Yield of Maize and Cowpea Under Variable Seasonal Rainfall, Land form, Tillage and Weed Management on the Vertisols of Ghana

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Abstract

The effects of seasonal rainfall pattern, tillage and weed management on the yield of maize and cowpea grown on two land forms (Camber beds and flat plots), on the Vertisols (Akuse series) in the Accra Plains were examined over a 3-year period (1997-1999). Camber beds, tilled plots, and glyphosate-treated plots gave significantly ($P<0.001$) higher crop yields than flat, non-tilled and hoe-weeded plots respectively, in seasons with normal or above-average rainfall. Maize yields of 1.97 and 2.3 t ha^{-1} on camber beds were 17.9% and 47.4% higher than those on flat plots (1.7 and 1.6 t ha^{-1}) in 1977 and 1999 respectively. The seasonal rainfall amounts in the 2 years were 129% and 91% respectively of the seasonal average. However, in 1998 when rainfall in the major season (489 mm) was almost 37.8% below average, maize yields on camber beds (1.3 t ha^{-1}) were 34% lower than those on flat plots (1.95 t ha^{-1}). Cowpea yield on camber beds (0.54 t ha^{-1}) was 21% higher than that on flat plots (0.44 t ha^{-1}) in 1999, but the difference in yield between 0.29 t ha^{-1} for camber and 0.28 t ha^{-1} for flat plots was not significant in 1998. However, in 1997 when rainfall was 80.6 mm, about 19.4% below average, cowpea yield of 0.18 t ha^{-1} on camber beds were 22% lower than that on flat plots of 0.22 t ha^{-1}. Notwithstanding the variations in seasonal rainfall, application of herbicide glyphosate (G2) over the 3 years, increased yields of maize (7.85 t ha^{-1}) and cowpea (1.25 t ha^{-1}) on camber beds by 180% and 85.3% respectively over the 2.8 t ha^{-1} for maize and 0.67 t ha^{-1} for cowpea on hoe-weeded flat plots.

Introduction

The climate of the Accra Plains in Ghana with its characteristic low and erratic rainfall regimes coupled with high intensities requires efficient soil water management practices for crop production. Kranjac-Berisavljevic (1994) analyzed the rainfall pattern at the University of Ghana, Agricultural Research Station (ARS), Kpong in the Accra Plains over a 37-year period and compared it with 79 years of data from Akuse, a nearby (8 km) synoptic station. The climatic pattern revealed variations in the number of dry and humid days during a cropping season causing appreciable differences in soil moisture storage. The rainfall pattern in a typical year is bi-modal with a mean annual total of 1,120 mm with a coefficient of variation of 24%. About 60% of this annual total occur in the major season, 30% in the minor season and the rest in the off-season. Dependable annual rainfall available at 75% probability amounts to only 633 mm.

Of the 183,000 ha of Vertisols in Ghana, about 90% (163,000 ha) occur on the Accra Plains (Brammer, 1967). These soils are dominantly montmorilonitic clay with high water-holding capacity. When wet, they swell (40-50% swelling) and become too sticky for farm implement operation. Under dry conditions they produce hard consistency and cracks thus making them very difficult to be tilled. In spite of their great potentials for crop production, the Vertisols have remained under-utilized in Ghana due to their physical limitations (Kowal, 1964). However, technologies have been developed to facilitate crop growth on these soils through soil, water and weed management strategies under rainfed conditions using land forms, which either drain excess water or conserve soil moisture under limiting water conditions (Ahenkorah, 1995; Asiedu, 1995; Darkwa *et al*., 1999; Terry *et al*., 2000 and Willcocks *et al*., 2000).

Based on detailed soil surveys, Kaiser Engineers & Constructions, Inc. (1965) and Brammer (1962) discussed the physical and chemical features of several soil series in the Accra Plains with recommendations for the cultivation of various crops. Kaiser (1965) further gave the irrigation requirements of some of the major crops cultivable in the area. Baranowski (1986) provided information on the growth of sugarcane with respect to soils and climate. However, studies on the growth of maize and cowpea under rainfed conditions on the Vertisols are lacking. It is, therefore, important to investigate the effect of the variability of seasonal rainfall and other cultural practices on crops grown on land forms on the Vertisols of the Accra Plains. This paper examines the effects of seasonal rainfall variations, land form, tillage, weed management and their interactions on the yield of maize grown in the major season and cowpea grown in the following minor season over a period of 3 years (1997-1999).

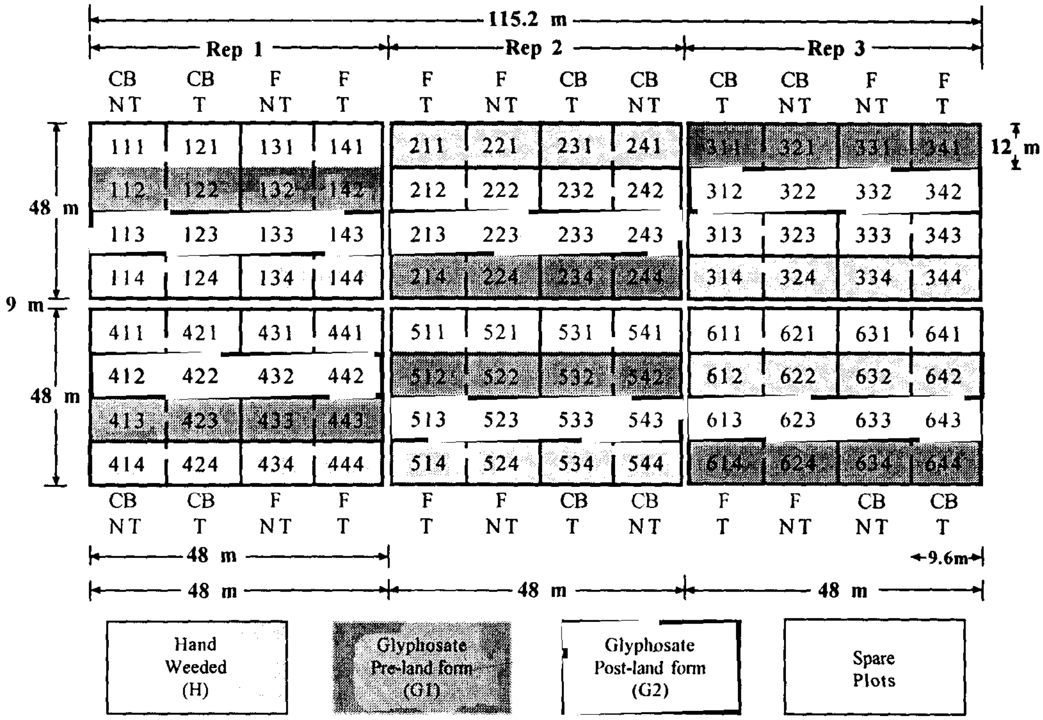
Materials and methods

Project site description

The experiment was conducted at the University of Ghana Agricultural Research Station (ARS), Kpong, located in the Accra Plains at an altitude of 18 m above sea level. The 1,024-ha research station is located at latitude 6° 09' North and longitude 00° 04' East. The major growing season begins from March to mid-July and the minor growing season from early September to mid-November. The mean air temperature is 27.2 °C with mean maximum and mean minimum temperatures of 33.3 °C and 22.1 °C, respectively. The relative humidity for the night time to the early hours of the day ranges from 70% to 100% throughout the year. The afternoon relative humidity falls to a range of 20-65% during the year. The topography of the farming land is gently sloping with slopes ranging from 1% to about 5%. This, coupled with the high clay content (30-55%), gives rise to poor drainage which subjects the land to occasional flooding during periods of high rainfall in flat and depressional areas.

Field experimental design

Land forms, tillage, weed management and their interactive effects on the yields of maize and cowpea were studied in each rainy season in a 2 × 2 × 3 multi-factorial experiment. Randomised complete block design (RCBD) was used with six replications. Fig. 1 shows the field layout for the experiment. Each replication consisted of a main plot (48 × 38.4) m, a subplot (48 × 9) m and a sub-sub plot (38.4 × 12) m. The main plot treatment was land form with two levels, i.e. camber beds (CB) and flat plots



Plot Numbering: Block = 1st digit, Tillage strip = 2nd digit & Crossplot = srd digit CB = Camber beds, F = Flat plots, T = Tilled plots, NT = Non-tilled plots

Fig. 1. Field layout plan

(F). Camber beds were formed by repeated passes of a polydisc plough to make a raised profile 0.4 m high from the trough to the top of the bed with a slope ranging between 10% and 16%, and 4.5 m wide. After a few rains, the camber beds settled to a height of approximately 0.3 m (Fig. 2). A disc plough was used to prepare the flat seedbeds.

The subplot treatment was tillage with two levels, tilled (T) and non-tilled (NT). Cultivation on tilled flat plots consisted of traditional primary tillage (ploughed to a depth of about 0.2 m using a disc plough and harrowed). On tilled camber beds, cultivation was done with a polydisc plough to a depth of about 0.1 m in seasons following the initial bed preparation, while in the non-tilled treatment cultivation was done with no soil loosening (slashing and planting).

The sub-subplot treatment was weed management with three levels namely; hoe-weeding (H), glyphosate herbicide (1.8 kg a.i. ha^{-1}) applied before camber beds formation (G1) and the same glyphosate dosage applied after camber beds formation (G2). In the G2 treatment, the experimental plots were left until an initial good weed cover was attained. Hence, glyphosate application was done on actively growing weeds using a knapsack sprayer. Hand weeding with hoe was done on all sub-subplots when necessary. After the first season, G1 and G2 were treated as the same. In 1999, glyphosate was not applied to G1 plot, so as to observe the residual effect of the herbicide applied over the last 2 years. All treatments were kept to the same plots throughout the 3-year duration of

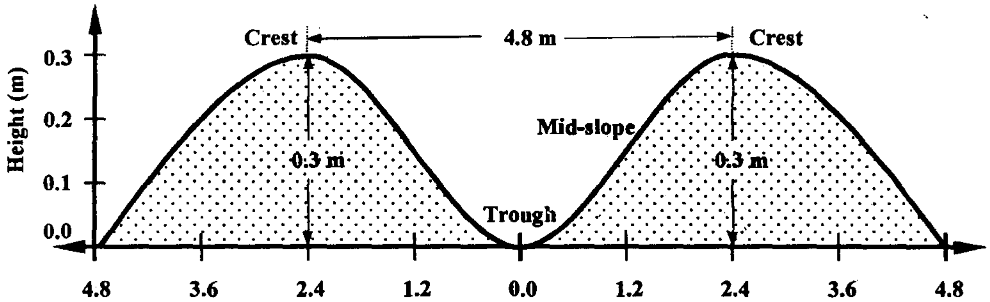


Fig. 2. Cross-section of camber beds from crest to crest (m)

the experiment. Due to the tillage treatment involved in the experiment, criss-cross design (Pearce, 1977) was used to facilitate the creation of the appropriate field layout. One sub-subplot in each main plot was kept as a spare plot.

An improved maize variety, Obatanpa, was sown in all the three major seasons of the experiment at a planting distance of 0.4 m within rows and 0.8 m between rows. The seeding rate was two seeds per hill. The minor season crop throughout the study was an improved cowpea variety, Bengpla, sown at a planting distance of 0.2 m within rows, 0.6 m between rows and at a seeding rate of two seeds per hill. On camber beds crop rows were oriented along the beds. Crops yield data were taken from harvest areas (4.8 × 5) m on each sub-subplot. The harvest areas on camber beds were positioned crest to crest across two adjacent beds (Fig. 2) to enable the assessment of spatial variability.

Results and discussion

Seasonal rainfall analysis

The seasonal rainfall pattern for the experimental period was categorised based on long-term (1955-81) rainfall data from the site. Analysis of the seasonal and annual rainfall data for the 27-year period revealed different rainfall categories as in Table 1. The mean annual total rainfall for the long-term period was 1,200 mm, with corresponding mean seasonal totals of 786 mm and 412 mm of rainfall in the major (Feb-Aug) and minor (Sep-Jan) seasons respectively. These observations are similar to those reported by Kowal (1964) and Kaiser (1965). The monthly rainfall distribution during the experimental period is compared with that of the long term (1955-

TABLE 1

Characterisation of wet and dry years at ARS Kpong (1955-81)

Rainfall category	*Total annual rainfall(mm)*	*Long-term average rainfall %*	*Years of occurrence*	*27 years duration %*
Very wet (a++)	>1500	>125%	1	4
Above average (a+)	1,200-1,500	100%-125%	11	41
Average (a)	1,200	100%	-	-
Below average (a-)	960-1,200	80%-100%	12	44
Dry (a--)	<960	<80%	3	11

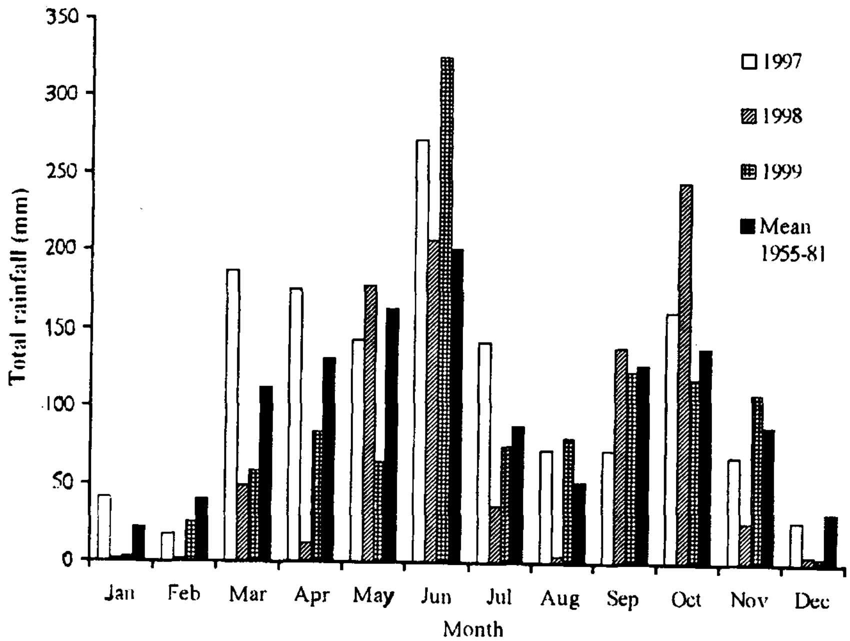


Fig. 3. Comparison of monthly rainfall for the experimental period with long term (27-years) monthly means.

81) mean monthly total (Fig. 3). The distribution confirmed the bi-modal rainfall pattern within a given year at the site with peaks in June and October in the major and minor seasons respectively. The annual rainfall totals from Fig. 3 for 1997, 1998 and 1999 were 1,383 mm, 908 mm, and 1,070 mm respectively.

The long-term seasonal averages were used to categorise the seasonal rainfall during the experiment (Table 2), to help explain the variation in yields over the period. The total rainfall amount in the major seasons of 1997 and 1999 were slightly above and slightly below the long-term major seasonal averages respectively. The major season of 1998 was very dry with a total rainfall of only 489 mm which was 38% below the long-term average. The probability of an annual rainfall of 908 mm as in 1998 is about 10% (Table 1) and the probability of a major season with only 489 mm rainfall is even less than 10%. The seasonal rainfall in the minor season of 1998 was about the same as the long-term minor seasonal average, but the minor seasonal averages in both 1997 and 1999 were slightly lower than the long-term minor seasonal average as in Table 2.

Crop yields

The yields of maize and cowpea as a result of seasonal rainfall variability, land forms, tillage and weed treatments are presented in Table 2. From Table 2a, maize yields on camber beds were significantly higher than on flat plots in 1997 and 1999 respectively, where seasonal rainfall amounts were 29% above and 9% below the long-term major seasonal average respectively. The better performance of the camber beds over the flat plots was due to the beneficial effects of raised land forms over flat plots on the Vertisols in Ghana, as discussed in detail by Ahenkorah (1995) and Asiedu

TABLE 2

The effect of seasonal rainfall variability, landforms, tillage and weed management on the yields of maize and cowpea

(a) Land forms

Year	*Major season (Feb-Aug)*					*Minor season (Sep-Jan)*				
	Seasonal rainfall		*Maize grain yield (kg ha⁻¹)*			*Seasonal rainfall*		*Cowpea grain yield (kg ha⁻¹)*		
	Amount (mm)	*Percent*† *(%)*	*Flat*	*CB*	*LSD* $_{(0.05)}$	*Amount* (mm)	*Percent*† (%)	*Flat*	*CB*	*LSD* $_{0.05}$
1997	$1,011^{a+}$	128.7	1,667	1,966	148.7	332^{a-}	80.6	222	182	24.2
1998	489^{a+}	62.2	1,949	1,286	186.0	420^{a}	101.9	276	292	27.0
1999	712^{a-}	90.6	1,574	2,320	275.6	386^{a+}	93.7	443	536	45.3
LSD $_{0.05}$			215.4	215.4				38.7	38.7	

(b) Tillage methods

Year	*Major season (Feb-Aug)*					*Minor season (Sep-Jan)*				
	Seasonal rainfall		*Maize grain yield (kg ha⁻¹)*			*Seasonal rainfall*		*Cowpea grain yield (kg ha⁻¹)*		
	Amount (mm)	*Percent*† *(%)*	*T*	*NT*	*LSD* $_{0.05}$	*Amount* (mm)	*Percent*† (%)	*T*	*NT*	*LSD* $_{0.05}$
1997	$1,011^{a+}$	128.7	1,851	1,782	148.7	332^{a-}	80.6	256	149	24.2
1998	489^{a+}	62.2	1,884	1,350	186.0	420^{a}	101.9	347	221	27.0
1999	712^{a-}	90.6	2,474	1,418	275.6	386^{a+}	93.7	531	448	45.3
LSD $_{0.05}$			215.4	215.4				38.7	38.7	

(c) Weed management

Year	*Major season (Feb-Aug)*						*Minor season (Sep-Jan)*					
	Seasonal rainfall		*Maize grain yield (kg ha⁻¹)*				*Seasonal rainfall*		*Cowpea grain yield (kg ha⁻¹)*			
	Amount (mm)	*Percent*† *(%)*	*G1*	*G2*	*H*	*LSD* $_{0.05}$	*Amount* (mm)	*Percent*† (%)	*G1*	*G2*	*H*	*LSD* $_{0.05}$
1997	$1,011^{a+}$	128.7	1,534	2,523	1,392	182.2	332^{a+}	80.6	217	262	127	29.7
1998	489^{a+}	62.2	2,183	2,002	666	227.9	420^{a}	101.9	353	361	139	33.1
1999	712^{a-}	90.6	1,481	3,251	1,109	337.5	386^{a-}	93.7	455	599	415	55.4
LSD $_{0.05}$			263.9	263.9					47.7	47.7	47.4	

Rainfall category: Above average (a+), Below average (a-), Very dry (a--), † Rainfall (mm) as a percentage of the 27 years average.

(1995). However, in the relatively dry year of 1998 where rainfall in the major season was almost 38% below the long-term major seasonal average, maize yields on camber beds were significantly lower than that on flat plots.

The water-shedding characteristics of camber beds did not promote good growth of maize whenever seasonal rainfall was low because the crops on camber beds suffered from moisture stress. Cowpea yields on camber beds were significantly higher than that on flat plots in 1999 where rainfall was 6.3% below average, but differences were not significant in 1998 with average rainfall. However, in 1997 when rainfall was about 19.4% below average, cowpea yields on camber beds were significantly lower than that on flat plots. The higher water holding capacity of flat plots and its effects on crop yield as compared to camber beds, under limited rainfall condition was observed and was similar to the situation in a dry major season.

Table 2b presents yields of maize and cowpea as influenced by tillage practice. Yields of maize and cowpea were always significantly higher on tilled plots than on non-tilled plots in the same year, except in 1997 where yield of maize was not significantly different on tilled and non-tilled plots. The higher yields of both crops on the tilled plots were due to the fact that, tillage invariably improved the soil physical environment, possibly increased soil microbial activities leading to more mineralisation of plant nutrients from organic sources. Asiedu (1995) gave other beneficial effects of tillage on the agronomic performance of crops.

The yields of maize and cowpea as influenced by weed management under variable seasonal rainfall are presented in Table 2c. Yields of maize and cowpea on glyphosate-treated plots (G1 and G2) were significantly higher than those on hoe-weeded plots within the same year, except in 1997 where maize yields on G1 treated plots were not significantly different from hoe-weeded plots. The higher yields of glyphosate-treated plots than the hand-weeded plots, was undoubtedly due to better weed control, particularly, early in the season when the crop was most vulnerable to competition as also observed by Terry *et al.*, 2000. The relative drop in yields observed on G1 plots in 1999 was due to the fact that glyphosate was not applied that year, but only the residual effect of the herbicide applied over the previous 2 years.

Interaction effects

The yields of maize and cowpea as a result of the treatment interactions are presented in Fig. 4 and 5. From Fig. 4a, maize yields on tilled camber beds (CB-T) > CB-NT and similarly the yields on tilled flat plots (F-T) were significantly higher than those on non-tilled flat plots (F-NT) in 1998 and 1999. In 1997, even though tilled-land forms gave higher yields than non-tilled land forms, the differences where not significant. In the very dry year of 1998, CB-T and CB-NT showed significantly lower yields than F-T and F-NT in both seasons, demonstrating again the higher water conserving characteristics of the flat plots under drought conditions over camber beds. From Fig. 5a cowpea yields were significantly higher on CB-T than CB-NT and F-T higher than on F-NT. This might be due to the improvement of the soil environment of land forms by tillage as explained earlier.

Application of herbicide as in the treatments G1 and G2 at the beginning of each season over the 3 years increased maize yields on camber beds by 90.3% and 180% respectively compared with flat hoe-weeded (F-H) plots (Fig. 4b). Similarly, G1 and G2 increased cowpea yields on camber

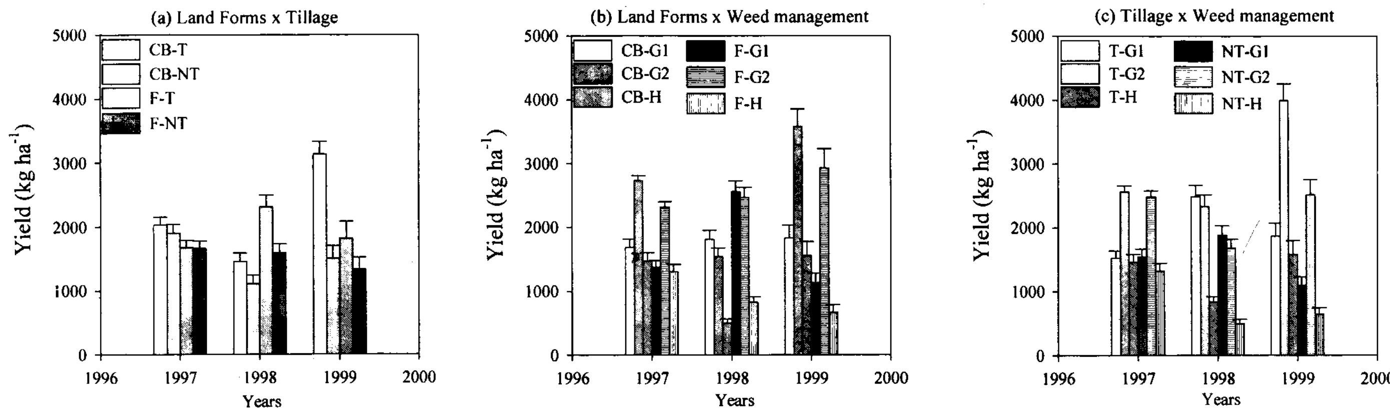


Figure 4: The effect of land forms, tillage and weed management interactions on the yield of maize in the major season

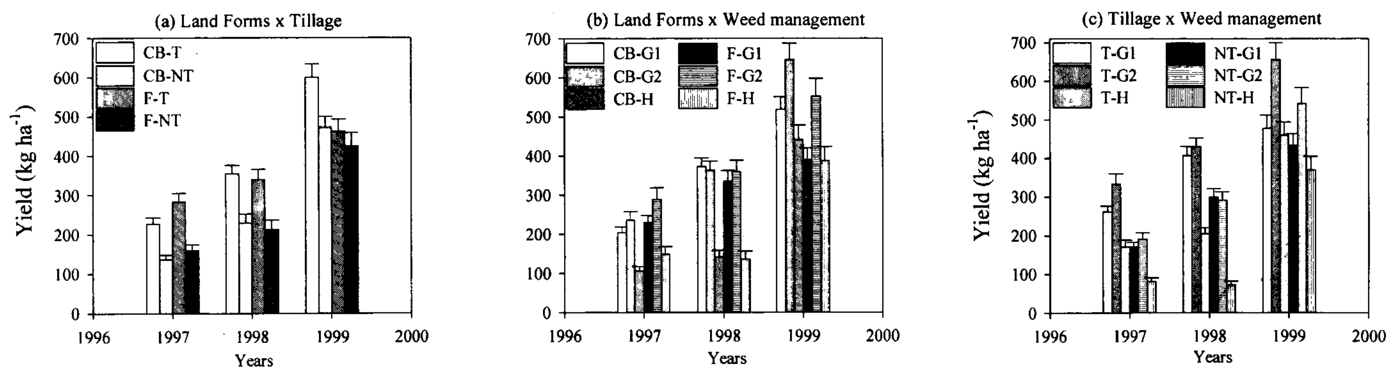


Figure 5: The effect of land forms, tillage and weed management interactions on the yield of cowpea in the minor season

beds by 63% and 85.3% respectively, over those on flat hoe-weeded plots (Fig. 5b). The highest maize yields on glyphosate-treated (G2) camber beds were 3.58 t ha^{-1} in 1999, 2.74 t ha^{-1} in 1997 and 1.54 t ha^{-1} in the drier 1998. Though much lower than on-station yields of 4.5 t ha^{-1} reported by the Ghana Grains Development Project (GGDP) (unpublished), they were higher than the 0.5-1.0 t ha^{-1} generally achieved by local farmers on Vertisols near Kpong (Kwadzo, 1995). The lower maize yield observed in 1998 was due to the lower rainfall during that season. The average cowpea yields over the 3 years were exceptionally low (0.224 t ha^{-1}), much less than the 1.75 t ha^{-1} reported by GGDP, (unpublished) but similar to that obtained by local farmers during the same period of drought.

The interactions of tillage and weed management did not show significant yield differences for maize in 1997 (Fig. 4c). However, there were significant differences between tilled weed treatments and non-tilled weed treatments in 1998 and 1999 for maize (Fig. 4c) as well as for cowpea (Fig. 5c). Application of G1 and G2 at the beginning of each season for the 3 years increased maize yields on tilled plots by 139% and 261% respectively over those on non-tilled hoe-weeded (NT-H) plots, Cowpea yields increased on tilled plots by 119% and 171% respectively, over those on non-tilled hoe-weeded plots. The best maize yields on glyphosate-treated tilled plots were 3.99 t ha^{-1} in 1999, 2.56 t ha^{-1} in 1997 and 2.33 t ha^{-1} in the drier 1998, while the highest cowpea yields were 0.66 t ha^{-1} in 1999, 0.43 t ha^{-1} in 1998 and 0.33 t ha^{-1} in 1997. The higher yields of both crops on the tilled glyphosate treated plots than NT-H plots could most possibly be due to the combined effect of improvement of the soil environment by tillage and better weed control, particularly at the initial growth stages of the crops.

All the treatments interactions (land form × tillage × weed management) did not show significant differences in the yields of both maize and cowpea under the variable seasonal rainfall conditions, indicating it is better to invest in only two of the factors for maximum yields. For the duration of the experiment, the two-factor interaction treatments that gave highest yields were in the order T-G2 > CB-G2 > CB-T with yields of 3.99, 3.58 and 3.13 t ha^{-1} respectively for maize and 0.66, 0.65 and 0.60 t ha^{-1} respectively for cowpea in 1999 where seasonal rainfalls were nearly normal.

Conclusion

The effects of seasonal rainfall variation, land forms, tillage, weed management and their interactions on the yield of maize and cowpea grown on the Vertisols in the Accra Plains were studied. Seasonal rainfall amounts during the experiment of period were categorised to facilitate explanation of the variations in yields due to rainfall. In seasons with normal or above-average rainfall, camber beds were more productive than flat plots. However, when the seasonal rainfall was low, flat plots appeared more suitable than camber beds for crop production. Notwithstanding the effects of variable seasonal rainfall, weed control by glyphosate treatment whether G1 or G2 gave higher crop yield than hoe weeding due to better weed control. The order of efficiency was G2 > G1 > H. Tillage gave better crop yield than non-tilled plots, due to improvement of the soil environment.

The interactions of all the three factors under the variable seasonal rainfall pattern, i.e., land form × tillage × weed treatment, gave no significant differences in their effects on the yields of both maize and cowpea. This may suggest that it is better to employ only two factor combinations to achieve high crop yields. For land form x tillage interaction the decreasing order of observed high yields was CB-T > CB-NT and F-T > F-NT; for land form × weed management interaction, CB-G2 > CB-G1 > CB-H and F-G2 > F-G1 > F-H and for tillage × weed management, T-G2 > T-G1 > T-H and NT-G2 > NT-G1 > NT-H.

Further studies on the soil water relationships with respect to the camber beds and flat plots will be important to broaden the knowledge base of crop performance on the Vertisols.

Acknowledgement

This paper is an output from a project (R6737). The authors are very grateful to the UK Department for International Development (DFID) for funding it. They are also grateful to the staff of the Ecological Laboratory, University of Ghana, for providing laboratory facilities for the analysis of the soils.

References

Ahenkorah, Y. (1995) Management of Vertisols for sustained rainfed small-holder production in Ghana. *Ghana-Vertisol IBSRAM Project. Final technical report to ODA and IBSRAM,* 85 pp.

Asiedu, E. K. (1995) Evaluation of four Vertisol management technologies using soil physical parameters. (M.Phil Thesis). Department. of Soil Science, University of Ghana. 97 pp.

Brammer, H. (1962) Soils of Ghana. In *Agriculture and land use of Ghana* (J. B. Wills ed.), pp. 88-126. London: Oxford Univ. Press.

Brammer, H. (1967) Soils of the Accra Plains, *Soil Research Institute Memoir* No.3. Kwadaso-Kumasi: Soil Research Institute.

Baranowski, (1986) Sugar cane in Ghana. *Crop Research Institute Bulletin* No. 2. Accra: Ghana Univ. Press. 95 pp.

Darkwa, E. O., Johnson, B. K., Nyalemegbe, K., Terry, P. J. & Willcocks, T. J. (1999). Control of *Cyperus rotundus* on Vertisols and vertic clays in Ghana. *Proc. Brighton Crop Protection Conf- Weeds, UK,* pp. 373-378.

Kaiser Engineers & Constructions, Inc. (1965). *Accra Plains irrigation feasibility study for Volta River Authority.* New York: Kaiser Engineers. Ch. 5-8.

Kowal, J. M. L. (1964). The agricultural development of the black clay soils of the Accra Plains. (Ph.D. Thesis). University of London. 150 pp.

Kranjac-Berisavljevic, G. (1994). Rainfall pattern analyses at ARS Kpong (1955-1991). Agro-climatological study *Journal of Ghana Institution of Engineers* **14** (1), 7-14.

Kwadzo, G. T. M. (1995). Socio-economic study of small-scale farm households on the Vertisols of the Accra Plains. Dept. of Agric. Economics, Univ. of Ghana, 93 pp.

Pearce, S. C. (1977). Field experimentation with trees and other perennial crops. *Commonwealth Agricultural Bureaux, Technical Communication* No, 23, pp. 26-27.

Terry, P. J. & Willcocks, T. J. (2000). Management of *Cyperus* in small-holder farming system on Vertisols and vertic clay soils. *Cyperus Project (R6737), Final tech. report to DFID.* 81 pp.

Terry, P. J., Darkwa, E. O., Johnson, B. K., Nyalemegbe, K., Yangyuoru, M. & Willcocks, T. (2000). Weed management on Vertisols for small-scale farmers in Ghana. (Abstract) *Third International Weed Science Congress, Brazil,* No. 403, pp. 192-193.

Willcocks, T. J., Darkwa, E. O., Johnson, B. K., Nyalemegbe, K., Terry, P. J. & Yangyuoru, M. (2000). How can the production potential of Vertisols and vertic clays contribute to the demand for more food? *Proc. of Tropical Ag. Assoc. (TAA) Biennial Res. Seminar, Edinburg*, 'Can Sustainable Agriculture Feed the Population of Tropical Countries for the Next 25 Years?' In *TAA Newsletter* Vol.**20**, No.1, pp. 29-30.