IDENTIFICATION OF OPTIMUM TILLAGE TIME IN KAFANCHAN AREA OF KADUNA STATE NIGERIA USING REMOTELY SENSED DATA

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ABSTRACT
Tillage has been identified as the single most expensive operation in crop production. Major causes of this are the amount of energy expended to overcome adverse soil conditions. These conditions exist because of wrong or inappropriate timing of the operation. Farmers in Kafanchan area have been observed to spend a great deal of resources during tillage for lack of knowledge the optimum time for the operation. The purpose of this work therefore, was to identify the optimum time for tillage operation in Kafanchan. The Thornthwaite and Mather model was used to compute the monthly potential evapotranspiration (PET) for Kafanchan from data gathered remotely in order to compute the climatic water balance. Results observed revealed that the area had water deficit in the months of January (0.00mm) to mid-May (484.09mm) and October to December (0.00mm). Water surplus was observed from May and ends mid-October. From the developed graphical model, it was concluded that the optimum tillage time in Kafanchan should be from the second week of May and should stop in the first week of June.

1. INTRODUCTION

Tillage operation in various forms have been practiced from the very inception of growing plants. Primitive man used tools to disturb the soils for placing the seeds (Davies, 1983). The word tillage is derived from 'Anglo-Saxon' words *Tilian and Teolian,* meaning to plough and prepare soil for seed to sow, to cultivate and to raise crops. Tillage is the mechanical manipulation of soil with tools and implements for obtaining conditions ideal for seed germination, seedling establishment and growth of crops (Kawuyo *et al*, 2017). Tillage remains the single most expensive operation in crop production. Sheruddin *et al* (1988) described it as the single most expensive input to crop production, contributing about 20% of factors involved in the operation can be on-season and off-season tillage (Khurshid *et al.*, 2006;). This is as a result of the energy intensity involved.

As a soil engagement operation, the condition of the soil is critical to the performance of tillage tools and so must be considered in every tillage system (Tanam and Babatunde, 1995). Whereas soil type is a major contributor to tillage quality, Ozgoz *et al* (2012) reported that temporal variability of soil physical properties can be greater than spatial variability. Ahaneku and Dada (2013), citing Lewandowski *et al* (1999) included timing of tillage and soil water content among factors that affect tillage quality. Similarly, Hua *et al* (2020), citing James and Kenichi (2005) and Romer and Romula (2018) included time, ambient temperature and load as external factor influencing soil behaviour. Adama *et al* (2022) referred to optimum time of field operation as the appropriate time for that operation, and added that failure to carry out the operation at the optimum time leads to reduction in both quality and quantity of yield. It must be added that not carrying out tillage operation at the optimum time leads to high energy consumption as more power may be required to overcome difficult soil conditions. Difficult soil conditions include hardness in dry condition and stickiness in wet condition. Tanam (1994) explained that moisture content greatly affects the type of failure soil undergoes during ploughing for instance, as well as the failure strength. Very high moisture content leads to low soil workability due to increased failure strength resulting from pore water pressure, or high slip level due to the molten nature of the soil. Friable stage of the soil, the moisture content between shrinkage limit and plastic limit, has been identified as the best stage of performing tillage. Farmers in and around Kafanchan have spent a great deal of resources during tillage for not knowing the optimum time for the operation. The aim of this work therefore, was to identify the optimum time for tillage operation in Kafanchan.

2. MATERIALS AND METHOD

2.1 Study Area

Kafanchan is the capital town of Jema'a Local Government Area of Kaduna state of Nigeria. Located in the southern part of the state, it lies on latitude 9°34'52.54" N and longitude 8°17'33.36" E and altitude of 742 m. The town lies within Southern Guinea Agro-Ecological *Zone* consisting of forests and savannah lands, *with a* population of about 79,522 majority of whom are predominantly farmers.

2.2 Data Collection

Three different soil textures, silty loam, sandy loam and loamy sand, were identified within the study area. The mean monthly precipitation and observed-runoff for the period of 31 years, January 1990–December 2021, for Kafanchan was obtained from remotely sensed Meteorological data of Kaduna State obtained from National Aeronautics and Space Administration (NASA).

2.3 Model Evaluation

Monthly potential evapotranspiration (PET) was computed using the Thornthwaite and Mather (TM) (1957) model given in equation (1) for determination of climatic water balance.

$$PET = 16 \times C \times \left(10 \times \frac{T}{I}\right)^{a} \qquad (1)$$

where

PET = the potential evapotranspiration (mm month^{-1});

T = the mean monthly temperature (°C);

I = the annual heat index for the 31 years ($I = \Sigma i$);

i = the monthly heat index $\left(i = \left[{}^{T}/_{5}\right]^{1.514}\right)$;

a = $6.75 \times 10^{-7} \times I^3 - 7.71 \times 10^{-5} \times I^2 + 1.792 \times 10^{-2} \times I + 0.49239$

C = a correction factor for each month ($C = [m/30] \cdot [d/12]$), where m is the number of days in the month and d is the monthly mean daily duration, that is, number of hours between sunrise and sunset and expressed as the average for the month.

The quantitative water surplus (+) or deficit (-) with P as precipitation was estimated using P - *PET*, which was determined in Table 2. The cumulative values of (*P - PET*) determined the accumulated potential water loss (*APWL*), for each month. Beginning with the first month after the rainy season that has a negative value, this was zero for months having positive P - PET values. The actual soil moisture storage (*STOR*) for each month was determined equation (2).

$$STOR = AWC \times e^{(APWL/AWC)} \qquad (2)$$

where *AWC* is the water holding capacity (Available Water Capacity) of the soil.

This was calculated based upon the land cover, soil texture and rooting depth as suggested by Thornthwaite & Mather (1957). Table 1 is the summary of the computation. Changes of actual storage (ΔSM) for all the months were calculated using equation (3).

$$\Delta SM_{month} = STOR_{month} - STOR_{previous\ month} \qquad (3)$$

Table 1: Computation of water holding capacity of the root zone and available water capacities (AWC) for different soil textures and land uses

Soil Texture	AWC (%)	Rooting	Depth of AWC (mm)
Sand	10	0.5	83
Sandy Loam	15	1.5	300
Loamy Sand	10	0.5	50
Silty Loam	20	0.62	125
Loamy Sand	10	1	100
Sand	10	0.3	20

Source: Author's Compilation, (2023)

Water infiltration and its addition to the soil moisture storage are implied by a positive value of SM, whereas a negative value of SM denotes subtraction of water from the storage that was used for evapotranspiration.

The actual evapotranspiration (AET) was computed for all the months, as given in equations (4) and (5).

$$AET = \Delta SM + P \quad \text{for} \quad \Delta SM < 0 \qquad (4)$$

$$AET = PET \quad \text{for} \quad \Delta SM > 0 \qquad (5)$$

Equation (6) was used to calculate the water deficit (DEF) for crop evapotranspiration in each month for the months having negative ($P - PET$).

$$DEF = PET - AET \qquad (6)$$

The amount of excess water that cannot be stored is denoted as moisture surplus (SUR). When storage reaches its capacity, SUR is calculated using equation (7).

$$SUR = P - PET \qquad (7)$$

When the soil storage is not at its capacity, no surplus exists. In a month in which the soil moisture storage capacity is just satisfied, SUR is obtained using equation (8).

$$SUR = P - (AET + \Delta SM) \qquad (8)$$

where ΔSM is the change in actual soil moisture storage.

The available annual surplus is defined by equal the actual runoff. The monthly computed surplus should be higher than the monthly runoff (RO) because of the delay between the time of precipitation and the time when water actually passes the gauging station. For large catchments, it can be expected that in any given month, about 50% of the surplus water that is available for runoff goes off (Thornthwaite and Mather, 1957). The remainder of the excess is stored in the basin's subsurface, groundwater, tiny lakes, and channels and is ready for runoff throughout the course of the following month.

Taking into account the area with various land uses and the corresponding values from the monthly water balance table, the annual amount of real evapotranspiration and runoff from the watershed was computed. Area-weighted data represent the monthly real evapotranspiration and runoff from each catchment area.

3 RESULTS AND DISCUSSION

Table 2 indicates the accumulated potential water loss ($APWL$) for Kafanchan Area from monthly precipitation and temperature as prescribed in the TM Model.

Table 2: Summary of the P, PET, AET and runoff for Kafanchan (mm).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
P	0.00	0.00	93.16	67.70	484.09	793.59	814.05	484.38	625.91	268.04	0.00	0.00	3630.93
PET	98.90	110.76	122.35	117.19	103.96	70.66	57.66	57.73	60.36	65.75	62.65	66.96	994.92
AET	-56.02	-24.95	89.15	62.28	103.96	70.66	57.66	57.73	60.36	65.75	0.00	0.00	486.57
Runoff	45.77	22.89	11.44	5.72	14.15	368.54	562.47	494.56	530.05	366.18	183.09	91.54	2696.40

Source: Author's Analysis, 2023.

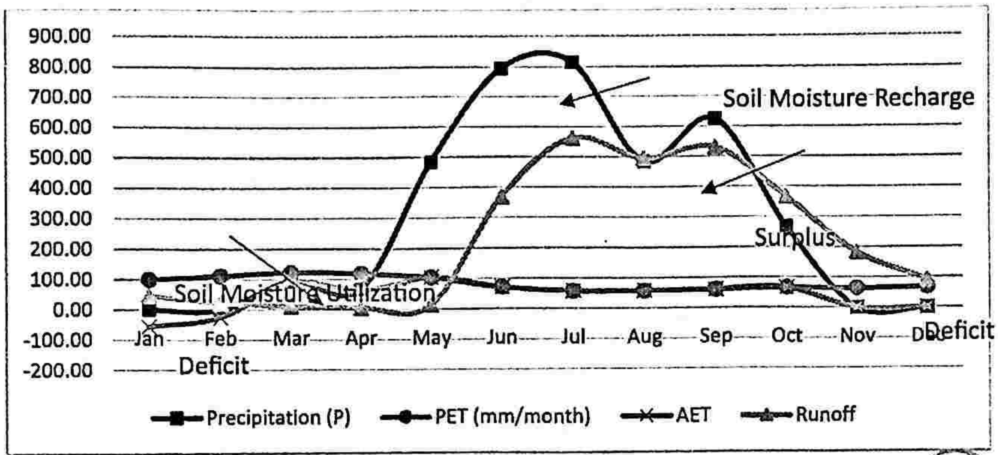

Figure 1: Water Balance Status of Kafachan Area

This graph gives a great deal of information regarding the water balance of the Kafachan area. Besides showing the seasonal pattern of precipitation, actual evapotranspiration (*AET*), potential evapotranspiration (*PET*) and runoff, it indicates the periods of moisture deficit, soil moisture recharge, soil moisture utilization and the optimum tillage time. Figure 2 is a comparison of water balance deficit and surplus in Kafanchan.

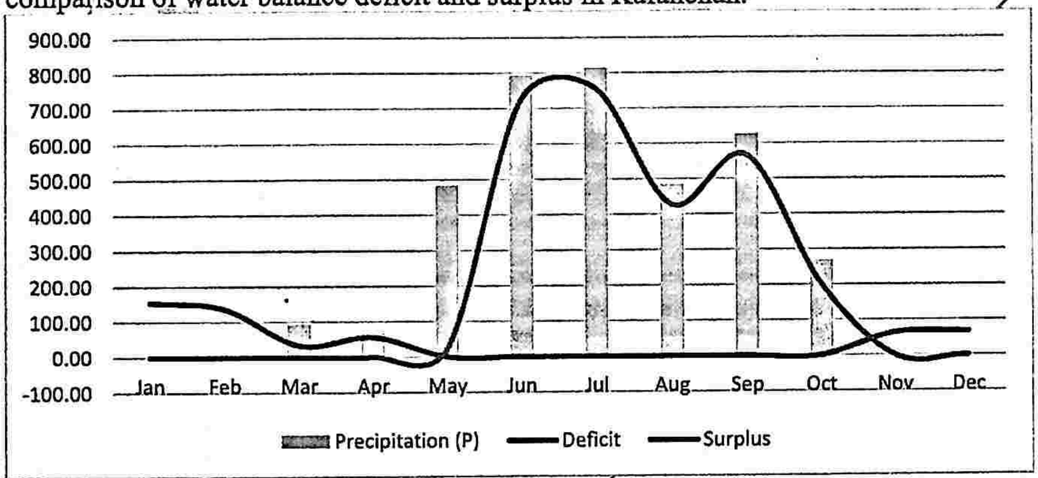

Figure 2: Water Balance Comparison between Surplus and Deficit in Kafachan Area

The moisture deficit indicates that plants will be under some stress during that period, indicating the need for irrigation. The area is relatively dry in the months of January–May. Further, it can be seen that there is a water deficit again in the months of October–December. Soil moisture recharge takes place from early May to August. From mid-May to December is the period of water surplus.

Comparatively, it be observed from Figure 2 that surplus within Kafanchan begins in May and ends mid-October. Whereas, Deficit reigns through mid-October back to May with peak deficit in the month of January (154.92 mm). Optimum tillage time therefore, should be from second week of May and should not exceed the first week of June.

4 CONCLUSIONS

A study of 31-year precipitation pattern of Kafanchan area of Kaduna State – Nigeria was conducted in order to determine the optimum tillage time for the area. The monthly potential evapotranspiration (PET) for Kafanchan was computed using Thornthwaite and Mather model using data obtained remotely from NASA to determine the climatic water balance for the area. Results obtained showed that the area was relatively dry in the months of January–May and there was a water deficit again in the months of October–December. There was a surplus from May to mid-October. The graphical model developed revealed that the optimum tillage time in Kafanchan should be from the second week of May to the first week of June.

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