The Effect of Camber Bed Drainage Landforms on Soil Nutrient Distribution and Grain Yield of Maize on the Vertisols of the Accra Plains of Ghana

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Abstract

The Vertisols of the Accra Plains of Ghana are water logged after significant rainfall due to the low-lying topography (0.1-1 %). Camber bed (Cb) drainage landforms have been developed at the Agricultural Research Centre, Kpong, for draining off excess water. Field experiments were conducted to verify if maize growth and yield gradient from the trough to the crest were the result of nutrient gradient or some other factors. Four 5 m and two 10 m Cbs and a 20-m flatland were prepared in a split-split plot design, with landform as main plot, nutrient levels as sub plot and crop row as sub-sub plot. A pot experiment was also carried out for detailed studies. Soil movement brought about a nutrient gradient from the trough of the camber bed to the crest, and also made the soil profile homogeneous. The trough was low in nutrients, compact and prone to water logging, but nutrient levels increased through the middle slope to the crest. The flatland did not have a nutrient gradient but was prone to water logging due to its low-lying nature. Total dry matter (TDM) of maize and grain yield similarly increased from the trough to the crest. Grain yield of maize on the flatland ranged from 2.5–2.6 t ha^{-1}, while yields on the 5-m Cb were 3.6, 4.2 and 4.8 t ha^{-1} on the trough, middle slope and crest, respectively. Excess application of 15-15-15 NPK and sulphate of ammonia fertilizers (150% of recommended levels) did not appreciably increase biomass and grain yield in the troughs. However, the maize crop in pots, with soil from the trough, responded positively to fertilizer application, thus confirming that low yield in the trough was the result of both low nutrient availability and the compact subsoil.

Introduction

The Vertisols of the Accra Plains of Ghana occur on about 163,000 ha land area (Ahenkora, 1995), which is 90% of the total area covered by Vertisols in Ghana (i.e. about 182,000 ha). They are dark-coloured, heavy, alkaline, cracking clays, which occur on gentle savanna topography, over the main basic gneiss belt, crossing the Accra and Ho-Keta plains (Brammer, 1967).

On average, rainfall within the Accra Plains ranges from 900 to 1200 mm per year, spread over two rainy reasons. The soils occur on slopes ranging from 0.1–1% and, therefore, in the major rainy season, they are liable to flooding, giving rise to stunted growth of maize and other upland crops (Duah-Yentumi *et al*., 1992).

Even though in Africa only about 6% of the Vertisols have soil fertility limitation

(Pushparajah, 1992), Vertisols in Ghana have remained underutilised for crop production due to physical limitations and absence of suitable technologies for their management (Ahenkora, 1995). The soils are difficult to manage, as they are sticky when wet and hard when dry.

In studies to alleviate agricultural pressures on steep slopes and reduce land degradation in parts of the Ethiopian Highlands, broad bed and furrow land management system was used to minimise soil loss on croplands during the rainy season (Wakeel & Astatke, 1995). Forage legumes were also grown to improve soil nutrients, to allow intensive cultivation of Vertisols in the Ethiopian Highlands.

On Vertisols in semi-arid Sudan, conservation of water is a priority (Willcocks & Yule, 1995) but, under the tropical climate of the Accra Plains in Ghana, technologies are needed to reduce the level of inundation and its damaging effect on crops. Duah-Yentumi *et al*. (1992) conducted studies on camber beds and ridges, in comparison with flatland, to facilitate drainage on the Vertisols in Ghana and, thus, increase productivity. In the study, the camber beds gave maize yield of 2215 kg ha^{-1}, followed by that on ridges (1504 kg ha^{-1}) and flats (851 kg ha^{-1}). Drainage was faster on the camber beds than the ridges and slowest on the flats.

In experiments conducted to study the control of *Cyperus rotundus*, which was the dominant weed that occurred on the drainage landforms, it has been confirmed that, in seasons with high rainfall, water logging occurs and the growth and yield of maize and cowpea are better on the camber bed than on the flat (Darkwa *et al*., 1999; Terry *et al*., 2000).

In the above study, soil compaction was measured across the flatland and camber bed landforms (Yangyuoru *et al*., 2006). On the flatland, bulk density values ranged from 1.41 to 1.44 mg m^{-3} at 0–15 cm depth of soil and 1.43 to 1.48 mg m^{-3} at 15–30 cm depth. Across the 10 m Cb, bulk density values in the trough were 1.35 mg m^{-3} at 0–15 cm depth and 1.37 mg m^{-3} at 15–30 cm depth; in the middle slope, bulk density values were from 1.30 mg m^{-3} at 0–15 cm depth and 1.33 to 1.34 mg m^{-3} at 15–30 cm depth; and in the crest, values were from 1.26 to 1.27 mg m^{-3} at 0–15 cm depth and from 1.28 to 1.29 mg m^{-3} at 15–30 cm depth. Although there was no specific trend in the variation of bulk density across the flat plots, variation of bulk density across camber beds was such that the bulk density was high in the trough and gradually decreased to a minimum at the crest of the beds.

The gravimetric soil moisture content, 24 h after a significant rainfall (22.8 mm), which was enough to saturate the soil, was determined as 26–27% across the flatland and 20–28% across the camber beds. The camber beds had low moisture levels at the crests and high levels in the troughs. The flatland and the troughs of the camber beds were, therefore, prone to water logging. In order to verify if the decline in growth and yield of maize from the crest of the camber bed to the trough was the result of nutrient variation alone or a combination of nutrient variation and other factors like soil compaction and saturation, a follow-up study was conducted.

Materials and methods

Field trials were conducted at the University of Ghana Agricultural Research Centre, Kpong, which is located between latitudes 6^0 00' and 6^0 10' N and longitudes 0^0 05' and 0^0 15' E. The rainfall is bimodal, with annual average of 1200 mm. Four 5-m and two 10-m camber bed and 20-m flat landforms were prepared in a split-split plot design, with landform as main plot, nutrient levels as sub plot and crop row (position on the landform) as sub-sub plot. Tillage operations, in the formation of the camber bed, involved the shaping of land into beds, using a one-way harrow drawn by tractor. Camber beds have troughs at both sides and rise at a gradient, through the middle slope to the crest, as described by Darkwa *et al*. (1999) and Terry *et al*. (2000).

There were four replicates, each with dimension 60 m × 60 m, within the experimental area of 120 m × 120 m. Each strip of landform was of dimension 20 m × 60 m. Four levels of nutrients were applied across the landforms, in a strip of 5 m × 60 m. These included control plots without fertilization (TI), recommended fertilization, i.e. 250 kg ha^{-1} 15-15-15 NPK fertilizer and 150 kg ha^{-1} sulphate of ammonia (T2), one and half times the recommended application, i.e. 375 kg ha^{-1} NPK and 225 kg ha^{-1} sulphate of ammonia (T3), and cowdung manure, 30 t ha^{-1} (T4).

Initial soil samples were taken before landforms were prepared, at depths of 0–15 cm, 15–30 cm and 30–45 cm, and analysed for soil *p*H, organic matter, nitrogen, phosphorus and potassium. Post tillage sampling was done after two significant rains to enable the soil stabilise, and before planting and fertilizer application. Soils on the 5-m Cb were sampled along a transect across the two camber beds in the middle, starting from the trough (0 m), at the middle slope (1.25 m), the crest (2.5 m), and repeated from the trough of the second 5-m Cb (0 m), the middle slope (1.25 m) and the crest (2.5 m). On the 10-m Cb, soils were sampled along a transect joining the crests of the two 10-m Cbs, starting from the first crest (5 m), at the middle slope (7.5 m), the trough (10/0 m), the middle slope (2.5 m), and the second crest (5 m). On the flat plot, samples were taken at six spots that were spaced evenly along a 10-m transect. The soil samples were analysed and average values determined.

Maize was planted in rows along the length of the camber beds, at a spacing of 80 cm between rows and 40 cm within the row. Agronomic practices were applied as recommended. Plant height, TDM at maturity and grain yield were determined on crop rows along the trough, middle slope and crest of the camber beds and also on corresponding rows on the flat.

A pot experiment was carried out, alongside the field experiments, for detailed studies under a well-controlled water regime. Soil to a depth of 15 cm was dug from the flat and from the furrow, middle slope and crest of the 5-m and 10-m camber beds, before planting and nutrient application. The soils were filled into pots, given nutrient applications similar to the field experiment and then watered to field capacity every 3 days. Plant heights were measured at weekly intervals and at mid cob formation (66 DAP), and stem biomass was determined.

Results and discussion

In the initial soil samples that were taken before the formation of landforms, nutrient levels varied within the soil profile, with soil *p*H and N content being higher in the upper layers (0–15 and 15–30 cm) than the 30–45 cm layer (Table 1). On the other hand, after the landforms were formed, the soil profile became more homogeneous, and nutrient levels did not differ between soil layers (Table 2). Nutrient contents were not appreciably different between landforms and within crop rows on the flatland (Table 3). However, nutrient levels in the crest of the camber beds were significantly higher than observed in the trough and middle slope (Tables 3 and 4).

Landform and crop row had an interactive effect on soil nutrient availability (Table 3). Nutrient levels did not differ between crop rows on the flatland but were lower in the troughs of the camber beds than the middle slopes and crests. That was due to the movement of surface soil from the trough to the middle slope and crest regions in the course of camber bed formation. This partly explains the poor growth of maize and lower grain yields in the troughs than on the middle slopes and crests of the camber beds, similar to the observations of Ahenkora (1995).

Although plant heights were higher on the flatland than the camber beds, TDM was not different between landforms (Table 5). On the other hand, grain yield was higher on the 5-m Cb than on the 10-m Cb and the flatland, and higher on the 10-m Cb than on the flatland. In view of the fact that nutrient levels did not differ between landforms, differences in grain yield between the 5-m and 10-m Cbs may be attributed to the fact that the 5-m Cb had greater ability to drain off excess water than the 10-m Cb. The 10-m Cb, being broader than the 5-m Cb, was likely to retain greater soil moisture, which could bring about poor internal drainage of the soil.

There has been interaction between landform and crop rows (Table 5). Plant height, TDM and grain yields were distinctly different between crop rows on the camber beds, while no differences were observed between rows on the flat plot. Also, plant height, TDM and grain yield were much lower on the trough than on the middle slope and crest of the 5-m and 10-m camber beds.

In spite of the low nutrient levels in the trough and flatland (Tables 3 and 4), response to fertilization has been low (Table 6). However, greater growth response (plant height and TDM) has been observed with application of cow dung manure. The inability of increasing levels of fertilizer application to reflect on maize yield pointed to the fact that, apart from nutrient deficiency, some other factors may have restricted fertilizer utilisation. This could be explained by results obtained in experiments conducted by Yangyuoru *et al.* (2006).

Poor growth and yield in the trough could also be explained by the fact that it was mainly compact subsoil, with water logging problem and poor root penetration and distribution. On the other hand, poor crop growth and yield on the flatland could be attributed to soil saturation after significant rainfall, that being the result of high bulk density of the Vertisol and the low-lying terrain. There has been tremendous response to fertilizer by the maize crop grown in pots (Table 7), and that confirmed the fact that soil compaction and water logging were additional factors that restricted crop growth and yield on the landforms studied. Muchena & Ikitoo (1992) found that lower grain yield in maize could be due to high moisture saturation. They explained that maize roots are confined to the top 30 cm of soil, which

TABLE 1

Initial nutrient levels of the vertisols of the Accra Plains of Ghana before formation of drainage landforms

Depth (cm)	p*H*	*OM (g kg^{-1})*	*N (%)*	*Available P (mg kg^{-1})*	*Available K (cmol kg^{-1})*
0–15	7.40	2.11	0.078	1.12	0.11
15–30	7.40	1.92	0.074	0.86	0.11
30–45	7.20	1.55	0.050	0.66	0.24
LSD (P = 0.05)	0.16	ns	0.020	ns	ns

TABLE 2

Nutrient levels of the Vertisols of the Accra Plains after formation of drainage landforms

Depth (cm)	*pH*	*OM (g kg^{-1})*	*N (%)*	*Available P (mg kg^{-1})*	*Available K (cmol kg^{-1})*
0–15	7.5	1.77	0.081	1.47	0.14
15–30	7.4	1.68	0.081	1.21	0.13
30–45	7.5	1.65	0.077	1.37	0.13
LSD (P = 0.05)	ns	ns	ns	ns	ns

TABLE 3

Interactive effect of landform and crop row on soil nutrient properties of the Vertisols of the Accra Plains

Landform	*Crop row*	p*H*	*OM (g kg^{-1})*	*N (%)*	*Available P (mg kg^{-1})*	*Available K (cmol kg^{-1})*
Flat						
	1	7.53	1.66	0.079	1.43	0.134
	2	7.53	1.66	0.079	1.43	0.134
	3	7.53	1.66	0.089	1.43	0.134
5-m Camber bed	1 (Furrow)	7.47	1.46	0.077	1.19	0.112
	2 (Middle slope)	7.49	1.69	0.076	1.28	0.141
	3 (Crest)	7.41	1.86	0.085	1.66	0.138
10-m Camber bed	1 (Furrow)	7.48	1.73	0.076	1.03	0.118
	2 (Middle slope)	7.42	1.66	0.078	1.15	0.109
	3 (Crest)	7.43	1.95	0.088	1.52	0.160
LSD (P = 0.05)		ns	ns	Ns	ns	0.028

TABLE 4

Nutrient levels at specified crop rows on camber bed drainage landforms on the Vertisols of the Accra Plains

Crop row	p*H*	*OM (g kg^{-1})*	*N (%)*	*Available P (mg kg^{-1})*	*Available K (cmol kg^{-1})*
1 (Furrow)	7.5	1.61	0.078	1.22	0.12
2 (Middle slope)	7.5	1.67	0.078	1.29	0.13
3 (Crest)	7.5	1.82	0.084	1.54	0.14
LSD (P = 0.05)	ns	0.15	0.004	0.22	0.02

TABLE 5

Interactive effect of drainage landform and crop row on growth and yield of maize on the Vertisols of the Accra Plains

Landform	*Crop row*	*Plant height (cm)*	*Total dry matter (t ha^{-1})*	*Grain Yield (t ha^{-1})*
Flat	1	112.17	7.02	2.61
	2	112.61	7.15	2.53
	3	112.21	7.18	2.55
5-m Camber bed	1 (Furrow)	97.39	6.44	3.55
	2 (Middle slope)	112.71	8.64	4.21
	3 (Crest)	114.96	9.58	4.78
10-m Camber bed	1 (Furrow)	94.44	5.51	1.63
	2 (Middle slope)	110.79	7.60	3.08
	3 (Crest)	110.72	9.36	4.38
LSD (P = 0.05)		5.95	1.14	0.49

TABLE 6

Effect of fertilizer application on growth and yield of maize on the Vertisols of the Accra Plains

Fertilizer treatments	*Plant height (cm)*	*Total dry matter (t ha^{-1})*	*Grain yield (t ha^{-1})*
Control	99.12	6.97	3.07
100% NPK fertilizer	109.99	7.95	3.37
150% NPK fertilizer	112.10	7.26	3.42
Cow dung	113.46	8.25	3.18
LSD (P = 0.05)	3.97	0.56	ns

TABLE 7
Effect of fertilizer application on growth and yield of maize grown in pots

Fertilizer treatments	*Plant height (cm)*	*Shoot weight (g plant^{-1})*
Control	88.60	59.40
100% NPK fertilizer	103.90	219.00
150% NPK fertilizer	103.20	253.50
Cow dung	90.00	65.60
LSD (P = 0.05)	6.03	22.63

is most severely affected by water logging early in the season and moisture stress late in the season.

The application of cow dung was intended to improve the physical property of the soil while enhancing soil nitrogen content. Oh (1979) was of the view that partially decomposed or fresh organic matter, e.g. rice straw, leads to the formation of water-stable aggregates, which give interspaces to soil as well as good supply of plant nutrients. Organic matter levels could also be increased through crop rotation with leguminous plants; thus, also sequestering carbon in the soil (Ramesh & Chadrasekaran, 2004).

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