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Research Article
Drought Assessment for Reduced Climate Impact on Cassava Production

[1]Boasiako Ohene Antwi, [2]Stephen K. Asante and [3]Joseph Yeboah

[1]CSIR-Soil Research Institute, Kwadaso, Kumasi, Ghana
[2]CSIR-Savannah Agricultural Research Institute, Nyankpala, Ghana
[3]Ministry of Food and Agriculture, IFAD-GASIP, Accra, Ghana

Abstract

Background: Cassava has been identified for food security and poverty alleviation in Northern Ghana. Unfortunately, understanding climate change and the stress on cassava establishment and production are the major problems currently addressed by IFAD-Ghana project (ProVACCA). **Objective:** The main objective of this study was to use simple tools for drought assessment, onset and cessation of rainy season and implement improved soil tillage system for cassava establishment. **Materials and Methods:** Standardized Precipitation Index (SPI) was used to assess drought severity at three-month time steps. Hydrological climate and precipitation accumulation models were used to determine onset and cessation of rainy season. Cone penetration tests were used to determine soil compaction on ridges across slope and mounds. Stat-Plus professional 5.8 was used for statistical analysis. The ability of cassava crop to withstand drought was assessed by yield of crop biomass, roots and harvest index. **Results:** Daytime temperatures and wind speed showed 73 and 71% correlation with evapotranspiration, respectively. The SPI accounted for 50-70% of drought severity. Models for onset and cessation of rainy season showed June-November to be the most reliable period to establish cassava. The highest cone penetration tests were 40 kPa. It occurred at 220 mm for ridges, 300 mm for mounds and 20 mm in furrows. Mulched ridges conserved more soil moisture within the rooting zone compared to planting on un-mulched ridges. The difference in mean yield of cassava biomass on ridges (22.92 t ha^{-1}) and those on mounds (15.8 t ha^{-1}) was insignificant at $p \leq 0.05$. However, there was significant difference between the harvest indices of cassava planted on ridges (58.77%) and those on mounds (51.02%) at $p \leq 0.05$. **Conclusion:** Planting within defined onset and cessation of rainy season using soil-water-conserving tillage practices reduced climate stress on cassava. Separating normal drought assessment criterion into positive and negative components removed the limitations of Standardized Precipitation Index for drought assessment in dry areas of Ghana.

Key words: SPI, drought, cassava, climate-resilient, onset of rainy season

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Corresponding Author: Boasiako Ohene Antwi, CSIR-Soil Research Institute, Kwadaso, Kumasi, Ghana

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Understanding the impact of climate stressors on agricultural production and the application of climate-resilience principles is a problem in most parts of West Africa. Climate-resilient agriculture adopted in most agricultural programs is a coping strategy[1,2]. Generally, climate-resilience agriculture is about adding considerations of climate variability and climate change to decision-making[3-5]. This study describes the characteristics of cassava and how to use simple climate assessment tools for cassava to withstand or escape excessive moisture deficit. This is illustrated with Ghana and International Fund for Agricultural Development (IFAD) project on cassava titled: 'Promoting a value chain approach to climate change adaptation in agriculture in Ghana (ProVACCA)' in 2012. The project addressed food security under climate change and weather variability with farmers. Relevant climate stressors were the climatic elements that enhanced potential evaporation and consequently moisture deficit. The most critical factors were the high temperatures, long dry periods and wind speed.

Response to climate change and achieving global food security are the two main problems currently facing the global community. Cassava plays this dual role. It absorbs carbon dioxide (CO_2) from the atmosphere and processes the carbon to food. Large amount of food processed is stored in the roots and the rest partitioned into stems and leaves. Bitter (high cyanide) cassava cultivars are known to produce higher photosynthetic efficiencies and yields than sweet cultivars[6]. Other added advantages make cassava cultivation important.

Cassava, *Manihot esculenta* Crantz is used for industrial starch production. It is also a major staple crop to address food security under climate change[7], though in terms of food quality, cassava roots are a poor source of protein[2]. Cassava was derived from a local name "casabi". It is Arawaks Amerindians word for starchy foods[8]. Its cultivation requires special soil conserving inputs such as un-compacted loam to sandy loam soil for root development, un-flooded soil conditions and exploitable soil volume. This shows that cassava requires less compact soils having low bulk density and high soil porosity[9-11]. Unfortunately, after heaping the soil, the soils are reversed to stable terminal bulk density depending on the frequency of alternating rainfall and dry periods.

Cassava tolerates extended periods of drought[12,13]. This is because cassava rooting system is able to absorb soil moisture from deeper soils[14] and exhibit stomata closure on the least soil moisture stress[15]. These characteristics make cassava suitable to be promoted in moisture stress environments. Therefore, framework to address cassava as a climate change crop should be pivoted on dry climate and weather events[16].

The framework of climate change and weather variability on crop production in West Africa should consider drought and floods as extreme events. Floods are generally less than 2 weeks while droughts extend to 6-8 months. Thus the impact of drought is a priority in terms of climate change adaptation in the sub-region. However, the negative impact of drought may be reduced through changes in agricultural practices and improved weather and early warning systems[17]. Drought has some elements of persistence of precipitation deficit[18], period of occurrence and the area[19]. It may be categorized as meteorological (precipitation, potential evapo-transpiration) and agricultural (soil moisture based). The localized indices of operational definition include a timescale (duration), magnitude (accumulated moisture deficit)[20] and severity (degree of precipitation deficit)[21].

Drought indices simplify the complex climatic functions. It quantifies climatic anomalies for their severity, duration and frequency[22]. The meteorological methods include Rainfall Deciles, Reconnaissance Drought Index (RDI), Standardized Precipitation Index (SPI)[23] and Palmer Drought Severity Index (PDSI)[20]. Time series rainfall data analysis helps to better understand drought climatology for cassava cultivation. It indicates changes in drought intensity, magnitude, frequency and duration required to manage the crop at field scale. To represent dryness, a simple measure is better than complex hydrological indices[24]. Standardized Precipitation Index (SPI)[23] is a popular meteorological drought index. It is simple and more effective for analyzing and building scenarios for drought climatology[25]. Similar to precipitation percent of normal, SPI compares precipitation with its multi-year average. The SPI overcomes the discrepancies resulting from using a non-standardized distribution by transforming the distribution of the precipitation record to a normal distribution. Narendra[26] found that correlation of SPI value of -1.0 with wilting point values was significant at 0.01 levels (two-tail test). He proposed SPI (-1.0) as threshold for soil moisture drought.

Negative departures of rainfall have been observed in most part of Northern Ghana especially in the 1990s[27] with negative impact on crop production. It makes it relevant to relate cassava yield to weather or climate variability and its productivity to global food security[28]. For any use of cassava, it is very important to quantify biomass production of the various parts[29]. For cassava, marketable root biomass is more important to household food security and income. As a forage crop, high productivity of the above ground biomass is the primary choice[30].

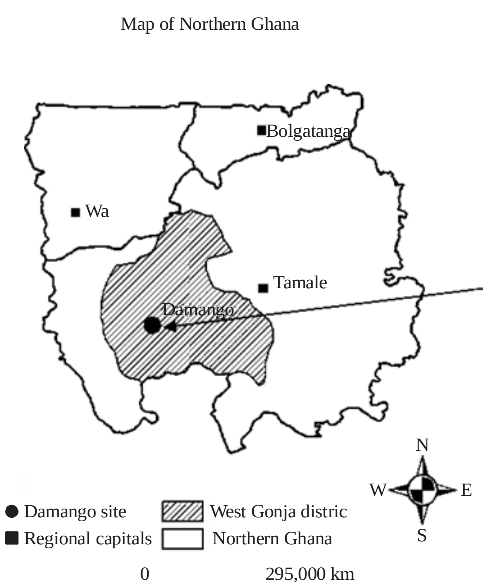
The challenge to successful rain-fed crop production is by predicting the rainfall period of a cropping season[31]. The irregularities in rainfall distribution (time and space) have made it a challenging task to predict the start of rains in West Africa[32]. However, some prediction methods have been proposed based on rainfall data alone[33,34]. Naturally, simple and locally formulated models based on water balance approach have been useful elsewhere[32,35]. The interactions between soil and atmosphere are important despite the complex linkages. While there are many pathways to undertake this task, we prefer to limit the study of climate extreme framework to (a) Drought assessment, (b) Onset and cessation of rainy season (c) Soil management and (d) Cassava yield partitioning.

MATERIALS AND METHODS

Site description: Figure 1 presents the location and summary of climatic data from the nearest meteorological station. Damango area is located on latitude 9.079°N and longitude 1.817°W in the Guinea savanna agro-ecological zone. The climate is influenced by the Inter-Tropical Divergence (ITD) Northwards[36]. It produces monsoon type of climate. Two air masses, the north easterlies that blows across Sahara and the South westerlies that comes from the Atlantic ocean[37,38] influence the seasons. Their positions determine the intensity of climate stressors that affect the soil-crop system.

Average annual rainfall is 1094 mm. About 87% of the total rainfall occurs between May and September. It reaches its climax between August and September. The mean annual temperature is 28.3°C, while the mean annual maximum temperature is 34°C. However, the maximum mean monthly temperature of 38°C occurs in March. The mean minimum temperature is 22.5°C. The lowest monthly mean minimum temperature of 19.1°C is observed in December. Evapotranspiration (ETo) ranges from 4.0-7.0 mm day^{-1} from January-April and from August-September. Since soil moisture deficit is the major stress factor to crops in the arid zone, correlation analysis of ETo was run with other climatic parameters. This was done to determine resource-compatible soil-crop management methods that can be used to address climate stressors.

The most extensive agricultural soils were deep well-drained sandy loams to loamy fine sand having upper 80 cm depth of productive soils. They were identified as lixisols, gleysols, plinthosols and acrisols. These soils supported moderately dense short and fire-tolerant deciduous trees. The ground flora comprised different grass species. Unfortunately, the vegetation was mostly degraded as a result of annual fires, firewood extraction, charcoal burning and farming. As a result of continuous cropping, the soils units had few trees mostly sheanut (*Butyrospermum parkii*) due to continuous cropping.



Month	Maximum temperature (°C)	Minimum temperature (°C)	RH (%)	Wind speed (km day^{-1})	ETo (mm day^{-1})	Rainfall (mm)
January	35.5	19.5	27.7	156	6.28	3.5
February	37.7	22.8	30.8	160.8	6.78	8.5
March	38.0	25.3	44.8	213.6	7.18	43.7
April	36.1	25.4	60.3	7.4	426	84.3
may	34.1	24.3	69.7	160.8	5.1	121.6
June	31.6	23.0	77.3	5.9	3.59	153.6
July	30.3	22.7	80.5	151.2	3.79	159.1
August	29.9	22.4	81.2	103.2	3.58	200.7
September	30.7	22.1	81.9	103.2	3.99	219
October	33.3	22.4	75.0	3.9	4.34	85.7
November	35.6	21.2	58.8	4.1	4.2	10.4
December	35.3	19.1	40.6	5.2	3.52	3.4
Average	34.0	22.5	60.7	89.6	4.72	

Source: Department of meteorology, Ghana

Fig. 1: Location and climate stressors

Table 1: SPI drought severity and wet condition categorization

Severity class	Magnitude
Extremely wet	SPI>2.00
Severely wet	1.6≥SPI≤2.00
Moderately wet	1.0≥SPI≤1.50
Normally wet	0.0≥SPI≤0.99
Normally dry	-0.99≥SPI<0.00
Moderately dry	-1.5≥SPI<-0.99
Severely dry	-2.0≥SPI<-1.50
Extremely dry	SPI>-2.00

Source: Modified from McKee *et al.*[23]

Drought and wet years: Drought has some elements of persistence of precipitation deficit[18], period of occurrence and the area[19]. It may be categorized as meteorological (precipitation, potential evapotranspiration) and agricultural (soil moisture based). This study adopted localized indices of operational definition[20] that include a timescale (duration), magnitude (accumulated moisture deficit) and severity (the degree of the precipitation deficit)[21]. Drin-C drought software[39] was used. Long-term climatological monthly record from Tamale was fitted to a gamma distribution. It was then transformed into a normal distribution so that the mean SPI was zero. A drought event starts when SPI value reaches -1.0 and ends when SPI becomes positive. The positive sum of the SPI for all the months within a drought event was used as drought magnitude[22]. Since cassava needs to escape moisture stress during initial establishment of 3-4 months, SPI was computed with time steps of 3 months. Data was analyzed using drought severity class[23]. Moderate to extreme wet values were combined. Further, by considering the soil conditions in arid zone of Ghana where the least dry conditions reduce soil moisture within the rooting zone, the normal class was separated into normal wet and normal dry conditions (Table 1). The probabilities of obtaining wet and dry months were estimated using relative frequencies of drought (negative PSI) and wet (positive PSI) values.

Seasonality characterization: In this study, two methods namely Water Balance Approach (WBA) using Hydrological Climate (HC) and Precipitation Accumulated (PA) methods were compared[35]. The two approaches were applied to climate records of 26 years (1977-2002). The hydrological climate traces climatological mean monthly moisture deficit (M_i) as the difference between mean monthly precipitation (R_i) and mean monthly potential evaporation (E_i). The E_i was estimated by the Thornthwaite method using average monthly temperatures. The R_i and E_i were plotted against months of the year. The M_i was estimated by Eq. 1:

$$M_i = \frac{1}{N}\left[\sum_{i=1}^{N}[R_i - E_i]\right] \quad (1)$$

Liebmann and Marengo's seasonality characterization[35] within a local area was applied to monthly rainfall data. Precipitation accumulation quantity (A_j) in the calendar month was expressed as Eq. 2:

$$A_j = \Sigma A_i\text{-}A_m X_j \quad (2)$$

where, A_i is the monthly climatological rainfall data as a function of the month of the year, A_m annual mean monthly rainfall, X_j is the month of the year. The rainy season is the period during which rainfall exceeds its climatological annual average. The method was applied by first estimating the mean of total record of precipitation events as normal season. The record was further sorted out for monthly precipitation data that were 10% lower than the mean month as drought year and 10% above the mean as wet year. In HC and PA methods, onset of rainy season was designated as the point where the graph crosses the month axis.

Field layout: Field layout and determination of harvest index: Cassava varieties were planted on ridges and mounds as treatments in July, 2015. They were replicated in 3 communities around Damango (Sumpini, Nabori and Sori) on upland soils. At each site, the treatments were replicated 3 times. Complete randomized design was used. The test crop was cassava. The choice of cassava variety depended on availability of planting materials for drought screening. The spacing between rows and within rows was 1.0 m for ridges. The spacing between rows and within rows for mounds was 1.5 m due to soil heaping arrangement for the formation of mounds. This crop was allowed to go through 5 months of moisture stress before harvesting. At harvesting (March, 2016), samples from an area of 16 m^2 were uprooted from un-mulched plots. The fresh biomass was separated into roots and above ground biomass and weighed. The root and shoot partitions were evaluated using percentage Harvest Index (HI) as expressed in Eq. 3:

$$HI = \frac{\text{Field weight of cassava root}}{\text{Total field weight of cassava root and shoot}} \times 100 \quad (3)$$

The objective was to ascertain whether there were differences in terms of biomass, root yield and harvest index when cassava was planted on ridges or mounds for erosion control, moisture conservation and field drainage. Analysis of variance (ANOVA) was carried out using Stat-Plus 2009 version 5.8 for the parameters. The Least Square Difference (LSD) was carried using pairwise t-tests for ANOVA tests that were significant.

Soil moisture determination on mulched and un-mulched plots: Soil samples were taken during the dry month of February, 2016 from some mulched and un-mulched ridges planted with cassava. Depth of sampling was at 10 cm depth intervals up to 50 cm depth. The samples were taken from within rows of cassava plants and were put in moisture cans for gravimetric moisture determination. Average moisture at each depth was determined and plotted to observe soil depth moisture distribution within the ridges at peak of droughty conditions.

Penetration resistance: Terminal penetration resistance of mounds, ridges and furrows were determined on farmer field trials at Sori community in Damango. The ridges were researcher introduced and had inter-row spacing of 1.0 m and within row spacing of 1.0 m. The mounds were farmers' practice with inter-row spacing 1.5 m and within row spacing of 1.5 m. A pre-calibrated penetrometer CP40II was used to record cone index values (kPa) after the soils had settled for cassava root development. The penetrometer was pushed through the top of selected mounds, ridges and furrows to a depth of 50 cm or until the cone could not penetrate any further. The penetration resistance (kPa) for mounds and ridges with no obstacles such as roots and twigs in the soil heap were recorded. The average resistance within the mounds, ridges and furrows were recorded from the digital screen. The results were plotted using excel software.

RESULTS AND DISCUSSION

Climate and weather variability: The results showed high correlation of ETo with day time temperatures and wind speed (Table 2). While a negative correlation was observed of rainfall and Relative Humidity (RH) with ETo. The result supported the rational that in West African sub-region, the framework of climate change and weather variability on crop production must be pivoted on extreme climate and weather events[40]. Principles and activities within the framework must address reduced ETo effect on crops and improved weather and early warning systems[17].

Drought and wetness assessment: Figure 2 compares the relative percentage wetness and drought magnitudes using Mckee's criteria. When normal wet and dry conditions were combined (Fig. 2a), the dryness of the environment came out as a normal occurrence despite decreasing rainfall trends. This produced inconsistent results when compared to the real situation in the field. Moderate to extreme dryness accounted for 20% for January-March, April-June, May-July and September-November 3-month steps. Two continuous 3-month steps within April-July indicated droughty conditions. Other 3-month steps from June-October showed low drought conditions. Unfortunately, from November-February field crops experienced extreme moisture stress, while SPI considered this condition as normal event. Using the criteria for drought normality assessment as $0.99<SPI>-0.99$ did not provide the necessary information to understand the droughty conditions. This was probably the reason why Adeogun *et al.*[41] reported some confusing results in Nigeria.

Figure 2b shows the results when the value for normality drought criterion was separated into positive and negative components. The results indicated that the frequency of normal dry conditions ranged from 50-70% while the normal wet condition was less than 10%. Though these were normal conditions, they related more to soil moisture stress on surface soils. The soils were sandy loams to fine sandy loams. It could be inferred that high daytime temperatures and wind speed contributed to excessive water vapor exchanges between the soil surface and the atmosphere[14]. The trend and severity of drought simulated the observed trends in Damango area.

The effect of ETo on drought severity was observed when soil samples from grass mulch and un-mulched ridges were taken in February, 2016 for gravimetric moisture analysis (Fig. 3). On the mulched ridges (Fig. 3a), the moisture content of the soil was high in the surface layer and decreased downwards before rising again. However, on un-mulched ridges (Fig. 3b), soil moisture showed rapid decline from the soil surface before rising again. The high soil moisture contents in the top soil layers of the mulched ridges was attributed to soil surface protection from daytime exposure to high temperatures and wind speed[42]. Further, the mulch adsorbed dew from the atmosphere at night because of the low night temperatures. This system reduced droughty conditions and had practical significance for addressing soil moisture stress on cassava cultivation.

Table 2: Percent correlation of potential evaporation with climatic parameters

	Maximum temp (°C)	Minimum temperature (°C)	Average temperature (°C)	Wind speed (km day^{-1})	Rainfall (mm)	RH (%)
ETo (mm day^{-1})	73.39	23.42	69.80	70.61	-53.59	-70.51

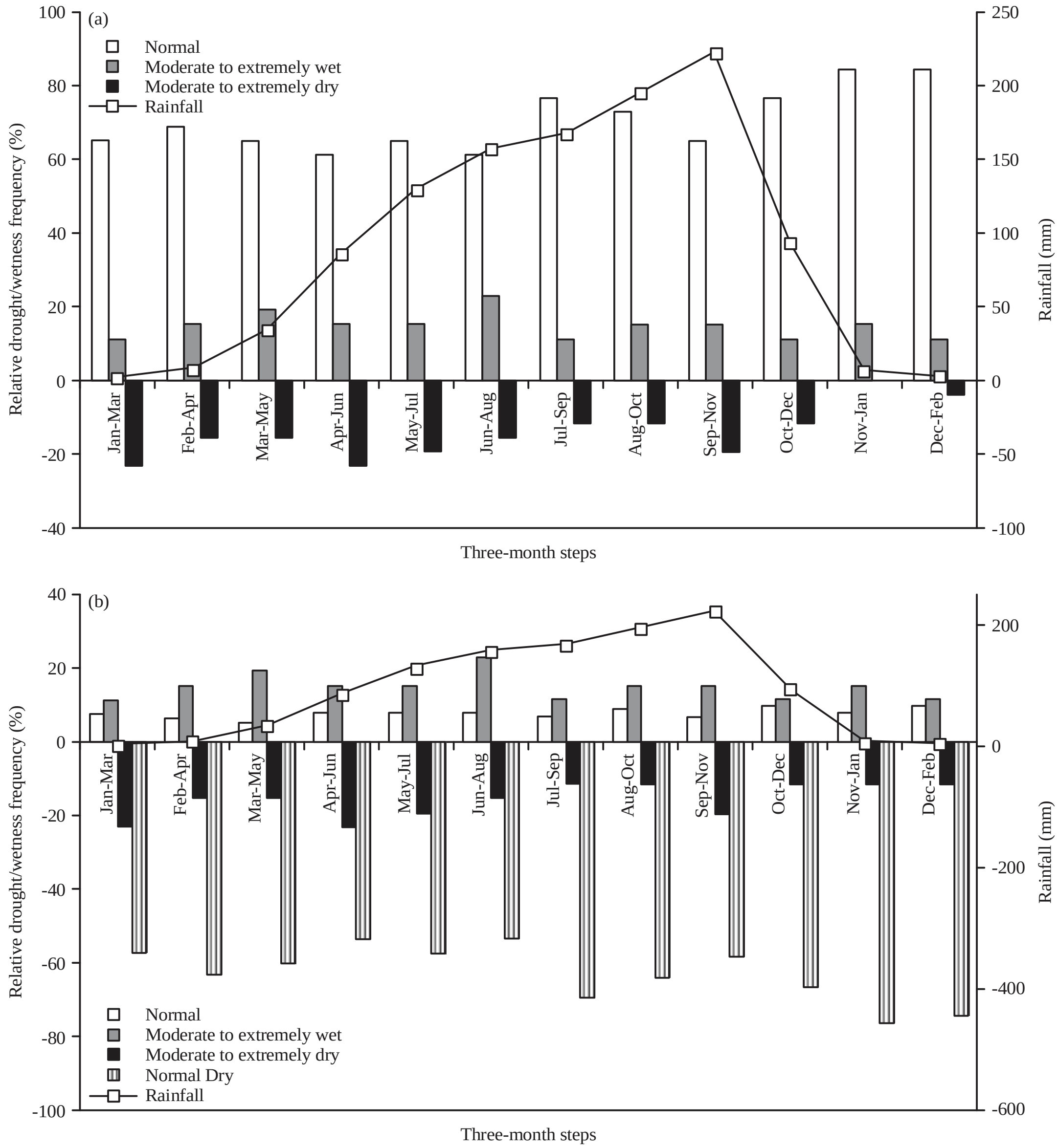


Fig. 2(a-b): Relative frequency of wetness and drought magnitudes, (a) Normal drought not separated and (b) Normal drought separated

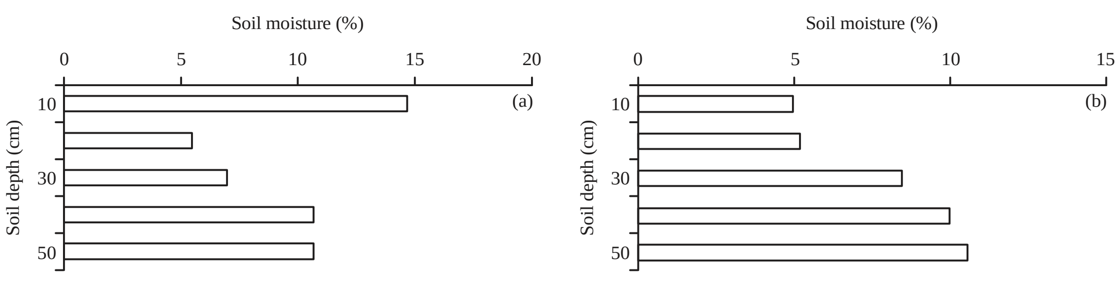


Fig. 3(a-b): Percent moisture on (a) Mulched and (b) Un-mulched ridges in the dry season ridge

Figure 4 compares the results of Hydrological Climate (HC) and Precipitation Accumulation (PA) methods. The HC (Fig. 4a) showed that rainfall deficit occurred in a period of 8 months. It started from October in the preceding year to

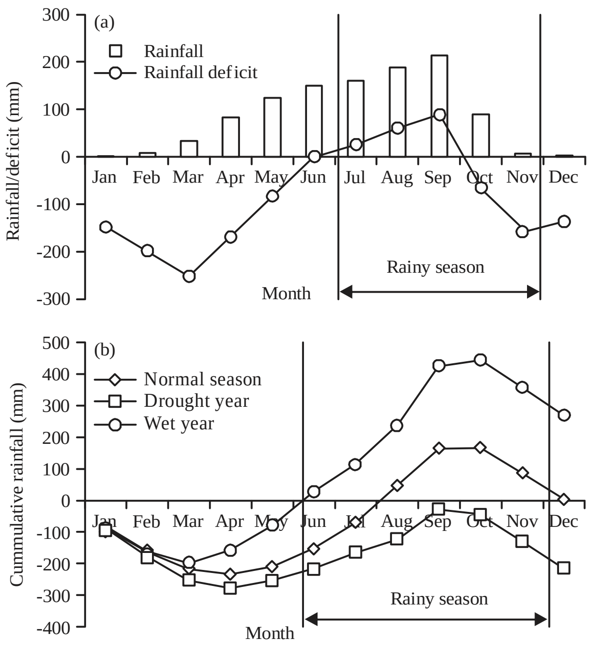


Fig. 4(a-b): Onset and cessation of rainy season, (a) Hydrological Climate (HC) approach and (b) Precipitation Accumulation (PA) method

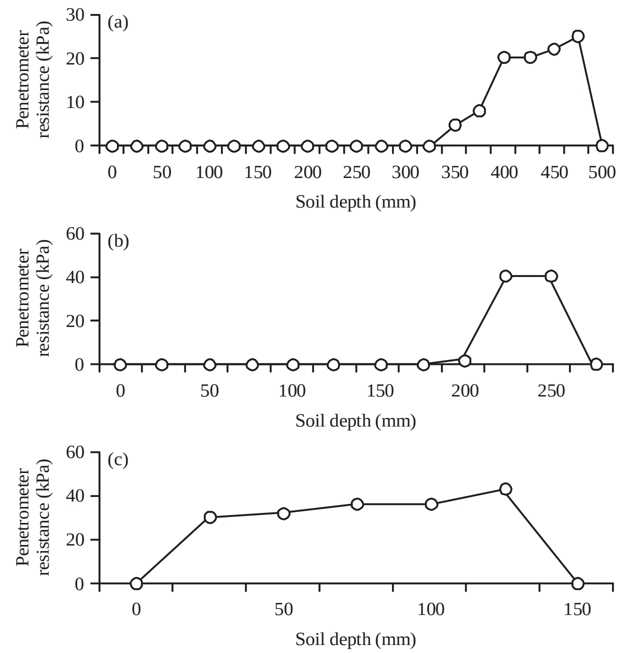


Fig. 5(a-c): Penetration test under (a) Mounds, (b) Ridges and (c) Furrows

May the following year. The continuous deficit precluded planting of any crop except under irrigation. Four continuous months (June-September) is available for crop production. In most communities around Damongo, land preparation starts in May and planting in June-July. Cassava needs 3 months to establish and HC could serve a useful guide to onset of land preparation and planting.

Onset of rainy season and seasonality characterization: The results of Fig. 4b indicates that Onset of Rainy Season (ORS) in extreme dry year cannot be predicted by the model. However, in normal years, ORS begins in 3rd week of July. Land preparation could be carried out within the first 3 weeks in July. This confirmed the case in areas around Damango to Tamale at present. In wet years, ORS starts around 2nd week in June. This is the period where most farmers plant cowpeas before the main crop. Therefore, monitoring the rising arm of Precipitation Accumulation (PA) graphs from January-April indicated the trend of wet, normal or extremely dry month for planning cassava plantation. This could serve as a useful guide not only for cassava cultivation but for other crops. The graphs of HC and PA rise gradually and cross the month of June to start the season. However, the cessation of cropping season is rapid for both models. The cessation for HC is October, while that of PA is in November. This may be explained by the movement of ITD. The ITD advances northwards slowly and retreats very fast[43].

Hydrological climate indicated a rainfall season from June to mid-September, while PA characterizes a normal season from July-November and wet season from June-November. Crops that could be planted and harvested within this period are maize, early millet and late millet, groundnut and cowpeas. Cassava planted in this season is however, not harvested at the cessation of the season since it requires a minimum of 6-18 months to mature depending on the variety. It is the appropriate period for establishing cassava crop. Cassava thrives during this period of moisture stress because the crop maintains high stomata conductance but closes them in response to even small decrease in soil water potential[15].

Sustainable soil management: Figure 5 shows the penetration resistance of soil depth on mounds, ridges and furrows. The results showed that mounds had the least soil resistance to penetration depth of 30 cm, followed by ridges (20 cm) and furrows (<10 cm). The highest penetration resistance at terminal depth for the mounds was 25 kPa, while the ridges and furrows were 40 kPa. Generally, the mounds had more exploitable volume of soil for root development compared to ridges. This implied that mounds are less resistant to cassava root development than ridges. This had implications for tolerance of cassava to drought through

Table 3: Cassava varieties and biomass partition

		Biomass (t ha^{-1})		Root yield (t ha^{-1})		Harvest index (%)	
Cassava variety	Replicates	Ridges	Mounds	Ridges	Mounds	Ridges	Mounds
Biambase	6.00	40.73	33.75	21.95	17.07	54.03	50.90
Bankyehemaa	6.00	35.03	31.45	18.92	15.97	54.13	50.81
Nyerikobga	6.00	35.18	30.33	22.70	16.13	64.52	53.19
Filindiakong	6.00	45.00	29.05	28.08	14.28	62.41	49.17
Mean		38.99	31.15	22.91	15.86	58.77	51.02
CV (%)		18.90	10.00	19.50	14.90	8.90	11.20

extensive root development. This confirmed the study of Attarod *et al.*[14] that cassava rooting system is able to absorb soil moisture from deeper soils.

The development of cassava industry firstly requires non-compact loam to sandy loam soil for its root development. Secondly, it does not survive under flooded conditions and thirdly, cassava root development depends on exploitable soil volume. Traditionally, to meet these 3 soil conditions, the study explains why farmers cultivate on tilled plots by making mounds and ridges with hand hoes or tractor driven implements[9]. The operations are known to loosen, granulate and crush soil particles[10]. Heaped and ridged plots usually have low soil bulk density and high total porosity[11]. Unfortunately, the heaped soils were reversed to stable terminal bulk densities through particle sorting by rainfall depending on the frequency of alternating rainfall and dry periods.

Cassava yield partitioning: Results (Table 3) showed that ridges across slope yielded 9% more (23 t ha^{-1}) than mounds (16 t ha^{-1}). However, the yield differences were not significant at (p<0.05%). The relationship between biomass production and root yield confirmed the observation that cassava root yield increases under improved but not excessive soil moisture regime[15]. The ridges across slope slowed down excess runoff and increase infiltration rate. The moisture conservation reflected in the increase of shoot biomass by 1% compared to mounds. However, the means were not significant at p<0.05%. This implied that spacing in the mounds did not restrict runoff flow. Therefore, mounds are required where the area is subject to flooding. Cassava on ridges showed higher coefficient of variation compared to those on mounds for biomass and root yield. This might be due to competition for space and crown development in the ridges compared to mounds. In cassava, closer spacing results in high productivity of above ground biomass at the expense of root development[30].

The coefficient of variation was low in harvest indices for cassava on ridges and mounds. This confirms that the harvest index seems to be a special characteristic of the varieties[44]. The means in harvest index on treatments were significant. The high harvest index for ridges may be attributed to moisture conservation by the ridge-furrow system.

CONCLUSION AND FUTURE RECOMMENDATIONS

The study proposed to reduce climate stress on cassava establishment. The results imply that:

- Daytime temperatures and wind speed are major climate stressors that cause high moisture losses and could be reduced by any type of soil cover
- Soil-water-conserving tillage practices and planting within defined onset and cessation of rainy season enhanced the resistance of cassava to climate stressors
- Separating normal drought assessment criterion into positive and negative components removed the limitations of Standardized Precipitation Index for drought assessment in dry areas of Ghana

It is recommended that:

- Cassava and other crop farmers in the savanna zones of Ghana need to practice mulching, cover cropping and minimum tillage to prevent over exposure of the soil to daytime temperatures and wind
- Pest control is necessary when cassava growth extends to the dry season since the green foliage attracts pests. Pest attack can be minimized by selecting early-bulking varieties (6-8 months)
- Educate farmers on specific indicators for dry or wet years in order to effectively utilize the rainfall onset and cessation tool for each farming year and for specific crops

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