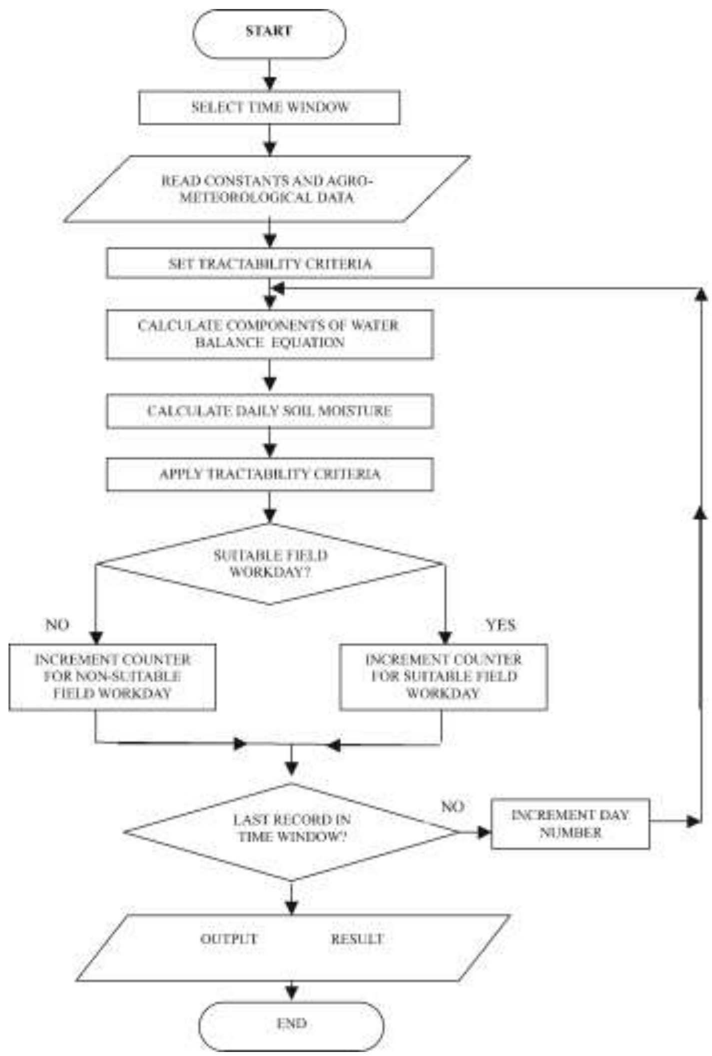

Fig. 1 Flow Chart of Suitable Field Workday Programme

The output data include all the input data as well as estimated soil moisture, an indication of whether the day is a good or bad workday (1 or 0), and the total SFW for the time period studied.

The programme was designed to be interactive and allows the user easy access to the input data file so that records can easily be updated or changed.

2.5 Model Validation and Application

Daily meteorological data for the period April through October, 1996 were used to validate the model. These were the months for which there was available data, especially soil moisture and actual observations of suitable field workdays. It is recognized that the period of validation is short. However, it was very important to test the predictive ability of the model before it could be adopted in any further study. Once an acceptable prediction is obtained on available data, projections can be made into the future by incorporating probability principles in predicting the relevant model parameters. Thus, the model was tested by comparing its predicted with observed suitable field workdays for sandy loam and clay soils of North Central Nigeria. For statistical confidence, the predicted and observed SFW were subjected to regression and correlation analyses.

3.0 RESULTS AND DISCUSSION

In evaluating the soil water balance equation, all input parameters except drainage coefficient were either measured or directly determined at the site of the experiment. This is to minimize the use of estimates from empirical equations in order to improve the level of accuracy and reliability of these parameters as advocated by Simalenga and Have (1994).

Monthly and yearly total rainfall for the years under review (1991-1996) are shown in Table 1. The rains generally start in April and reach a peak in June, July or September. In some years, two distinct peaks were observed as shown in the Table. It means that for rainfed agriculture (dryland farming), planting has to be done between April and September.

Table 1: Total monthly rainfall (mm) at NCAM, Ilorin, 1991-1996

Month	1991	1992	1993	1994	1995	1996
January	7.5	0	0	0	0	0
February	30.5	0	20.6	0	0	52.1
March	105.7	0	67.9	47.1	60.6	61.9
April	85.7	20.9	39.6	57.6	78.7	134.8
May	206.3	146.8	112.8	194.4	270.2	95.1
June	197.5	95.0	102.1	228.8	170.9	238.3
July	355.4	79.6	119.2	82.4	123.9	104.1
August	130.2	46.2	204.2	82.2	184.6	97.6
September	246.4	351.2	270.9	259.7	256.5	188.4
October	170.1	93.2	143.8	297.9	194.4	107.4
November	0	39.5	0	0	10.9	0
December	0	0	0	0	0	0
Total	1535.3	872.4	1081.1	1250.1	1350.7	1079.7
1^{st} Peak	July	May	Aug.	Sept.	May	June
2^{nd} Peak	Sept.	Sept	Sept.	Oct.	Sept.	Sept.

The actual number of rainy days are shown in Table 2. Between May and September, on the average, rain was observed for at least half of the days in a month. When one notes that Fridays and Sundays are likely to be days not available for work (for religious reasons in the area of study), it is clear that the farmer is faced with a very short period for activities that require work in the farm especially when machines and tools have to be used.

Table 2: Number of rainy days at NCAM, Ilorin*

Month	1991	1992	1993	1994	1995	1996
January	1	0	0	0	0	0
February	2	0	3	0	0	1
March	6	0	4	5	7	2
April	6	6	4	9	7	10
May	17	6	11	13	15	10
June	12	11	14	8	10	13
July	18	9	7	5	16	9
August	10	8	17	12	18	12
September	14	19	16	17	13	15
October	8	10	10	15	13	6
November	0	1	0	0	4	0
December	0	0	0	0	0	0

* Note that this refers to days in which there were rains irrespective of the quality or duration.

Testing and validation of the model was done for April – October, 1996, period for which a complete set of data was available. Table 3 is a summary of the observed and predicted suitable workdays. Figs. 2 and 3 graphically illustrate the trend of the model for the two soil types investigated. The fluctuations in the figures indicate the month-to-month variability in days suitable for field work. Despite the fluctuations, the model was close in predicting SFW for the period studied. In April, the model was in error by 2 days for the sandy loam soil and 5 days in error for the clay soil. In May, the model was in error by 1 day for sandy loam and 2 days for the clay soil. In June, the model prediction was equal to the observed number of days for the sandy loam but was in error by 5 days for the clay. In July, the model prediction was in error by 4 days for the sandy loam and 2 days for the clay soil. Thereafter, the model tended to over predict the results up to October. This could be attributed to the higher soil moisture regime within the period. Although the model predictions were not exact, these results are encouraging when it is remembered that there are many coefficients and assumptions in the model. The model was found to be very sensitive to the coefficients (eg. Drainage coefficient) in the equations. These coefficients on the other hand were determined by separate experiments with inherent experimental errors.

The statistical analysis for assessing the relationship between the observed and predicted SFW gave correlation coefficients of 0.93 for Sandy loam and also 0.93 for clay soil. These values indicate that there was good agreement between the observed and predicted SFW for the soils investigated.

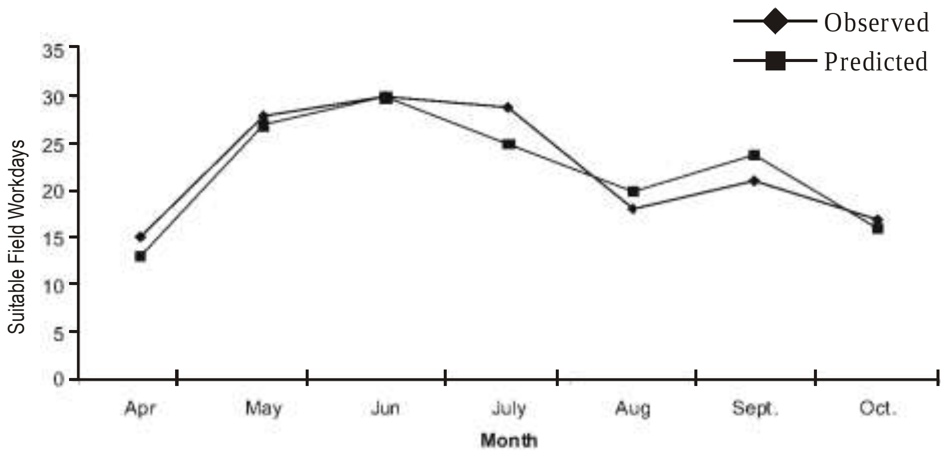

Fig. 2 Observed and predicted suitable field workdays for April – Oct., 1996, for sandy loam soil

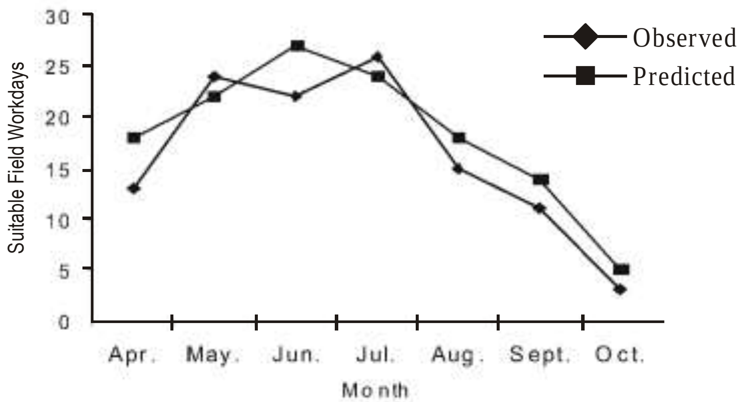

Fig. 3 Observed and predicted suitable field workdays for April – Oct., 1996, for clay soil

4.0 SUMMARY AND CONCLUSION

A simulation model was developed to predict suitable field workdays for soil tillage operations in Ilorin, North Central Nigeria using established tractability criteria. The model was validated by comparing its predictions with observed suitable field workdays data for Ilorin on two soil types, namely sandy loam and clay. There was good agreement between the predicted and observed field workdays data. Despite the minor deviations of the predictions from the observed data, it can be inferred that the model is a veritable tool for predicting suitable field workdays for tillage operations.

Because information on suitable field workdays may be crucial to farm managers during those periods of the farming season when weather and soil conditions might cause delay in farm operations, the need for this information becomes imperative for planning purposes. Equipped with this information, the farm manager could make better decisions with respect to machinery/equipment selection and scheduling of field operations in order to optimally utilize available time.

A major strength of this prediction model is that virtually all the input parameters were either measured or determined at the experimental site.

REFERENCES

1. Hunt, D.R. Engineering models for agricultural production. AVI Publishing Co. Inc., 1986.
2. Baier, W.J. Dyyer; H.N. Hayhoe and A. Bootsma. Spring field workdays in the Atlantic Provinces. Atlantic Committee on Agro meteorology (ACA) Publication No.1 Nova scotia, Canada, 1978.
3. Rutledge, P.L. and F.V. McHardy. The influence of weather on field tractability in Alberta. Canadian Agricultural Engineering. 10, 1968, 70-73.
4. Selirio, I.S. and D.M. Brown. Estimation of spring workday from climatologically records. Canadian Agricultural Engineering 14, 1972, 79-81.
5. Frisby, J. Estimation of good working days suitable for tillage in Central Missouri. Transactions of the ASAE. 13(5); 1970, 641-643.
6. Baier, W. Estimation of field workdays in Canada from the versatile soil moisture budget. Canadian Agricultural Engineering. 15, 1973, 84-87.
7. Tulu, M.Y; J.B. Holtman; R.B. Fridley and S.D. Parsons. Timeliness costs and available working days-shelled corn. Transactions of the ASAE 17(5), 1974, 798-800.
8. Hassan, A.E. and R.S. Broughton. Soil moisture criteria for tractability. Canadian Agricultural Engineering. 17, 1975, 124-129.
9. Elliot, R.L; W.D. Lembke and D.R. Hunt. A simulation model for predicting available days for soil tillage. Transactions of the ASAE 20(1); 1977, 4-8.
10. Dyer, J.A. and W. Baier. Weather based estimation of field workdays in fall. Canadian Agricultural Engineering. 21; 1979, 119-122.
11. Nath, S. and W.H. Johnson. Development of soil moisture model to predict soil moisture and tractability for harvesting. Agricultural Mechanization in Asia, Africa and Latin America (AMA). 11(1); 1980, 73-78
12. Idike, F.I; C.L. Larson and D.C. Slack.. Modelling Soil Moisture and effects of basin tillage. Transactions of the ASAE 25(5); 1982, 1262-1267.
13. Witney, B.D. and O.K. Eradat. The basis of tractor power selection on arable farms. J. of Agricultural Engineering Research. 27; 1982, 513-527.
14. Babeir, A.S., T.S. Colvin and S.J. Marley. Predicting field tractability with a simulation model. Transactions of the ASAE 29(6); 1986, 1520-1525.
15. Thangavadivelu, S. and T.S. Colvin. Trafficability determination using Fuzzy set theory. ASAE Paper No. 90-7553. ASAE, St. Joseph, MI 49085-9659, 1990.
16. Simalenga, T.E. and H. Have. Predicting soil moisture status and suitable field workdays under tropical conditions AMA 25(3); 1994, 9-12.
17. Gwarzo, M.A; F.G. Braide; A.A. Ramalan and O.J. Mudiare. Computer analysis for the selection of suitable work-days for agricultural machinery field operations. Proceedings NSAE. 13; 1989, 27-36.
18. Ahaneku, I.E. 1997. Soil Degradation and Water Balance Studies Under Different Tillage Systems. Unpublished Ph.D. Thesis, University of Ibadan, Ibadan, Nigeria.
19. Doorenbos, J. and W.O. Pruitt. Guidelines for Prediction of Crop water requirements. FA) Irrigation and Drainage. Paper No. 24, F.A.O. Rome, 1975.