CROP PROTECTION PROGRAMME

Management of *Cyperus* in small-holder farming systems on Vertisols and vertic clay soils

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EXECUTIVE SUMMARY

Vertisols and vertic clays are very significant resource for food production but they have generally not been regarded as such because they are very difficult to manage with traditional cultural practices, the soils being very sticky when wet and hard and cloddy when dry. These montmorillonitic clays are generally more fertile and have a higher water holding capacity than many tropical soils. Vertisols represent a vast underdeveloped crop production resource as it is estimated that there are about 308 million ha in the world, of which 90 million ha are in Africa, including 180,000 ha in Ghana. An ODA-supported project (T0336) in Ghana showed that raised land forms (camber beds) improved water management on Vertisols and produced crop yields up to 90% higher than on traditional, flat plots. However, the formation of camber beds and their subsequent maintenance by minimum tillage also proved favourable to the growth of a perennial sedge, *Cyperus rotundus* L., reputedly the worst weed in the world. Hence, the advantages to be derived from camber beds could be negated by the uncontrolled growth of this weed. Many researchers, including some on ODA-supported projects, have demonstrated the practicality of controlling *C. rotundus* with glyphosate. There has been little or no success in finding biological control agents for the practical management of this weed but there is considerable potential for suitable organisms in developing and developed countries.

The project's goal was to identify methods for the control of *C. rotundus* that enable more effective utilisation of Vertisols and vertic clay soils by smallholder farmers and, in particular, enhance the performance of camber beds. This was primarily an adaptive research project where known technology (particularly the control of *C. rotundus* by glyphosate herbicide) was tested on the research station and on farmers' fields. In doing this, the project also investigated the synergetic advantages of using effective weed control measures in conjunction with camber beds to control excess surface water and waterlogging. Not only were technical solutions sought for the *Cyperus* problem, but work was also done on the economics, acceptability to farmers and the promotion of the improved technology. A separate study, within the project framework, was done to find pathogens of *C. rotundus* in Ghana that would have the potential for being developed as biological control agents for this weed.

On the research station, over 99% reduction in the tubers (propagating organs) of *C. rotundus* was achieved within six cropping seasons (three years) by the application of 1.8 kg a.e./ha of glyphosate herbicide at the beginning of each season. This treatment, together with supplementary weeding (usually one hand weeding to control annual weeds) and camber bed land forms increased maize and cowpea yields by 188% and 86%, respectively, compared with traditional tillage and hand weeding on flat plots. Under the less rigorously controlled conditions of on-farm trials, glyphosate plus camber bed treatments increased maize and cowpea yields by 61% and 31%, respectively.

Camber beds gave higher crop yields than flat plots in seasons with normal or above-average rainfall. In on-station trials, maize yields on camber beds were 18% and 47% higher than on flat plots in 1997 and 1999, respectively. However, in 1998, when rainfall during the major cropping season was almost 40% below average, maize yields on 5m-wide camber beds were 34% lower than on flat plots. During this very dry season, 10m-wide camber beds, with their less vigorous water shedding characteristics, did produce higher maize yields than flat plots on a demonstration farm. Cowpea yields on camber beds were 21% higher than on flat plots in 1999 but differences were not significant in 1997 and 1998. In on-farm trials, there were no yield differences in maize yields between flat plots and camber beds in 1998 but the lower input camber bed system gave significantly higher yields in 1999. Cowpea yields from on-farm trials were too inconsistent to draw conclusions about the effects of land forms but camber beds allowed farmers to crop fields in low lying, waterlogged areas that they could not use with traditional flat systems and the camber bed systems had much lower input costs due to the reduced tillage with the polydisc.

Surveys for biological control agents revealed that a significant proportion of the co-evolved pathogens of *C. rotundus* already occur in Ghana and that classical biological control as a long-term management strategy is not relevant. Preliminary results from the pathogenicity studies suggest that there may be potential for an inundative strategy but, clearly, more screening of the material collected

is necessary in order to reach a firm conclusion. Based on taxonomic uniqueness and affinities, at least ten of the isolates/species merit at least a preliminary if not a full evaluation.

The project developed a cost-benefit model for the traditional and improved crop production systems in Ghana and the economics of using glyphosate compared very favourably to hand weeding. The reduced tillage input costs for camber bed tillage also had a significantly positive impact on the profitability of crop production on these Vertisols and vertic clay soils. Gross margins for glyphosate treatments are higher than for hand weeding because of the greater yields and reduced labour costs for weed control. The synergistic advantage of using glyphosate on camber beds resulted in farmer profits of £320/ha, compared with £75/ha for small family farmers using hand weeding on flat plots. Preliminary cost-benefit studies with cowpea, okra and pepper crops also showed the economic advantages of the improved crop production systems. The viability of this low input glyphosate and camber bed system has shown a gratifying robustness as it has withstood the onslaught of the severe devaluation of the Cedi over the past year which has dramatically increased machinery, fuel and chemical costs. Feedback from farmers has been very positive; several stated their intention to use glyphosate and camber beds in the future.

Dissemination of outputs has been done through papers and posters at three international conferences and one tropical seminar. One paper has been submitted to a peer-reviewed journal and others are being prepared. A booklet on the management of *Cyperus* is being prepared for use by farmers and the extension service. Two field days for farmers were held, one of which was filmed for presentation on *Agrolink*, a Ghanaian TV programme with an audience of three million viewers.

Opportunities are being explored to promote the outputs of the project through further activities supported by the NRSP and a charitable institution in the USA. A PhD student from Ghana plans to continue research on *C. rotundus* at Reading University.

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1. BACKGROUND

Vertisols and vertic clays have generally not been regarded as a significant resource for food production because they are difficult to manage, being very sticky when wet and hard and cloddy when dry. These montmorillonitic clays, however, are generally more fertile and have a higher water holding capacity than many tropical soils. They represent, therefore, a vast underdeveloped crop production resource as it is estimated that there are about 308 million ha in the world (Coulombe *et al*., 1996), of which 90 million ha are in Africa (Willcocks & Browning, 1986), including 180,000 ha in Ghana (Ahenkora, 1995).

The development of effective management systems for Vertisols will make significant progress when the focus is on the control of water and weeds. 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 impact of higher rainfall and its damaging effects on crops. Options for managing Vertisols in Ghana were explored during a three-year, University of Ghana (UoG) / IBSRAM / ODA project (T0336, during 1992-95) which showed that raised land forms gave superior crop yields to those obtained on traditional flat beds (Ahenkorah, 1995). Camber beds, 4.8 m wide and 0.3 m high, were the most successful land form studied, increasing crop yields by 90% compared with flat beds. However, two perennial weeds, *Cyperus rotundus* L. (Plate 1) and *Imperata cylindrica* (L.) Raeuschel, proliferated on camber beds, seriously reducing the benefits of these land forms.

Cyperus rotundus, reputedly the worst weed in the world (Holm *et al*., 1977), is widespread in West Africa (Akobundu & Agyakwa, 1987). It reduces crop yields, causing losses, for example, of up to 89% in vegetables (Williams & Warren, 1975). Cultivation can be effective for controlling *C. rotundus* by exposing the perennating organs (tubers) to desiccation or by exhausting the food reserves but this is not practical on Vertisols because of the difficulties in cultivating the soil. In Ghana, the persistence and vigour of *C. rotundus* is well recognised by the farmers who have given it the name, *'meet me at 6 o'clock'* because of its tendency to reappear in the evening after it has been 'controlled' in the morning. Glyphosate is one of the few herbicides that controls *C. rotundus* but there is some concern about the economics and practicality of using this product in small-scale farming systems of sub-Saharan Africa. The activity of glyphosate against *Cyperus rotundus* and other perennial weeds of arable land has been exploited for over 20 years (Terry, 1985) but it has found most utility in the developed countries and large scale enterprises in the Third World. There is little doubt that glyphosate will control *Cyperus rotundus* in Vertisols but original research in the natural sciences and socio-economics is needed to ascertain how best to use this product in smallholder systems being devised for improved management of Vertisols.

Plate 1. Maize smothered by *Cyperus rotundus* on Vertisol

The need for tillage of Vertisols is questionable. Deep and costly tillage of these cracking clays has been shown to be unnecessary because, through their shrinking and swelling properties, Vertisols are self-loosening. It is evident from observations and investigations in Africa and India that there is little or no need to loosen Vertisols at depth in order to enhance crop root elongation (Willcocks, 1989). However, reduced tillage management can be penalised by the opportunistic growth of weeds, especially perennials, which exploit such conditions. *Cyperus rotundus* is a classical example of a weed that thrives in cropped land subject to reduced tillage. Indications from the UoG / IBSRAM / ODA Vertisol Project on the Accra Plains in Ghana were that camber bed land forms effectively controlled water and could retain moisture during the dry season, a situation that encourages weed growth and possibly negating the benefits of moisture conservation. Combining good weed control with tillage practices to conserve moisture has been found to be effective on communal farming systems in Zimbabwe (Ellis-Jones *et al.*, 1993). In essence, the effective management of Vertisols centres on the management of water and weeds.

In comparisons of commercial energy requirements for conventional and reduced tillage using glyphosate and paraquat, Willcocks (1981) showed up to 60% savings in energy requirements on Vertisols when herbicides were used. If energy requirements are equated with cost, the economics of herbicide use must be favourable.

The capacity of farmers to adopt the technology is seen as a researchable constraint. Information exists on land use and cropping systems on Vertisols of the Accra plains (Owusu-Bennoah & Duah-Yentumi, 1989). Although this report contains little quantitative data, it did conclude: "the Vertisols of the Coastal Plains of Ghana are at present virtually uninhabited and very little utilised." A socio-economic study of small-scale farm households on the Vertisols of the Accra Plains (Kwadzo, 1995) showed that 67% of farmers use tractors and 23% use power tillers (sample size = 132 farmers). Several important issues were not addressed, leaving the need for further socio-economic studies to ascertain the capacity of farmers to adopt the project's technology. The precedents are good: socio-economic studies of farmers in Indonesia have shown that even the poorest categories of farmers are prepared to buy glyphosate to control *Imperata cylindrica* (research done by the ODA *Imperata* Project - F0028 in 1992-97).

Although the possibilities of using insect natural enemies for biological control of *C. rotundus* are remote, due mainly to insufficient host damage and lack of specificity (Evans, 1987), the potential of fungal pathogens appears good, particularly since several highly damaging and seemingly host-restricted species have already been identified (Evans, 1987). For example, *Phytphthora cyperi* has been associated with severe damage to the roots and tubers of *C. rotundus* in Sudan, Taiwan and India, whilst the phycomycete, *Duosporium cyperi,* has been reported as causing severe epiphytotics on this host in Brazil, and its biocontrol potential is currently being evaluated (Barreto & Evans, 1995). Similarly, the rust *Puccinia canaliculata* is a widespread pathogen of *Cyperus* spp. and has been registered as a mycoherbicide for the control of *C. esculentus* in the USA. Despite the damaging nature of these pathogens, severe infection usually only occurs towards the end of the cropping season, due to slow inoculum build-up, too late to have a significant impact on tuber production. However, studies have shown that it is possible to significantly reduce growth of *Cyperus*, and subsequently of tuber formation, by introducing fungal inoculum early in the season. Thus control of *C. rotundus* through the use of fungal pathogens could be considered using two radically different approaches: by manipulation of indigenous pathogens (either as crude inoculum or a formulated product) or by the release of exotic coevolved pathogens (classical introduction). The aim of this study is to assess if either approach is feasible within Ghanaian farming systems.

During implementation of the UoG / IBSRAM / ODA Vertisol Project in 1992-95, it became apparent that weeds, particularly *Imperata cylindrica*, were a serious problem. An ODA-sponsored weed consultant to the project confirmed the severity of *I. cylindrica* and also *Cyperus rotundus* and recommended that research be done to find practical solutions (Willcocks & Terry, 1994). Within the limited resources of the project, research commenced to test simple weed management options.

However, there was a need for an integrated weed management approach employing herbicides, cultivations, cultural techniques and biological control which was beyond the resources of the project. The UoG / IBSRAM / ODA Vertisol Project conformed in major aspects to ODA's Natural Resources Strategy for future UK aid to Ghana and Vertisol research has been included in the National Research Strategic Plan for Ghana (Syers *et al.*, 1995). Hence, a project on the management of *C. rotundus* on Vertisol is compatible with research strategies of DFID and the Ghana Government.

2. PROJECT PURPOSE

The project's purpose is to devise methods of managing *Cyperus rotundus* that integrate cultural, biological and cultivation. Techniques will be developed to allow small-scale farmers in Ghana to utilise Vertisols and other clay soils to their full potential. Management of the weed complex associated with *C. rotundus* on these soils, particularly *Imperata cylindrica*, would also be addressed.

This was primarily an adaptive research project where known technology (particularly the control of *Cyperus rotundus* by glyphosate herbicide) was tested in a system previously developed by the UoG / ODA / IBSRAM and project, 'Management of Vertisols for sustained rainfed smallholder crop production in Ghana (T0336)'. Not only were technical solutions to the *Cyperus* problem sought, but work was also done on the economics, acceptability to farmers and promotion of this technology. A separate study, within the project framework, was done by CABI Bioscience to find pathogens of *C. rotundus* in Ghana that would have the potential for being developed as biological control agents for this weed

3. RESEARCH ACTIVITIES

3.1 Socio-economic studies

The objective of this study was to provide socio-economic information in support of the "Management of *Cyperus* in smallholder farming systems on Vertisol and vertic clay soils in Ghana". Items mentioned were:

- crop production resources available to small-scale farmers;
- constraints faced by smallholders;
- market outlets;
- development options for improved crop production;
- development options for improved supply systems.

The terms and references for this study added the following specific outputs:

a) socio-economic description of crop production systems, particularly weed management practices for different categories of farmers;
b) potential and comparative productivity of Vertisols for arable cropping, livestock production, and wildlife indigenous harvesting of traditional foods;
c) gender analysis to identify the role of women in crop production from different categories of households, e.g. in decision making, field operations labour, weed control, purchase of farm inputs, and access to land and other resources.

This study was basically a follow-up study to an earlier survey (Kwadzo, 1995) on request of the former UoG / IBSRAM / ODA project. That study was a survey among 132 farmers cultivating the Vertisols in the Accra plains; sample locations were Kpong, Akuse, Asutsuare, and Somanya. Another earlier land use survey was undertaken by Owusu-Bennoah and Duah-Yentumi in 1989, who interviewed 44 farmers cultivating the black clay soils in four farming centres, i.e. Kpong, Somanya, Akuse and Juapong.

The central objective of the present study was to highlight better local farming systems. Because no good impression existed before undertaking this study of the location of farms, population and settlements, nor of the variability in farming systems or resource endowment, no formal sampling procedure was followed. Instead, it was decided to implement a reconnaissance survey, that is, visits were paid to key informants, and farmers were interviewed using formal questionnaires. Some 28 farmers were interviewed in 10 locations in the coastal Vertisol area, on both sides of the Volta River (Table 1). This sample size was a function of time and budget available. Sample selection was purposeful, that is, survey locations were not selected randomly but were identified during the course of surveying with the aim to have geographical spread. Farmers interviewed were those available at that location at that time but were selected on the criterion that they were principally engaged in non-irrigated arable farming.

Table 1. Sample locations for socio-economic study

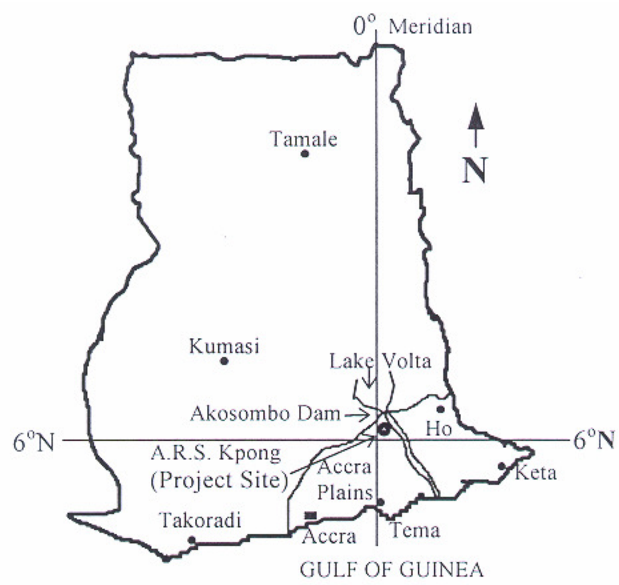
Number	Village	District	Capital	Region
1	Trom			
2	Togorme	North Tongu	Adidome	Volta Region
3	Okwenya	Yilo Krobo	Somanya	Eastern Region
4	Armedika			
5	Dayumu	Dangbe West	Dodowa	Greater Accra
6	-			
7	Yokornya Lano	Dangbe West	Dodowa	Greater Accra
8	Dufuor Adidome	North Tongu	Adidome	Volta Region
9	Tagadzi	North Tongu	Adidome	Volta Region
10	Adakope	North Tongu	Adidome	Volta Region

Field work was conducted by the NRI socio-economist and one of the University of Ghana agricultural economists, with two assistants, and accompanied by front line staff of the Ministry of Food and Agriculture.

3.2 Long-term management trial

A long-term trial was done to approximate conditions on farms but allowing the rigour of a formal experiment. The main objective was to evaluate the control of *Cyperus rotundus* using glyphosate but the experiment was designed to look at the interactions with land form (flat plots and camber beds), residual herbicides and minimum tillage. The trial site on Vertisol was prepared at the Agricultural Research Station Kpong, Ghana (6°08'N, 0°05'E) (Fig. 1), a location where annual rainfall averages 1,200 mm distributed between a major season (March to July, approx. 800 mm) and a minor season (September to December, approx. 400 mm). See Annex 1 for rainfall statistics. Maize was grown in the major seasons of 1997, 1998 and 1999; cowpeas were grown in the minor seasons of these years.

Fig. 1. Location of project site at ARS Kpong, Ghana



3.2.1 Site preparation

Site preparation started in late 1996 when an area of long-term fallow land infested with a variety of small shrubs, annual weeds and a high density of *C. rotundus* was mechanically slashed to ground level. In March 1997, a disc plough was used to prepare flat seedbeds, the standard land form used by farmers in the area. Camber beds were formed by repeated passes of a polydisc plough to make a raised profile 4.8m wide and 40cm high from the furrow to the top of the bed. After a few weeks, the camber beds settled to a height of approximately 30cm (see Fig. 16).

3.2.2 Crops

In the major cropping seasons, maize var. *Obatanpa* was sown 40cm apart in rows 80cm wide (31,250 plants/ha). In the minor cropping seasons, cowpeas var. *Bengpla* were sown in rows 60 cm wide. Crop rows were oriented along the camber beds. Fertilisers and insecticides were applied as necessary to promote healthy growth.

3.2.3 Treatments

Land forms and weed management treatments were studied for their effects on maize and weeds in a multi-factorial trial where traditional (i.e. farmers') practices were compared with new practices (Table 2). Treatments were kept to the same plots for the duration of the experiment.

Table 2. Factors in long-term trial at ARS Kpong

Factor	Farmers' practice	New practice
Land form	Flat plots (F)	Camber beds, 4.8m wide (CB)
Cyperus control	Hand weeding (hoeing and/or slashing), usually twice per season (H)	During initial land preparation, glyphosate was applied before (G1) or after (G2) camber beds were prepared. Thereafter, glyphosate was applied at the beginning of subsequent cropping seasons and followed by one supplementary hand weeding if necessary.
Residual herbicide	None (0)	Lasso/atrazine herbicide for maize (L) Dual herbicide for cowpeas (D)
Land preparation	Primary tillage by disc plough (T) to approximately 20cm depth. From 1998, half of the plots received no soil-loosening primary tillage, only minimum tillage (MT) with hoes to control weeds.	Camber bed construction with multiple passes of a polydisc in season 1. In subsequent seasons, the camber beds were lightly cultivated to approximately 10cm with the polydisc (i.e. reduced tillage, RT). From 1998, half of the plots received no soil-loosening primary tillage (i.e. no T or RT), only minimum hoe tillage (MT) to control weeds.

3.2.3.1 Weed control treatments. Weeds were allowed to grow and glyphosate at 1.8 kg a.e./ha was applied with a knapsack sprayer to actively growing *C. rotundus* at the beginning of every season. No rain fell within eight hours of the glyphosate applications. Maize or cowpeas were then sown. Hand weeding with hoes was done when necessary on all treatments. When hoeing proved impossible on the wet Vertisol, weeds were slashed to ground level with a cutlass.

Two residual herbicides were evaluated, Lasso/atrazine (a proprietary mixture of alachlor + atrazine) at 2.0 kg a.i./ha in maize and Dual (trade name for metolachlor) at 2.0 a.i./ha in cowpeas. These were applied with a knapsack sprayer to soil before crop emergence. Both herbicides have activity against a weed flora composed of annual grasses and broadleafed weeds but they have little or no activity against *C. rotundus.*

3.2.3.2 Land preparation. Two methods of preparing land were evaluated. Conventional flat tillage (T) by disc plough was used to simulate farmers' practice. This was compared to reduced tillage (RT) where the seedbed was prepared using a low draught polydisc at a shallow depth (approximately 10cm).

3.2.4 Experimental design

The site was divided into six blocks, each containing four randomised main plots measuring 38.4m x 12m (Annex 3a). The main plot treatments were (a) farmer practice (i.e. mechanical land preparation followed by hand weeding), (b) glyphosate applied prior to camber bed formation (treatment code G1), and (c) glyphosate applied after camber beds had been constructed (treatment code G2). One main plot in each block was kept as a backup spare. After the first season, glyphosate treatments G1 and G2 were treated in exactly the same way. Each main plot was divided into two split plots, one consisting of four camber beds in an area of 19.2m x 12m, the other consisting of a flat bed of the same size (Annex 3b). The split plots were further divided into plots that received a residual herbicide and no herbicide (Annex 3c) and into plots that received traditional tillage and minimum tillage (Annex 3d). This produced 24 treatment combinations. A criss-cross design (Pearce, 1977) was used to facilitate the creation of the land forms and subsequent tillage and herbicide applications. The design of the experiment and subsequent analyses were done in consultation with a statistician.

3.2.5 Assessments

In maize, crop growth and yield parameters were measured in each of six rows, 5 m long, within harvested areas of each plot. In cowpeas, crop growth and yield parameters were measured in each of eight rows, 5 m long. This enabled the effects of planting position across soil profiles to be determined. In 1999, only total plot yields were determined.

Tuber densities of *C. rotundus* were evaluated in July 1998, November 1998 and November 1999 using two 20 cm x 100 cm quadrats per main plot. Quadrats were randomly placed on flat beds but only on the tops of the camber beds where growth of *C. rotundus* was greatest. Soil was excavated to a depth of 30 cm in each quadrat and removed from the site before tubers were extracted by washing with water. ANOVAR was done on transformed data [square root or log (x+1)].

The effects of treatments on above-ground weed growth were determined by quadrat counts and subjective assessments of percentage ground covers of the three categories of weed, grasses, broadleaves and sedges (i.e. mostly *C. rotundus*).

3.2.6 Data analysis

Variance homogeneity was tested for all data and the appropriate transformations were made before ANOVA. No transformations were needed for any of the crop yields.

3.3 Distribution and movement of *Cyperus* tubers

With traditional overall tillage on flat plots, using soil inversion disc ploughs, *Cyperus* tubers on and near the soil surface are buried at the ploughing depth and other tubers within the plough depth are brought to the surface. In this way the weed is generally spread uniformly across the field. With camber beds, however, it was observed that there was a concentration of *C. rotundus* towards the top of the camber bed. This could be attributed to the tillage action of pushing the soil up from the furrows towards the top of the 5m- or 10m-wide camber beds. A small trial was designed, therefore, to investigate this feature of CB land form management.

A site was chosen that had a high infestation of the *C. rotundus* and was wide enough for three 5m-wide camber beds. Transects were excavated across the site to estimate the level of *C. rotundus* infestation on the site before cultivation. The site was then tilled with a tractor mounted polydisc

(Plate 2) and, at the halfway stage towards CB construction, more tuber transect counts, across the CB, were made to establish how the tuber densities had been reorganised by the polydisc tillage at this

Plate 2. Tilling a camber bed with a polydisc

stage. Tillage was then continued until the construction of the 5m-wide camber beds was completed, when tuber counts were again made. Soil surface profile (SSP) measurements were also made during this trial (ref. para. 3.4.2 below) to establish the height and shape of the camber bed produced in this trial.

3.4 Soil and water management (S&WM) research activities

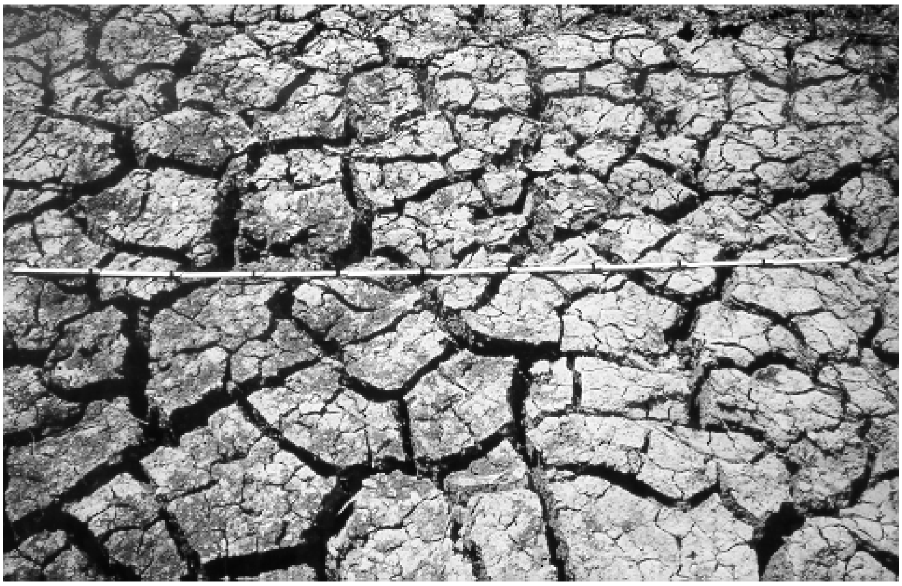
The effective control of water and weeds is the essence of good management of Vertisols for reliable and profitable crop production (Ghana Vertisols have 30% to 50% clay content). Rainfall is intrinsically linked to the management of crops on Vertisols. Precipitation during the years of the project is given in Annex 1. The efficient control of water will facilitate access to the field that will, in turn, enable the effective control of weeds. The soil and water management aspects of the *Cyperus* Project studies have focused, therefore, on:

- ❑ a comparison of the effects and input costs of different land forms (Flat, 5m CB and 10m CB) and tillage systems on water control and crop yield under different seasons and rainfall regimes, the outputs from this have been used in the cost-benefit analysis of the tillage and crop production systems investigated,
- ❑ the stability and degradation of camber beds on Vertisols by taking time delay soil surface profile measurements (SSPM) over several seasons,
- ❑ the variation in soil moisture transects across camber bed and flat plots and the changes with time over a range of climatic conditions by taking pre-rains and sequential post-rains soil moisture measurements and
- ❑ *Cyperus* tuber movement through the construction and tillage of camber beds (see para: 3.3 above).

3.4.1 Land forms

Crop production on the relatively fertile and under-utilised Vertisols and vertic clays on the Accra plains (approximately 163,000 ha of Vertisols) has been severely limited by seasonal waterlogging and serious weed growth, particularly *C. rotundus*. Vertisols are very difficult to manage under traditional methods of tillage since they are hard and cloddy when dry and so sticky when wet that movement or traction across them is virtually impossible. These montmorillonitic clays are, however, 'self mulching' as they shrink during drying and expand on wetting. This dynamic means that large fissures occur under dry conditions and these cracks are typically 50mm to 100mm wide at the soil surface and about one metre deep (Plate 3). With the onset of rains, loose soil and trash are washed into these cracks and, as the soil mass expands on wetting, there is an upward movement and churning of the soil profile. This action results in a mixing and loosening effect that generally provides suitable porosity levels for crop growth thereby reducing the need for the soil to be loosened through tillage.

Plate 3. Cracked Vertisol. Ruler marked in 20cm divisions



To understand, develop and provide suitable conditions for soil, water, weed and crop management on Vertisols in Ghana, it was necessary to create and evaluate land forms that shed excessive surface water so that field access could be enhanced and the crops were not submitted to undue levels of waterlogging. To this end, several field trials were established in this project to evaluate the performance of various dimensions of camber bed compared with traditional flat systems of soil and water management. Vertisol and vertic clay areas on the Accra Plains are generally rather flat and field sites were chosen in flat areas (slope <2%) where plots were prone to seasonal waterlogging and where the water shedding properties of camber beds would be advantageous. A large, six block experiment site was developed on the ARS Kpong (see Section 3.2.4) and on-farm trials were designed and set up with more than 20 farmers to investigate the advantages and performance of 5m-wide and 10m-wide camber beds compared to traditional flat tillage, under typical smallholder farming conditions.

3.4.2 Soil surface profile measurements (SSPM)

At the outset of this *Cyperus* Project in 1996, the need arose for a simple soil surface profile (SSP) gauge to monitor reliably the variation in soil surface height across various widths of camber beds and flat plots. The SSPM were used to monitor the changes to the profiles through tillage and the degradation of the land forms through weathering during and between seasons. The instrument needed to be simple and robust, able to span across a 5m-wide camber bed (and half a 10m-wide CB) and preferably be constructed from locally available materials. The overall design was based on that developed for the study of *ngoro* pits in Tanzania and trash lines in Kenya and Uganda (Willcocks & Gichuki, 1996).

The SSPM apparatus and use procedure are as follows:

- The SSP gauge's main component comprised a straight beam marked with numbered measurement points every decimetre along its length. Initial designs were made of localhardwood but these proved to be too heavy for a span in excess of 5m. A 6m beam was designed and made of from two easily connectable three metre lengths of aluminium box section 75mm x 38mm x 3mm (3in x 1.5in x 1/8th in) which could be readily transported by Land Rover. Other items in the SSPM kit included: two wooden posts (approximately 1.5m long), spirit level, two metal G clamps (15cm), one metre long steel datum pegs (25mm angle iron being suitable) and a clearly marked 1m ruler or tape to measure the distance from the horizontal beam down to the soil surface.

- The steel datum pegs were driven into the soil at the edge of the plot to provide a consistent datum height reference for the initial and subsequent measurements. Because Vertisols shrink and swell, it was found necessary to concrete some these datum pegs into position so that they were held at a constant height. The datum pegs also acted as a location marker so that SSP transects were made along the same line for each subsequent measurement.
- The SSPM beam was set up as shown in Plate 4, it being supported by two posts usually at about 50mm above the ground. The zero or 10cm position was positioned above the fixed datum peg and the beam was aligned at right angles across the camber bed (or flat plot). The beam must be horizontal and this is achieved by using a level and adjusting the height as necessary with the two clamps holding the beam to the upright posts. Vertical readings, to the nearest mm, are then taken with a ruler from the top of the beam to the soil surface at 10cm intervals along the length of the beam.

Plate 4. Measuring a soil surface profile with an aluminium beam

- The measurements are then expressed graphically by using the top of the steel peg as datum. The results are also analysed to provide camber bed height above datum, furrow depth and total height from furrow bottom to the top of the camber bed.
- The degradation of the land forms has been qualitatively assessed by comparing the SSP graphs from the measurement sequence throughout the seasons. Quantitative assessments being achieved by comparing the heights of the camber beds between construction and at the end of the season. In addition to this, the series of SSP height measurements were used to estimate degradation of the CBs by calculating the roughness indices of the land forms and comparing the changes between early and late season roughness indices across the SSP transects. This was done using the method of Kuipers (1957) expressed as, $R_k = 100Log_{10}S$, where R_k is the surface roughness index and S is the standard deviation of vertical elevations.

3.4.3 Soil moisture (SM)

Observations during the early part of the project provided a good overall picture of the soil and water management aspects of the tillage systems and land forms. Soil water transects were made across the camber beds in conjunction with SSPM and this showed the distribution of soil moisture relative to site position on the camber beds. However, because the growth (and subsequent grain yield) of many maize plants in the flat plots and most plants in the furrows of the camber beds were severely stunted, more information was needed to explain these phenomena. The soils work, therefore, focused on the need for further soil moisture measurements and analysis to provide more evidence and understanding of the level of short term waterlogging within the land forms and its detrimental effects upon maize crop growth. It was evident from this project and other studies (Drew, 1992), that relatively short periods of waterlogging can cause irretrievable damage to maize growth.

The soil water studies, therefore, looked into the levels of crop available moisture (CAM) and damaging waterlogged conditions. This was achieved by taking measurements of soil moisture in the field experiments and estimating the wilting and saturation points of Kpong Vertisols by conducting soil moisture tension measurements, using pressure plate apparatus, at the University of Ghana - Legon. The soil water measurement transects across the flat plots and camber beds were designed to indicate where damagingly high (or low) levels of soil water were encountered. Visual monitoring of waterlogged conditions in the field was also carried out.

In addition to the in-field studies, a new trial was developed to address these waterlogging issues under a more controlled environment on a laboratory scale. A pot experiment was set up to monitor the response of maize growth to various periods of waterlogging. Maize was submitted to waterlogging from one to five days at the 1-leaf (day 5) and 4-leaf (day 20) growth stages of the crop (results can be seen in Section 4, Fig. 22). Studies were also done to monitor soil nutrients in the field (on flat plots and across camber beds) and in pots, using maize as the indicator plant.

3.5 On-farm trials

Researcher-coordinated trials were done on 24 small-scale farms within a 20-km radius of the Agricultural Research Station Kpong. All farms were sited on Vertisols or vertic clays where *C. rotundus* was a problem weed. The first on-farm trials were with cowpeas in 1997; thereafter, maize and cowpeas were grown in the major and minor seasons, respectively, in 1998 and 1999.

3.5.1 Land preparation

A disc plough was used to prepare flat seedbeds, the standard land form used by farmers in the area. Camber beds were made by repeated passes of a wider polydisc to make a raised profile 5m-wide and 40 cm high (Fig. 16) from the trough to the top of the bed. After a few weeks, the camber beds settled to a height of approximately 30cm. In subsequent seasons, the flat plots were prepared by disc ploughing and harrowing whilst the camber beds were again lightly cultivated with a polydisc. In 1998, all ten collaborating farmers used 5m-wide camber beds but, in 1999, seven farmers used 5m-wide beds and ten new sites used used 10m-wide beds. Mechanised inputs were provided by the research station using equipment similar to that available for hire to farmers.

3.5.2 Weed management

Herbicide-treated plots were compared to hand-weeded treatments. On herbicide-treated plots, weeds were allowed to grow and produce a leafy target for glyphosate applied at 1.8 kg a.e./ha applied with a knapsack sprayer. No rain fell within eight hours after the glyphosate application. Hand weeding was done, usually once, to remove late germinating weeds that were not controlled by glyphosate. On the hand-weeded treatment plots, weeds were removed when necessary, usually twice during the season. This was done with hoes but, when this proved impossible because of the wet Vertisol, weeds were slashed to ground level with a cutlass.

3.5.3 Crops

Maize var. *Obatanpa*, was sown in the major seasons at a spacing of 40 cm apart in rows 80 cm wide (i.e. six rows per 5m-wide camber bed) to give a population of 30,000 plants/ha. Cowpeas were grown in the minor seasons in rows 60cm apart (i.e. eight rows per 5m-wide camber bed).

3.5.4 Experimental design

The on-farm plots covered an area of 30m x 40m which was divided into four plots of 15m x 20m to accommodate each of the treatment combinations in the 2 x 2 factorial design (Annex 3e). The raised plots contained three 5m-wide camber beds, i.e. slightly wider than the 4.8m beds on the research station. In 1999, 10m-wide camber beds were tried on some farms, where individual plots measured 20m x 20m (Annex 3f). For the purpose of statistical analyses, each farm was treated as a single block.

3.5.5 Weed assessments

Weeds were estimated by subjectively assessing the percentage ground covers of sedges (mostly *C. rotundus*), grasses (mostly annuals and/or *Imperata cylindrica*) and broadleaves (mostly annuals) present on each plot. This was usually done twice during each season, prior to the first and second hand weedings.

3.5.6 Crop assessments

Crop yields were determined by harvesting one area of 5 x 10m in each plot on small-scale farms with 5m camber beds or 10 x 10m on farms with 10m camber beds. Maize cobs were shelled to determine grain weight per plot, from which yields were calculated as kg/ha.

3.5.7 Data analysis

Variance homogeneity was tested for all data and the appropriate transformations [square root, logit or log (x+1)] were made before ANOVA. No transformations were needed for any of the crop yields.

3.6 Biological control of *Cyperus rotundus*

The biological control component of the project was essentially an autonomous sub-project incorporated within the framework of the main project. The specific objective of this sub-project was to assess the biological control potential of fungal pathogens present in the region, on the basis that, if the results of this probationary phase proved to be negative (partly or wholly), then there would be no justification for moving into an applied phase. Conversely, if the results showed promise, then the biological control component would be expanded and, in the long-term, integrated into a management strategy, for which, given the financial constraints of the present project, new funding would have to be sought.

3.6.1 Surveys

Two surveys were undertaken in Ghana during 1997; one in May, to coincide with the beginning of the wet season and the other in September, towards the tail end of the rains. The initial survey covered the Greater Accra, Eastern, Ashanti, Brong-Ahafo and Northern Regions; whilst the follow-up survey was focused more on the Ashanti and Northern Regions and extended into the Volta Region. Populations of *C. rotundus* were either identified from the road or during random forays into various cropping systems. Specimens with symptoms of disease were collected, bagged and transported to the UK for processing, using standard plant disease diagnostic and isolation techniques. Isolates were provisionally identified and suspected disease causal agents, assessed on the basis of taxonomic affinities, were forwarded to the International Institute of Mycology (IMI) for confirmation of identity and, potentially, of pathogenic status.

3.6.2 Pathogenicity tests

Selected isolates (five only could be accommodated in the pathogenicity assessment screens) were bulked-up in a standard liquid culture medium and hand-sprayed onto actively-growing plants of both *C. rotundus* (ex Ghana) and *C. esculentus* (ex farmer's field, grown for sale in local market as tiger nuts), in the quarantine facilities at IIBC, UK.

Four disease observation plots (50 x 40 m) were established within small farmer-type vegetable gardens at Kwadaso Agricultural College, Kumasi, Ashanti Region. These were monitored/sampled monthly during the rainy season (May - October 1997) by J.A. Timbilla, Entomologist/pathologist, Biocontrol Division, at the nearby Crops Research institute (Kwadaso campus) of CSIR (Council for Scientific and Industrial Research). Diseased specimens were collected, pressed and stored for later processing during the follow-up visit. Additional material collected post-survey was despatched to the UK by courier.

3.7 Economics

Sustainable systems of crop production are quite simply those that work, both in the short and long term. Existing and improved systems, therefore, must be easily managed within the physical and economic resources of the farmers. In general Vertisols are underutilised for crop production because they are so difficult to manage and traditional tillage and hoe systems are not effective in cultivating the soil when hard and dry or will not cope with the control of excess surface water or perennial weeds.

Data were collected on all aspects relating to inputs and outputs in the production of crops. This included the costs of labour (for hoeing, planting, harvesting, etc.), tractor hire for tillage, herbicides and fertilizers. Crop values were determined and a model was developed for determining gross margins for three types of farmers, categorised according to their inputs (Table 3).

Table 3. Types of farmers and their inputs

Inputs	Type of farmer		
	Low input i.e. family farmer with little cash	Medium input i.e. farmer with cash	High input i.e. semi-commercial farmer
Land preparation with tractor	Cash purchase	Cash purchase	Cash purchase
Seed and planting	Own seed	Seed purchased	Seed purchased
Fertiliser and application	None	50% of recomm-ended dose rate	100% of recommended dose rate
Nitrogen top dressing	None	None	100% of recommended dose rate
Weeding costs:	Low	Medium	High
1st hand weeding	Family labour	Some hired labour	Hired labour
2nd hand weeding	Family labour	Some hired labour	Hired labour
Glyphosate (if used)	Cash payment	Cash payment	Cash payment
Harvesting	Family labour	Some hired labour	Hired labour
Storage and transport	Family resources	Some cash payment	Cash payment

4. OUTPUTS

4.1 Socio-economic studies

The general findings of the socio-economic study by Ellenbroek *et al.* (1997) (full details of paper on page 46) are presented below.

4.1.1 Crop production systems on the Vertisols

The survey established a divergence between size of farm holding, and area cropped. Land use ratios ranged between 58-61% for farm holdings under 20 ha and only 9% for holdings over 20 ha. The average area cropped was 3.7 ha (and the median 2.2 ha), against averages of 1.1 ha found in Kwadzo (1995) or 1.4 ha in Owusu-Bennoah & Duah-Yentumi (1989). Idle land is fallow land, used by larger farmers with cattle as grazing lands without fencing it off - other herds are not prevented to roam on it. Smaller farmers do not seem to put aside land to fallow: most respondents said they cultivate a field until they see its fertility decline. Only two respondents mentioned they have an intentional fallow system. Kwadzo (1995) found this fraction to be 35% in his sample.

Under-utilisation of the land and small average farm size can therefore not be explained by supposing land scarcity or fallow practices. Rather, arable farming is constrained, first of all, because of the heavy nature of the soil, which becomes sticky when wet, and these conditions prevent most mechanised field operations like ploughing and harrowing. Most respondents do hire tractor for ploughing (21 out of 28), but all other cropping activities are non-mechanised, i.e. manual. Animal traction was not encountered.

Secondly, farmers emphasised they are constrained in their financial means. Even though almost all local farming households earn off-farm income, farmers apparently cannot develop a sufficient level of savings to expand farming operations significantly. Most farmers in the survey do not work with credit at all, but some may get some financial help from relatives or friends. Some farmers may accept pre-financing from middlemen, or can pay their tractor services in instalments. But not one respondent had formal credit in direct negotiation with a bank. Formal credit is offered by at least two banks with a local presence, but they offer credit on terms which smallholders either cannot meet or decline to accept. Group borrowing is a possibility, promoted by MofA in association with Sasakawa/Global 2000 but group organisation has not reached all Vertisol population settlements yet.

Thirdly, although the Vertisols are believed to be fertile by nature, yields are variable and income is insecure. In 1996, major season rains were heavy, affecting crops by waterlogging; minor season harvests failed in many instances due to drought immediately after germination. Productivity as estimated by respondents varied considerably, for all crops. Dependent on technology applied (fertiliser), cost structure (hired labour), and prices obtained, gross margins showed a similar divergence, with frequent entries for near-zero or negative gross margins, across all categories of producers, across all crops. Although maize and cassava were found to be the least remunerative crops on a per hectare basis, they occupy the largest areas. It seems a logical conclusion that climatic variations in the Vertisol area lead farmers in general to adopt a risk-averting strategy, by dedicating large shares of their farms to the production of staple food. The farmers were not questioned on the choice of crops as such, but it can be assumed that maize and cassava are favoured for reasons of food security, reliable production, and assured demand. (Yet, maize and cassava are not only grown for household consumption: high degrees of commercialisation were observed, also for maize and cassava, around 50% and 60-80% for farmers cropping under 5 ha, respectively.)

All these factors make that Vertisol farming can be characterised as low external input farming. Despite the general use of tractor power to prepare the land, all other power is hand labour. Fertiliser is not applied to cassava, or to pepper, in most cases. About a third of fields with maize or okra were fertilised (10 out of 29, and 4 out of 12 respectively), but doses are generally below the recommended level. Only 5 out of 27 respondents own a sprayer, and pesticides were only occasionally applied to pepper (3 out of 13 respondents), or okra (4 out of 12 fields).

4.1.2 Weed control

The survey established that farmers principally rely on manual means of weed control. Few farmers use herbicide (glyphosate, marketed as Roundup), only applying low doses to specific spots within fields. Farmers do not consider weeds a priority problem for improving yields, but instead they seem to accept weeds as an impediment intrinsic to farming.

The most serious weeds listed were particularly *Imperata cylindrica*, and secondly, *Cyperus rotundus*.

Most farmers will control weeds in two rounds of hoe weeding, with a minority weeding in three or even four cycles. Apparently, this is the weeding intensity at which most farmers feel the marginal benefit of weeding (reduced yield loss) equals the marginal cost of weeding (i.e. the cost of wage labour, or the opportunity cost of household labour). Survey team composition (all economists) and timing of the study before the real emergence of weeds, did not allow a true assessment of the seriousness of weeds on farm land. It is therefore recommended that the project first undertakes in-season surveys to assess the real levels of infestation of *Cyperus rotundus* on farm lands, and subsequently predicts how the camber bed / herbicide technology compares in terms of yield improvement against additional working capital requirements.

4.1.3 Land use options for the Vertisol area

This survey concentrated on arable farmers. Irrigated rice farmers were taken to be an entirely different category of farmers, even though rice farmers tend to have arable plots, and vice versa. Rice farming is generally believed to be more rewarding than rainfed arable farming, but this cannot be assessed on the basis of this survey. Even though it was planned at the time of the construction of the dam to develop the whole Accra Plains as a rice farming area, it is found to be not as profitable as originally estimated, certainly not for large scale farming (Kpong Farms Ltd. is reducing its rice acreage). Farmers near the fringes of the Volta River have access to irrigation water, and a new 4,000 acres (1,600 ha) irrigation scheme is being developed, but clearly, the remainder of the Vertisol area is necessarily destined for non-irrigated uses.

Resident farmers mostly grow a combination of maize, cassava, cowpea, okra and pepper. Other crops or trees can be found, but in far smaller acreage. The survey that okra is the most remunerative crop (Cedis 3,450,000 per ha on average), followed by pepper (Cedis 500,000 per ha on average). Maize and cassava produced only 270,000 and 380,000 Cedis per ha on average, yet it must be borne in mind that in most years, two maize harvests are feasible.

The question why farmers grow more maize and cassava than okra and pepper, was not put to the farmers directly. Above, it was assumed that farmers choose maize and cassava as their productive base because of yield reliability, household food security, and assured market demand. Labour demand and working capital requirements will also play a role.

A third land use category to be distinguished is livestock raising. Livestock farmers need not be resident of the area, on the one hand, many pastoralist herds pass through the Vertisols, and on the other hand, large cattle rangers have their farms on the Vertisols but do not crop the Vertisol land.

Resident livestock farmers tend to be the more prosperous members of the farming community who own more than 20 ha. Only 9 out of 28 respondents own cattle, of whom the majority (5) own over 20 ha of land. Only one cattle owner had less than 2 ha of land, i.e. cattle ranching is not within reach of any farmer.

Fowls, goats and sheep are kept by fair shares of respondents (respectively around 80%, 50% and 15%) but mostly as a complement to farming. Intensive broiler and layer production is undertaken by some, with varying results due to pests and diseases. Intensive piggery was not found.

Data from the survey are not sufficiently firm to draw conclusions on the potential or comparative productivity of the Vertisols for arable cropping, livestock production, or other uses. What can only be remarked on this here, is that MofA has departed from the idea of developing the whole of Accra Plains for irrigated farming, and now rather undertakes to reinforce what is found on the ground: small scale irrigated farming, arable farming, and livestock production. Each line of production still shows a considerable gap in actual productivity in comparison with potential yields.

4.1.4 Women's involvement in Vertisol farming

The survey established that among the Krobo, Ada, and Ewe people, who are the most numerous in the Vertisol area, women could not inherit their fathers' land, unless it was private. As a result, women hardly ever hold land, locally. Similarly, women tend not to cultivate their own fields, or their own crops. Female-headed households exist only in the case where the woman is single, or where the man is bound to a different occupation. Otherwise, man and wife(s) tend to share in all farm tasks, although male labour is more used in land clearing, land preparation, and weeding, while female labour is more devoted to harvesting and on-farm processing.

Similarly, hired labour can be of either sex for any sort of labour, be it that men will be preferred for land preparation and weeding, and women for harvesting.

Nonetheless, intra-household digressions may exist between male and female members, but these were not brought to light by the survey. For example, women may be more prepared to accept labour-saving technologies, against men preferring cash-saving technologies. Or women may be more concerned over taste and nutritional quality of crop varieties, while men may be more concerned with gross production. Again, while respondents emphasised a strong convergence of interests among male and female household members, potential variations in interests may play a role in the adoption of new technologies, but cannot be identified on the basis of this survey.

4.1.5 Development options for Vertisol farming

Discussing technology development, Willcocks (1989) observed that improved cultural practices should not only reduce the inputs necessary to produce a crop, but they should achieve it more reliably than with existing methods, and above all, the new technology must be sustainable within a given environment. For this, it is essential (Willcocks and Twomlow 1993) to have an understanding of the existing technical, managerial, financial, and social resources available to local farmers and their perceived constraints to reliable crop production. This approach should ensure that the development of improved cultural practices would meet real farmer needs raising its chances of being adopted. Ellis-Jones *et. al*. (1995) add that the strengths, weaknesses and possible improvements of new cultural practices are to be assessed using farmers' own evaluation criteria. Research and extension workers must have a greater awareness and understanding of the goals and criteria used by resource-poor farmers within the wider social and economic context.

Without exact projections at hand, it can be believed that the camber bed / herbicide technology the project on "Management of *Cyperus* on Vertisols" is developing, will require substantially increased levels of working capital, both for the initial investments in the establishment of the camber beds, as for increased recurrent cash outlay to finance annual spraying of herbicide. Therefore, given the fact that farmers have a restricted capacity to generate working capital, by lack of savings on the one hand, and low disbursement of credit on the other hand, it follows that the camber bed / herbicide technology can only be introduced successfully if better conditions for credit extension and uptake can be brought about.

A positive condition for the introduction of the camber bed / herbicide technology is that mechanised land preparation is quite accepted already on the Vertisols. However, it remains to be assessed whether the private tractor operators do have the necessary equipment to construct camber beds. On the other hand, successful results from pilot demonstrations may create a demand for the camber bed / herbicide technology, providing an incentive for tractor operators to invest in the necessary equipment - provided that they can recover costs by charging their clients.

Also, sprayers and herbicides can easily be purchased locally, but farmers generally still prefer hand weeding which cannot be avoided anyway. Non-adoption of herbicide technology may be a result of ignorance on the side of farmers of the (economic) benefits of herbicides, or a lack of skills in using them. When surveying weed control measures in smallholder rubber-based farming systems in Indonesia, Conroy and Bagnall-Oakeley (1995) found that herbicide application for controlling *Imperata cylindrica* would vary considerably among farming systems, with highest adoption in high input, multiple cash crop systems. But, even among those farmers, practices often differed from recommended application rates so as to save on cash lay-out, or when they simply prefer hand-weeding.

Crop selection is presently limited basically to maize, cassava, pepper and okra, of which okra was found to be the most remunerative. Maize and cassava are grown both for home consumption and market purposes, while pepper and okra are typical cash crops. Earlier local tests of the camber bed land form used maize and cowpea. Instead, pepper and okra may be better test crops, since being pure cash crops, farmers will be more motivated to invest in yield improvement for these crops. It is to be expected that, given the investments involved, interested farmers will only partially adopt the technology, and use the camber bed land form only for the most remunerative crops.

The best method to judge whether an innovation fits into the local farming system is to involve farmers of specific target groups in on-farm technology development schemes. This was done already under the former ODA/IBSRAM project and will be continued under the present "Management of *Cyperus* on Vertisols" project. One recommendation though, to improve the linkage with the extension system, is to have more direct involvement of MofA District Offices who have both the field personnel to monitor on-farm trials, and the necessary goodwill with farmers.

Low (1986) emphasises the fact that much on-farm research is concerned with increasing farm income, while farmers are concerned with stabilising and increasing their entire welfare, much of which may come from non-farm production. To the extent that farmers very often compromise on crop and livestock production, not because of lack of knowledge or cash to purchase inputs, nor because inputs are not available, but because of time constraints. It is therefore recommended that the on-farm trials are not only evaluated for their yield enhancing performance, but also that consideration is given to such economic aspects as impact on farmer income, on household labour demand (by gender), cash flow, and the farmers' capacity to manage the technology. Such economic monitoring of on-farm trials was already suggested in earlier reports by the former ODA/IBSRAM Vertisol project (Willcocks & Terry, 1994) and this recommendation is strongly endorsed for the current "Management of *Cyperus* on Vertisols" project.

4.2 Control of *Cyperus rotundus*

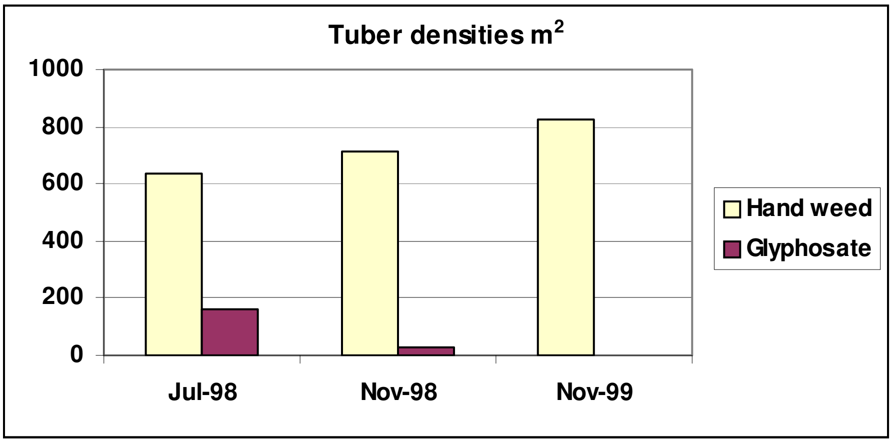
The best determinant of the control of *C. rotundus* is the tuber populations remaining in the soil after treatment. Assessments made in July and November 1998 and in November 1999, i.e. in the third, fourth and sixth seasons after the start of the long-term experiment, showed marked reductions in tuber populations (Table 4 and Fig.2). By November 1999, glyphosate treatments reduced tuber densities by over 99% compared with the traditional practice of hand weeding (Fig. 2).

Table 4. Back-transformed tuber densities (tubers/m^2) of *C. rotundus* at three dates

Date	Flat		CB		F-test	
	Hand-weed	Glyph-osate	Hand-weed	Glyph-osate	CB>F	Hand>Gly
July 1998	503	119	765	205	*	***
November 1998	602	18	826	40	*	**
November 1999	842	4	811	2	NS	***

*, **, *** = Means differ significantly at probabilities of 0.05, 0.01 and 0.001, respectively. NS = not significant

Fig. 2. Back transformed mean tuber densities for both and forms (tubers/m^2)



Visible evidence for the control of *C. rotundus*, manifested by percentage ground cover of the above ground shoots, also revealed the success of glyphosate for controlling this weed (Table 5).

Table 5. Back transformed % ground cover of *C. rotundus* at two dates

Date	Flat		CB		F-test	
	Hand-weed	Glyph-osate	Hand-weed	Glyph-osate	CB>F	Hand>Gly
July 1998	31.8	10.1	36.0	9.5	NS	***
October 1998	34.8	12.2	53.6	13.2	NS	***

*** = Means differ significantly at probabilities of 0.001. NS = not significant

Minimum tillage in the major season of 1998 and the minor seasons of 1997 and 1998 reduced percentage ground covers of *C. rotundus* but, as indicated later, crop yields were reduced by this practice.

4.3 Distribution and movement of *Cyperus* tubers

Tuber count data have confirmed that use of a polydisc (or disc plough) moves tubers from the furrow to the top of the camber bed. An initial trial in April – July 2000 determined tuber populations in the top 20cm of soil before preparation of the camber bed, the halfway stage of preparation and after the completion of the bed (Fig. 3). Whilst indicating that tubers were concentrated at the top of the camber bed during land preparation, the densities on the half-formed and fully-formed camber beds were lower than on the beds before they were prepared. The reason for this anomaly is not clear but it could have been related to the fact that tubers were buried below the 0-20cm soil layer during preparation of the camber beds.

Tubers were examined at a second site of pre-formed camber beds to determine their distributions at two depths (0-20 cm and 20-40cm) on the top, side and furrow of six camber beds. Excavations of the 40-60cm layer at the top of the bed produced a few isolated tubers, so this data was ignored. Comparisons were made with six adjacent flat plots. The stratification of the tubers in the soil is shown in Fig. 4. The furrows had very few tubers in the 0-20cm layer, the side of the camber bed had approximately the same tuber density as the flat plot, and the top of the camber bed had approximately twice as many tubers (i.e. 1,300/m^2) as the flat plot. At the 20-40cm depth, flat plots had only 62

Fig. 3. Distribution of *C. rotundus* tubers during construction of camber beds

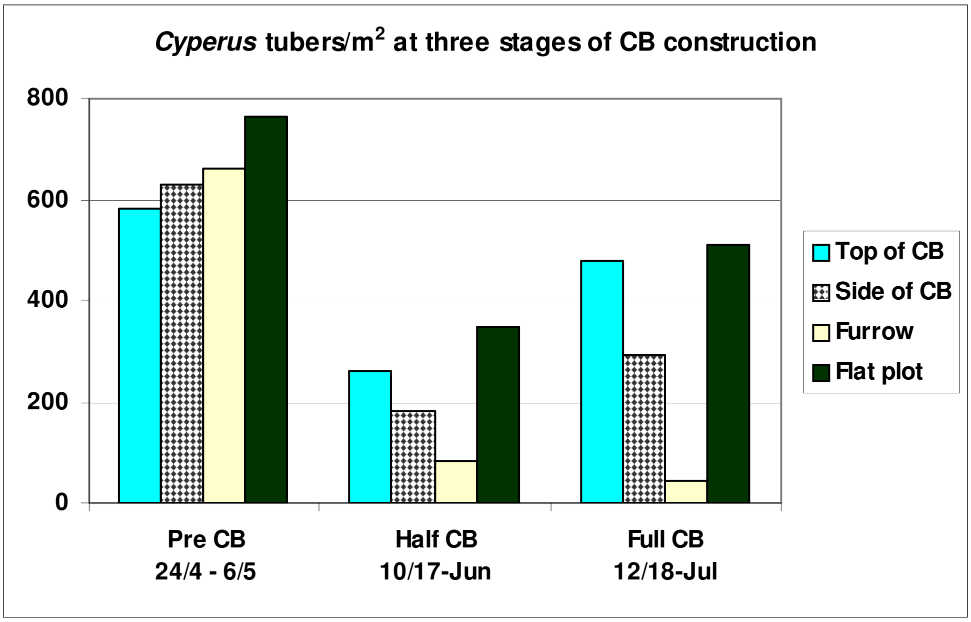
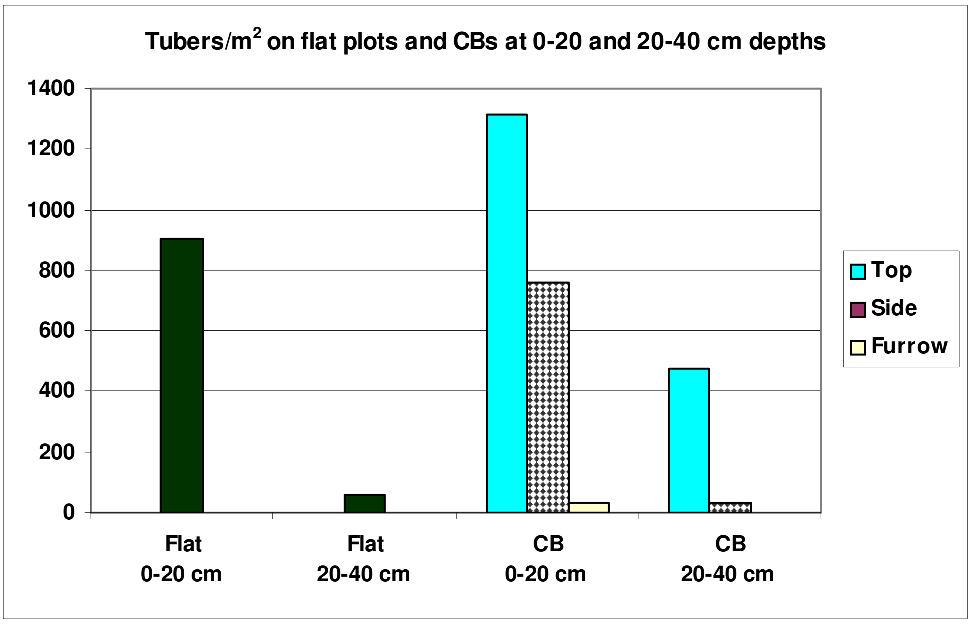


Fig. 4. Distribution of *C. rotundus* tubers on flat plots and camber beds



tubers/m^2, compared with 908 tubers/m^2 at 0-20cm. However, the camber bed had 477 tubers/m^2 at 20-40cm.

The practical implications of tuber movement are that the formation of camber beds concentrates *C. rotundus* on the top and side of the bed where it can compete with the crops (Plate 5). The low population of *C. rotundus* in the furrow has little practical significance because crop growth is too poor to be affected. The high proportion of tubers in the 0-20cm layer (94% on flat plots and 80% on camber beds) is significant because this is where *C. rotundus* tubers are most likely to sprout and grow. Below 20cm, the physical barrier of the soil and adverse conditions for sprouting (e.g. low oxygen) are likely to inhibit the growth and propagation of tubers.

Plate 5. *Cyperus rotundus* controlled by glyphosate on camber beds. Note furrow with poor growth of maize and absence of *Cyperus*.

4.4 Control of other weeds

A strategy to control *C. rotundus* has little practical relevance unless other weeds are also managed. Indeed, removal of a perennial weed such as *C. rotundus* often permits other weeds to grow that were hitherto suppressed. Percentage ground covers of three weed categories [sedges (i.e. *Cyperus*), broadleaves and grasses] were recorded for four seasons in 1997 and 1998. A summary of statistically significant differences, after logit transformations, is given in Table 6.

In general, the residual herbicides Lasso/atrazine in maize and Dual in cowpeas gave significantly greater control of broadleafed weeds and grasses than hand weeding alone. In some cases, there was an interaction with the glyphosate treatments. Flat plots generally had more grass weeds than camber beds. Minimum tilled plots had no significant effect on broadleafed weeds or grasses.

4.5 Crop yields

A major influence on crop yields was rainfall. In the 1997 and 1999 major seasons, it ranged from 28% above average to about 9% below average (Annex 1). However, in 1998, it approached 40% below average and this not only affected yields but also the performance of camber beds (see section 4.6). The residual herbicide mixture, Lasso/atrazine, had no effect on maize yields in 1997 but gave an increase in yield in 1998 (Fig. 5). The residual herbicide, Dual, increased cowpea yields in 1997 but had no effect in 1998 (Fig. 6).

The use of residual herbicides in maize and cowpeas was inconclusive. The expectation was that Lasso/atrazine and Dual would both increase yields but only if the plots that did not receive these treatments were not adequately weeded, as appears to be the case in maize in 1998 and cowpeas in 1997.

Table 6. Summary of statistically significant weed data in maize and cowpea in 1997 and 1998

Maize 1997	**Date**	**Cyperus**	**Broadleaves**	**Grasses**
Land form	15-May-97			
	15-Jun-97			
	15-Aug-97	CB>F		
Glyphosate	15-May-97	H>G1>G2		H,G1>G2
	15-Jun-97	H,G1>G2		H,G1>G2
	15-Aug-97			
Lasso/atrazine	15-May-97		0>>Lasso/at	
	15-Jun-97	0>Lasso	0>Lasso/at	0>Lasso/at
	15-Aug-97		0>Lasso/at	

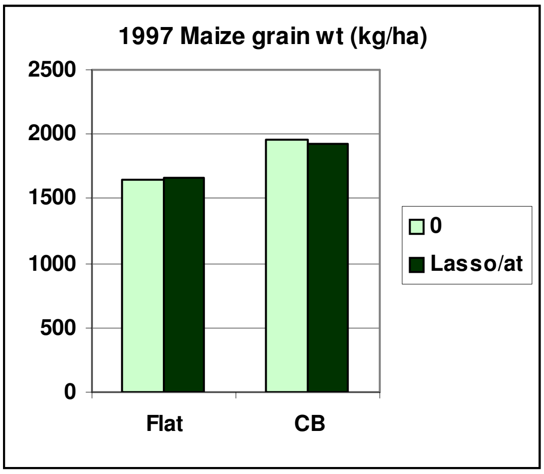
Cowpea 1997	**Date**	**Cyperus**	**Broadleaves**	**Grasses**
	22/24-Nov-97			F>CB
	27/30-Dec-97		For H: CB>F For G1: NS	
Glyphosate	22/24-Nov-97	H>>G1>G2	For Dual: H,G1>G2	For Dual: H>G1>G2 For no Dual: H,G1>G2
	27/30-Dec-97	H>G1>G2	For CB: H,G1>G2	For Dual: H>G1>G2 For no Dual: H>G1,G2
Dual	22/24-Nov-97	0>Dual	0>Dual	0>Dual
	27/30-Dec-97	For G1 & G2: 0>Dual		0>Dual
Tillage	22/24-Nov-97	T>MT		
	27/30-Dec-97			

Maize 1998	**Date**	**Cyperus**	**Broadleaves**	**Grasses**
Land form	8/10-Jul-98			F>CB
Glyphosate	8/10-Jul-98	H>>G1>G2	For no Lasso/at: H<G1,G2 For Lasso/at: H>G1,G2	H>G1,G2
Lasso/atrazine	8/10-Jul-98		0>Lasso/at	Lasso/at>0 (especially for H)
Tillage	8/10-Jul-98	T>>MT		For H: MT>T

Cowpea 1998	**Date**	**Cyperus**	**Broadleaves**	**Grasses**
Land form	15-Oct-98	For H,G1: CB>F		F>CB
Glyphosate	15-Oct-98	For CB: H>G1>G2 For F: H>G1,G2	G1,G2>H	
Dual	15-Oct-98		0>Dual	0>Dual
Tillage	15-Oct-98	T>MT		

F = flat plot, CB = camber bed, H = hand weed, G1, G2 = glyphosate treatments, T = tillage, MT = minimum tillage, 0 = no residual herbicide; Dual = trade name of metolachlor, Lasso/atrazine = trade name of alachlor + atrazine.

Fig. 5. Effect of Lasso/atrazine on maize yields in 1997 and 1998



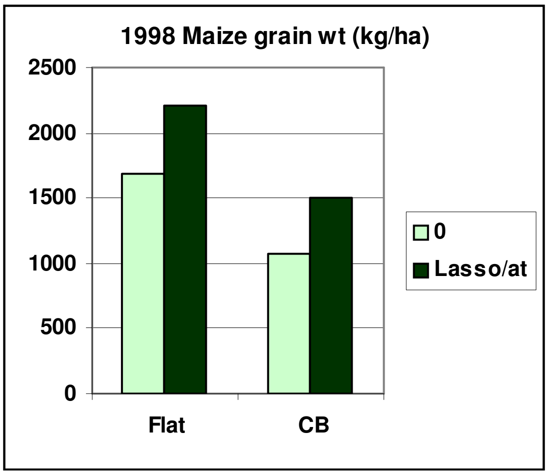
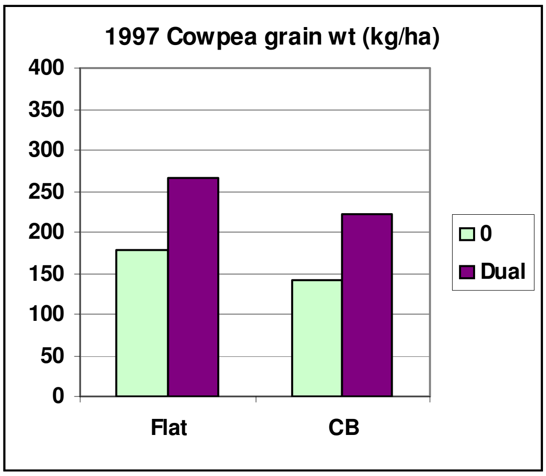
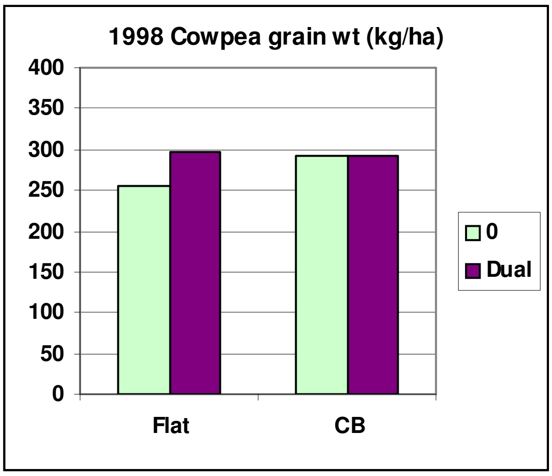


Fig. 6. Effect of Dual on cowpea yields in 1997 and 1998





Crop yields on glyphosate-treated plots (Glyph1 and Glyph2) were always significantly greater than on hand-weeded plots (Figs. 7 & 8). This is undoubtedly due to the suppression of weed growth early in the season when the crop was most vulnerable to competition. It is not possible to say what proportion of the increase was due to control of *C. rotundus* but the result is consistent with the findings of other researchers who have observed yield increases after control of this weed (Williams and Warren, 1975). In 1999, glyphosate was not applied to treatment Glyph1, hence the lower yields.

Fig. 7. Effects of hand weeding and glyphosate treatments on maize grain yields in the long-term experiment in 1997, 1998 and 1999

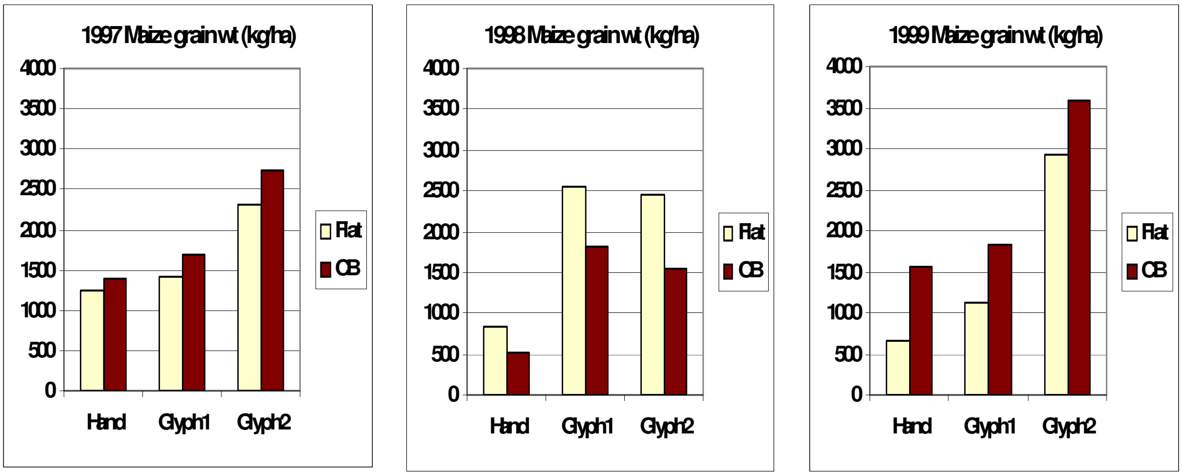
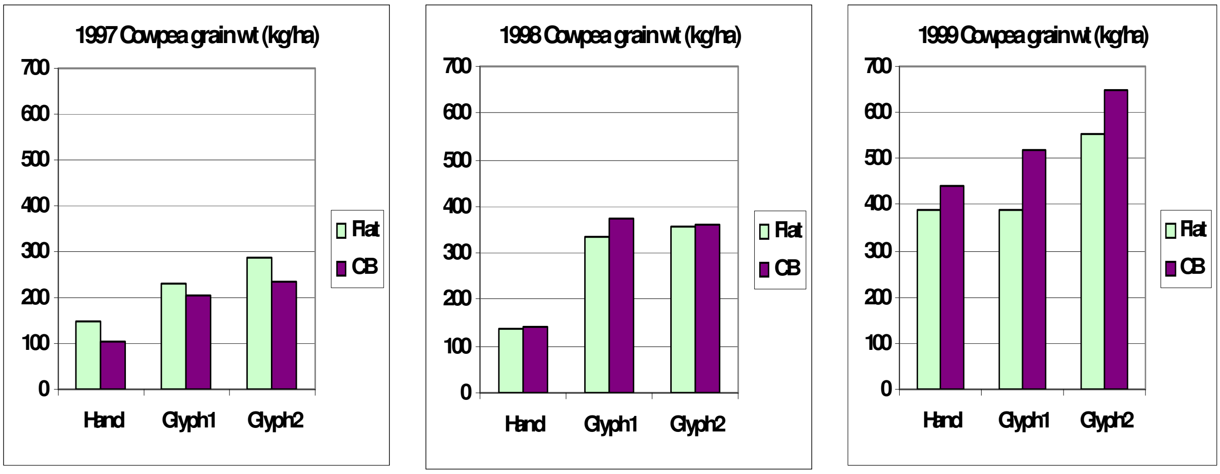


Fig. 8. Effects of hand weeding and glyphosate treatments on cowpea grain yields in the long-term experiment in 1997, 1998 and 1999



Minimum tillage treatments suppressed yields of maize (Fig. 9) and cowpeas (Fig. 10) in 1998 and 1999. Cowpeas yields were also suppressed in 1997 (data not shown) but the major season maize crop was not given this treatment in this year.

Fig. 9. Maize grain yields on tillage and minimum tillage treatments in 1998 and 1999

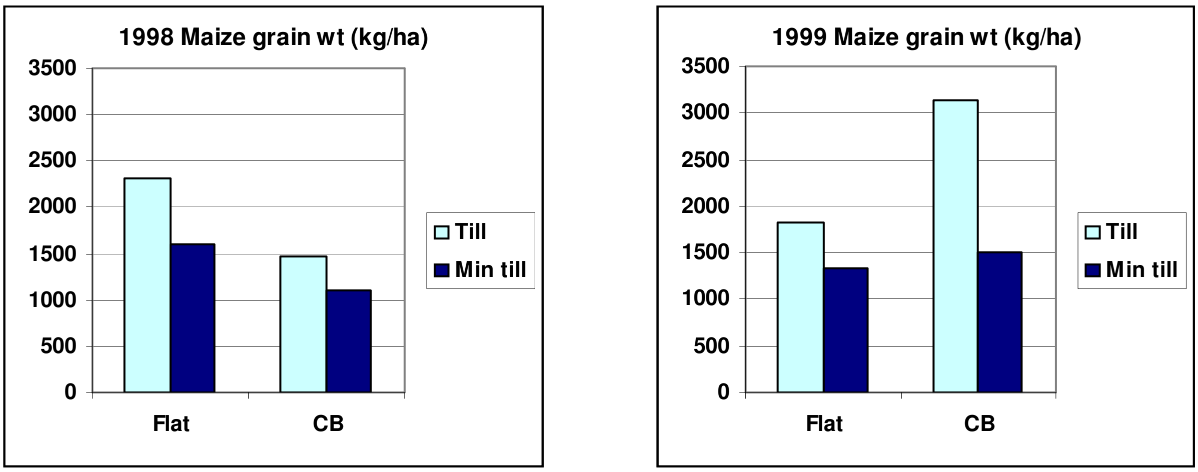
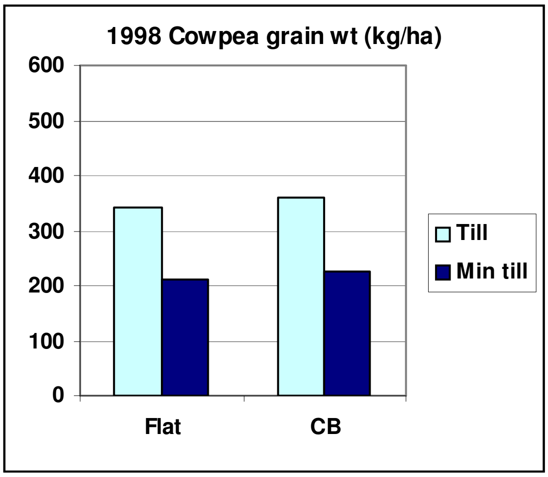
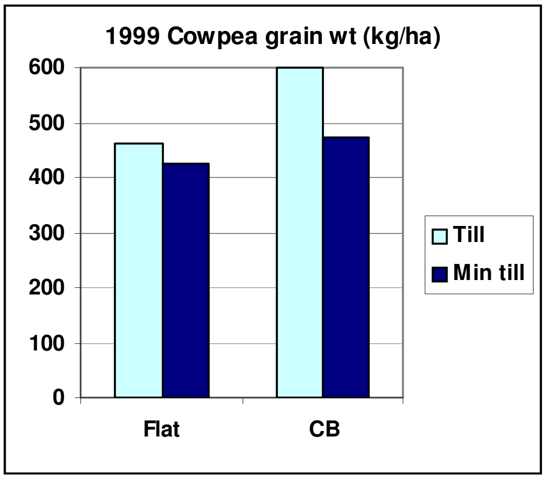


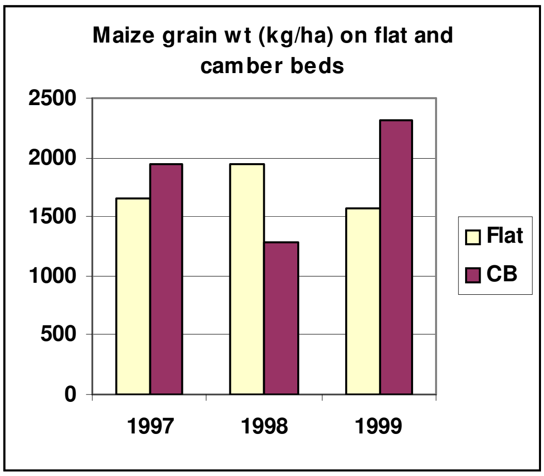
Fig. 10. Cowpea grain yields on tillage and minimum tillage treatments in 1998 and 1999

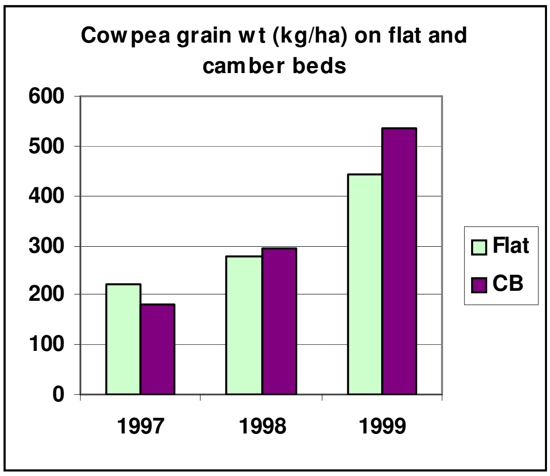




Relative yields on flat and camber beds were not consistent. In 1997, maize yields on the long-term trial appeared to be higher on camber beds (Fig. 11) but this was not statistically significant. During 1999, at the same site, camber beds gave significantly higher yields than flat plots but, in the very dry 1998 major season, the reverse was true. The differences can be attributed to rainfall in the three seasons. Whilst the major seasons of 1997 and 1999 had slightly above average and near normal precipitation, respectively, rainfall in the major season of 1998 was only 491 mm or 38% below average, a situation that has arisen only three times at ARS Kpong since 1955. It appears that the water-shedding benefits of 5m camber beds are negated for maize when rainfall is low and the crops are subjected to moisture stress. For cowpeas, camber beds gave significantly ($P<0.05$) higher yields than flat plots in 1999 but there were no significant differences in 1997 and 1998.

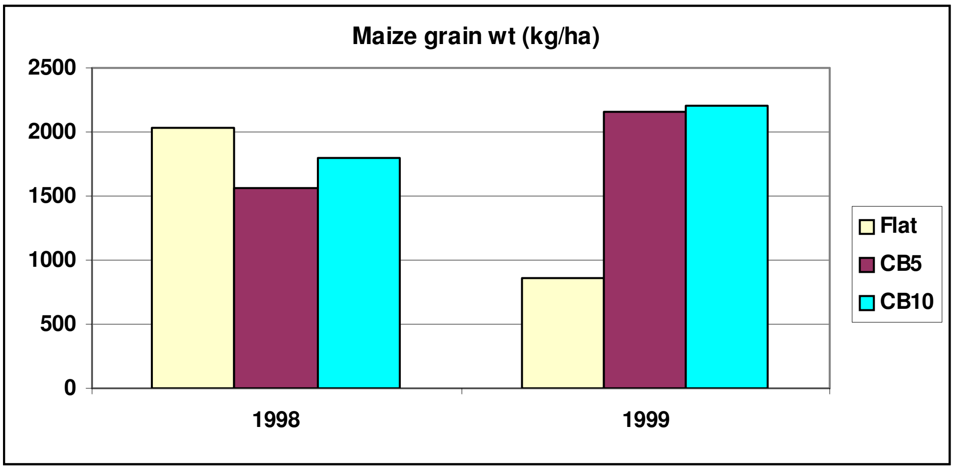
Fig. 11. Maize and cowpea yields on flat and camber beds in 1997-1999
(N.B. The 1998 major season for maize was exceptionally dry)





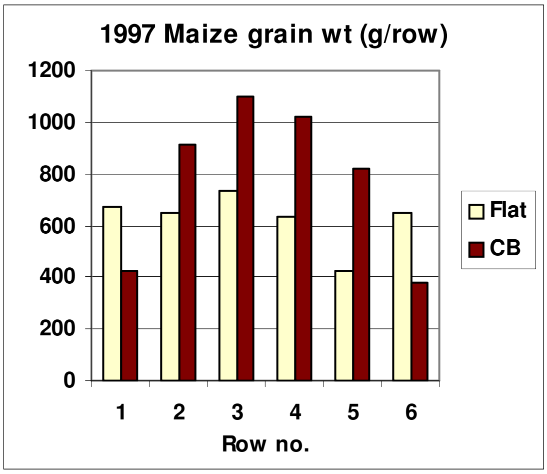
Demonstration plots at a nearby location also revealed the influence of rainfall on the maize yields from different land forms. In the dry year of 1998, there was little difference between flat plots and 5m and 10m camber beds (Fig. 12). In the normal wet year of 1999, the flat plots suffered from waterlogging whilst both camber beds produced relatively good yields.

Fig. 12. Maize grain wt on flat, 5m and 10m camber beds in dry (1998) and normal (1999) seasons



In order to interpret the effects of land forms on yields, individual crop rows were harvested on flat plots and camber beds. In 1997 and 1998, maize growing on the top (rows 3 and 4) and side (rows 2 and 5) of camber beds gave significantly ($P<0.05$) higher yields than maize grown in the furrows (rows 1 and 6) (Fig. 13). In 1997, maize from the top and side of the camber bed gave significantly higher yields than maize on flat plots but the yields on flat plots were significantly higher than maize in the camber bed furrows. In the poor rainfall season of 1998, rows on the sides and furrows of camber beds gave significantly ($P<0.05$) lower yields than on flat plots, and the overall yield from flat plots was significantly higher than from camber beds. The difference in yields between the 1997 and 1998 seasons is attributed to low rainfall in the latter and this is discussed further in Section 4.6. The differences between rows on camber beds are attributed to rainfall and fertility. Temporary flooding in furrows (Plate 6) suppressed growth of maize in rows 1 and 6 but this poorer growth could also be attributed to reduced fertility of furrows caused by the movement of top soil during creation of the camber beds.

Fig. 13. Grain yields of maize on rows in the above average rainfall major season of 1997 and the very dry major season of 1998



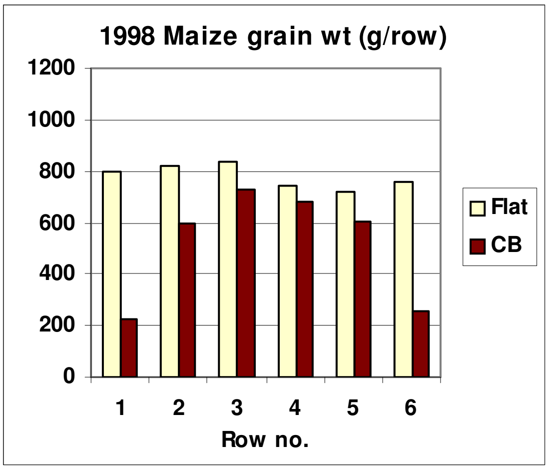
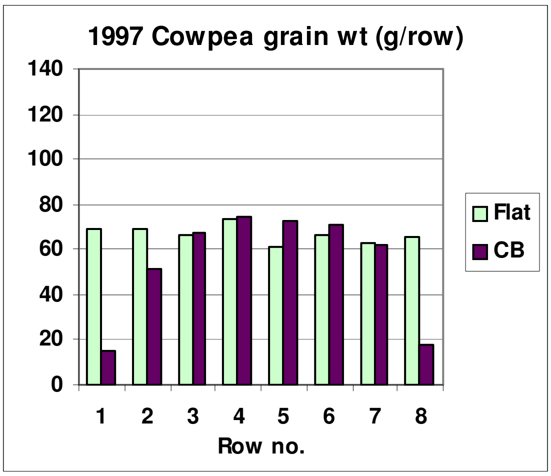
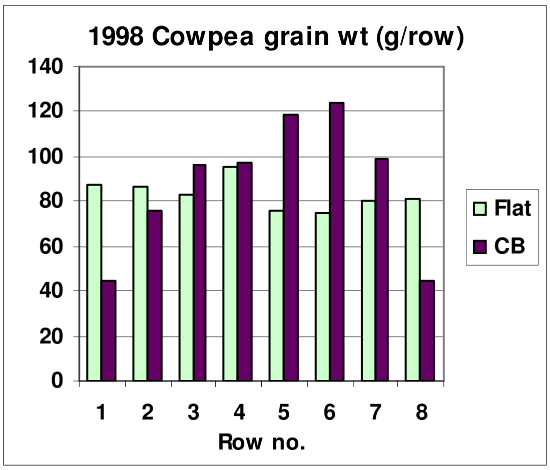


Plate 6. Camber bed showing the height differentials of maize growing on the top, side and waterlogged furrow

Yield differentials across camber beds were also apparent for cowpeas in 1997 and 1998 (Fig. 14), where rows 4 and 5 are on top of the beds and rows 1 and 8 are in the furrows. However, cowpea yield differences between flat plots and camber beds were not statistically significant in these years.

Fig. 14. Grain yields of cowpea on rows in the below average rainfall minor season of 1997 and the average minor rainfall season of 1998





4.6 Soil and water management (S&WM) research

Effective water control on Vertisols can be achieved with camber beds and this facilitates access to the field and, therefore, the control of weeds.

As shown in section 4.5, maize grew better on camber beds than on flat plots when rainfall was near to or above the seasonal average. However, in the very dry major season of 1998, crops generally performed better on the flat plots. From these observations it was apparent that the water shedding characteristics of the 5m-wide camber bed were too vigorous in periods of low rainfall when water conservation was needed.

During 1992 to 1995, the UoG / IBSRAM / ODA project also showed that crop yields from 4.8m-wide camber beds were generally significantly higher than from flat plots, ridges (0.8m-wide) or 1.6m-wide Ethiopian beds (Ahenkora, 1995). However, since then, results from the *Cyperus* Project have shown that during 'drier-than-normal' seasons, crop yields from 5m-wide camber beds have not been as high as from flat plots (or from 10m-wide camber beds). These observations are summarized in Table 7.

Table 7. Relationship between seasonal rainfall and crop yields from camber bed and flat plots

Year	Season (months)	Rainfall (mm) and % of 27-year average	Rainfall category	Maize grain wt (kg/ha)		Cowpea grain wt (kg/ha)	
				Flat	5m CB	Flat	5m CB
1997	Major (Feb-Aug)	1,011 (129%)	Above average	1,649	1,941		
	Minor (Sep-Jan)	332 (81%)	Below average			222	182
1998	Major (Feb-Aug)	489 (62%)	Very dry	1,949	1,286		
	Minor (Sep-Jan)	420 (103%)	Average			276	292
1999	Major (Feb-Aug)	712 (91%)	Below average	1,574	2,320		
	Minor (Sep-Jan)	386 (94%)	Below average			443	536

Plots treated with glyphosate have consistently produced better yields than from hand weeded treatments on both flat plots and camber beds. To better understand the potential crop production performance and limitations of the camber bed and flat land forms, more analysis was (and still is) needed on seasonal rainfall patterns and their effect on crop production through the measurement of soil moisture profiles and estimations of crop available moisture (CAM) in the soil.

The first step towards a better understanding of the impact of climate upon crop growth is to obtain more information on the monthly distribution of the annual rainfall. The 27 year average rainfall, from the 1955 to 1981 records, and the annual precipitation records from 1996 to 2000 are given in Annex 1. Analysis of the rainfall data for the 27-year period from 1955 to 1981 has revealed the following frequency of rainfall categories (Table 8). For presentation simplicity the 1197.1mm average has been rounded up to 1200mm.

Table 8. Frequency of ‘wet’ and ‘dry’ years at ARS Kpong (1955-81)

Rainfall category	Rainfall (mm)	% of average rainfall	No. of years	% of the 27 years
Very wet	>1500mm	>125%	1	4
Above average	1200 - 1500	100% - 125%	11	41
Average	1200	100%	-	-
Below average	960 - 1200	80% - 100%	12	44
Dry	<960	<80%	3	11

From our experience with the poor crop yields in 1998, when the annual rainfall of 950mm was only 79% of the 27-year average, we can reasonably assume that in years with 80% or less of the average rainfall, then water deficit (or even drought conditions) will be encountered during the growing seasons. Under water deficit (or semi-arid) conditions, land forms that conserve water, through soil surface catchment techniques, are beneficial to crop growth as they enhance soil moisture levels. From this information, it is apparent that the probability of there being only 950mm of annual rainfall, as in 1998, is about 10% and the likelihood of a major season with only 62% of the average rainfall is even less probable.

4.4.1 Land forms

Results from studies at ARS Kpong over the past seven years have generally shown that land forms which shed excess surface water (e.g. 5m-wide camber beds with 12% to 16% slope) will enhance crop growth and yield. Recent results from drier periods suggest that a land form with a less vigorous water shedding slope, like the more gentle 5% to 8% slope profile of a 10m-wide camber bed, would be advantageous as it would conserve more water in drier periods and still shed water in wet seasons

Tillage inputs were monitored in these studies where the performance and cost of traditional disc ploughing was compared with lower input (shallow & fast) tillage using the polydisc and these results have tied in with observations made elsewhere (Willcocks, 1981 & 1989). On-station operations with the three furrow disc plough operating at about 5.7 km/h achieved a net work rate of nearly 0.6 ha/h. However the lighter draught nine-disc polydisc could be pulled at over 7 km/h and could plough at a net work rate of 1 ha/h. In field on-farm performance is slower than this due to turning at furrow ends, rough ground, ‘pit’ stops, etc. Plough specifications and performance are summarized in Table 9.

Table 9. Tractor tillage work rates and cost to cultivate one hectare

Implement plough	No. of discs	Operat-ional width (m)	Tillage depth (cm)	Forward speed (m/s) [km/h]	Net work rate (ha/h)	Typical field efficiency (%)**	Typical field work rate (ha/h)	1999*** tractor hire rate (Cedis/ha)
Disc On-station*	3	0.9 - 1.2	17 - 28	1.58 [5.69]	0.57			
Disc On-farm	3	1	20	1.2 [4.32]	0.43	70%	0.3	135,000
Polydisc On-station*	9	1.4 – 1.7	7.5 - 12	2.02 [7.27]	1.09			
Polydisc On-farm	9	1.5	10	1.5 [5.40]	0.81	75%	0.6	86,500

* On-station data are from the monitoring of ploughing performance during the tillage of 48m and 105m tillage strips in the large, obstruction-free experiment

** Field efficiency values are lower than normal because they are related to smallholder fields of, say 0.4 to 1.0 ha

*** Costs are based on an exchange rate of £1 = Cedis 4,300

Under the traditional flat cultivation system, disc ploughing is conducted for each and every season (i.e. twice per year). A few farmers also have secondary cultivations carried out on their land and the work rates for disc harrowing would be about double that of disc ploughing.

Initial cultivations with the camber bed land form system necessitate tillage that will move the top soil to construct the camber beds, i.e. beds separated by furrows. The construction of 5m-wide camber beds requires passing up and down the field 6 to 8 times with the polydisc so that furrows are created at 5m spacing and the excavated soil is moved up between the furrows to form the raised bed. The camber bed construction can also be achieved with the readily available disc plough which would require from or 8 to 12 passes up and down the field to produce a camber bed 5m wide. Camber beds 10m wide can be constructed in the same way but naturally require more implement passes. However, the tillage inputs per 10m wide camber bed are likely to be less per hectare, between 10% and 20% less depending upon the skill of the tractor operator. For the purposes of the cost-benefit analysis, the following input costs for tillage were used, based on the 1999 ploughing season rates (Table 10).

Table 10. Cost of constructing and cultivating camber beds over 10 seasons (5 years)

Season	Construction / cultivation	Cost (Cedis/ha)	Cost (Cedis/ac)
1	CB construction with polydisc*	247,100	100,000
2	Tillage and CB maintenance	123,550	50,000
3 - 10	Polydisc tillage of CBs	86,490	35,000
10 season av.	Polydisc tillage	106,250	43,000

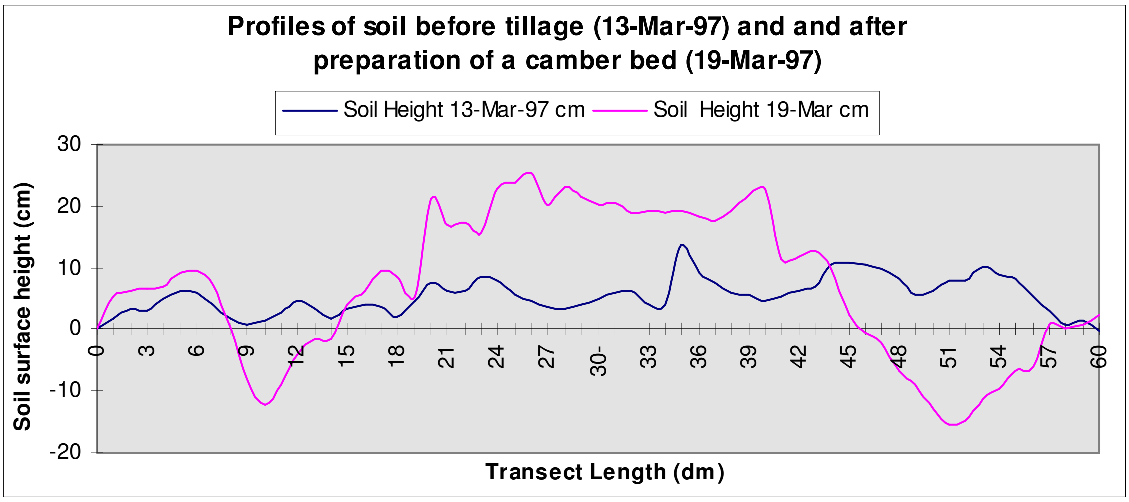
*Polydisc cost calculations are related to the commercial price that was charged for disc ploughing in 1999 at 55,000 Cedis/ac

4.4.2 Soil surface profile measurements (SSPM)

The SSP monitoring work has provided base line information on:

- changes in the SSP resulting from tillage (Fig. 15). This also illustrates why there tends to be a concentration of *Cyperus* tubers on top of the camber bed by the action of the polydisc or plough in its construction.

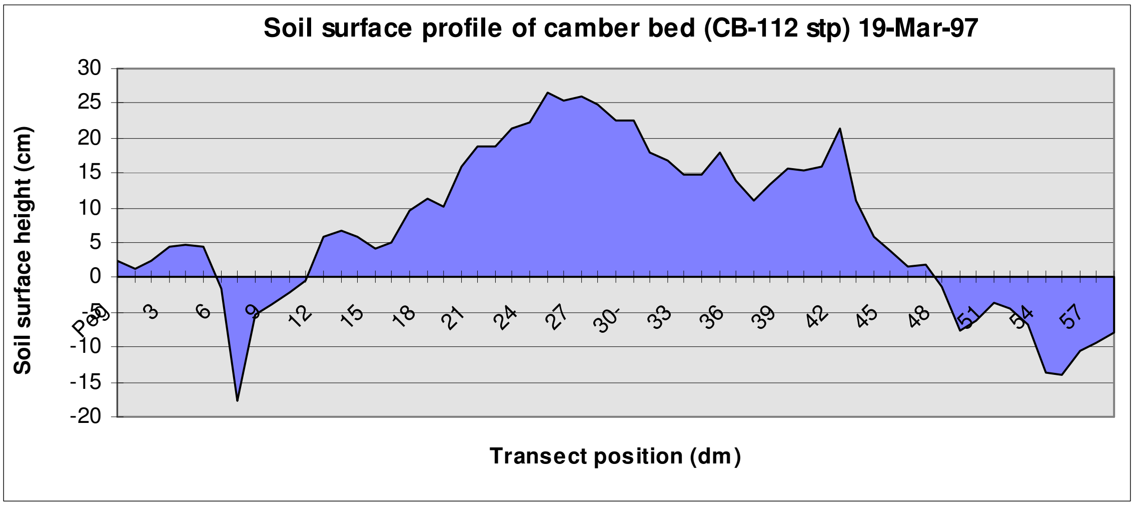
Fig. 15. Soil profiles before (black line) after (purple line) preparation of camber bed



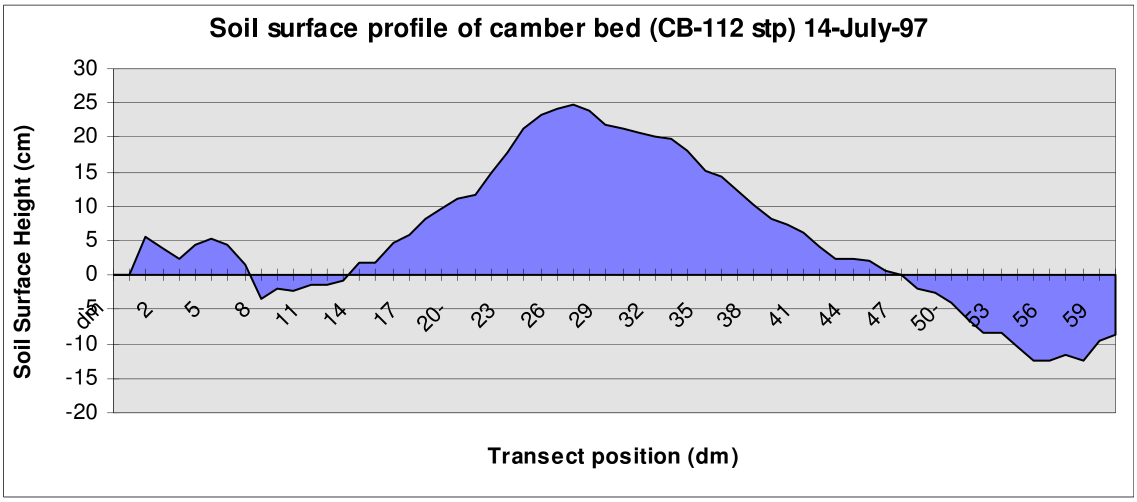
- physical dimensions of the various land forms (Fig. 16) which show changes in height, including predominant slopes and, therefore, the water shedding runoff potential of the land form being measured

Fig. 16. Profile of a camber bed in March 1997 (a) and four months later (b) after weathering during the major season rains.

(a)



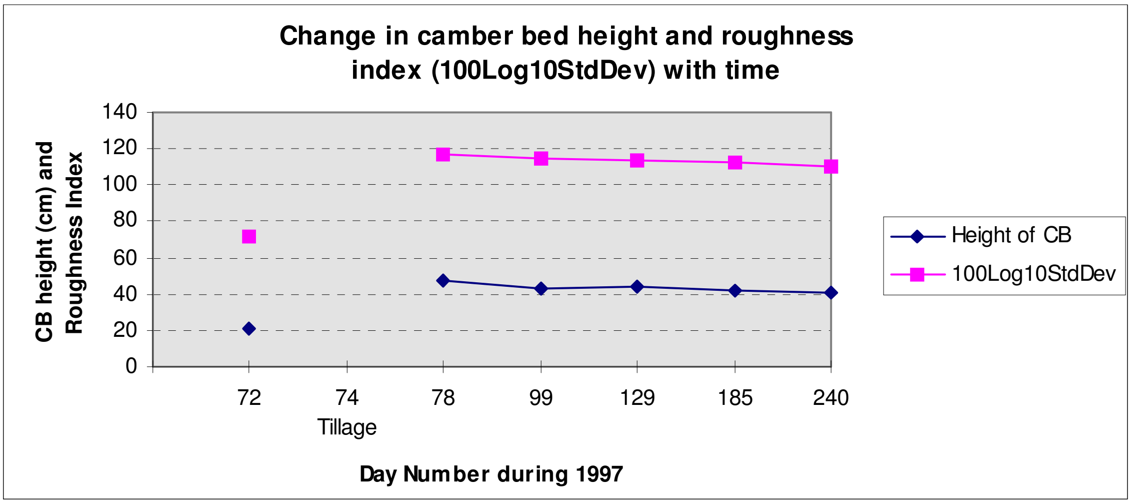
(b)



- durability of the land forms to degradation (Fig. 17) showing the reduction of camber height with time and an indication of the smoothing of the roughness indices of the land form and tilth with rainfall over the season (see also Fig. 16a & b). The soil surface height and roughness index points on day 74 in Fig 17 show the pre-tillage soil surface condition. Fig. 16b confirms that the camber beds are quite stable with time and any loss in height can easily be made up with light seasonal tillage with a polydisc.

- soil surface profiles also indicate where there is any potential for, or lack of, depression storage capacity across the land form, particularly when the soil surface profile measurements are conducted at the same time as soil moisture transects (see Section 4.4.3).

Fig. 17. Durability of a camber bed, as indicated by height and roughness index, over a period of 166 days after tillage



4.4.3 Soil moisture (SM)

The soil moisture transects that were conducted in conjunction with the soil surface profile (SSP) measurements of the land forms clearly show the variation in soil water levels across the land form relative to the shape of the SSP (Figs. 18 a & b). These transects also clearly show how and where crop damaging waterlogging can and does occur within the plots investigated. Figure 18 shows how soil water levels on the camber bed were generally below 30% (vol.) in May 1998, whereas soil moisture in the camber bed furrows and on the flat plots were much higher. It is in the camber bed furrows and the flat plots where crop-damaging waterlogging can and does stunt or terminate crop growth.

The soil moisture retention curves of the Vertisol samples from ARS Kpong are shown in Fig. 19. The pF tension points relevant to these studies are summarized in the Table 11 below:

Table 11. Average soil moisture retention points for ARS Kpong Vertisol

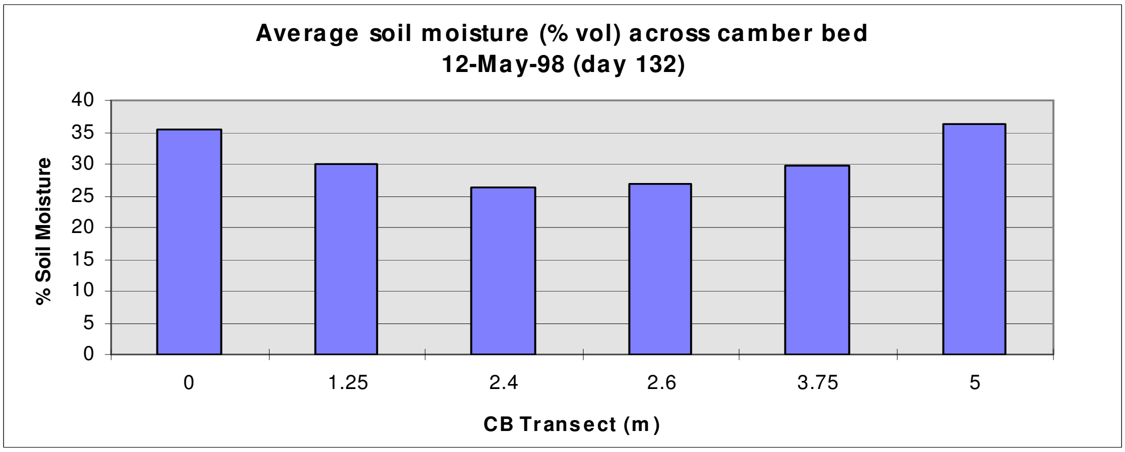
pF	Point	Soil moisture (g/g)
1.00 (pF 0 cannot be shown)	Saturation	35.4%
2.53 (0.33 bar)	Field capacity	29.0%
4.18	Permanent wilting	18.5%

These tension measurements, that estimate wilting and saturation points, have allowed the soil moisture data to be transposed into crop available moisture (CAM) information across the land forms (Fig. 20). These results again show where plants are likely to be submitted to detrimental waterlogging or water deficits in drier periods. Fig. 21 depicts some drying curves at various locations across the camber bed and shows how the damp soil dries following rainfall and also indicates how some areas of the soil surface profile remain wet for a longer period.

The damaging effects of even short term (1 to 5 days) waterlogging on maize growth are indicated in Fig. 22. It is apparent that brief waterlogging at the four leaf growth stage is much more damaging than at the one leaf growth stage, so much so that one day's waterlogging of four leaf maize is more damaging than five day's waterlogging at the one leaf growth stage.

Fig. 18. Variations in soil moisture levels across camber bed (a) and flat (b) land forms. Note that the CB furrows (1m and 5m transects) are wetter than the side and top (2.4m and 2.6m transects)

(a)



(b)

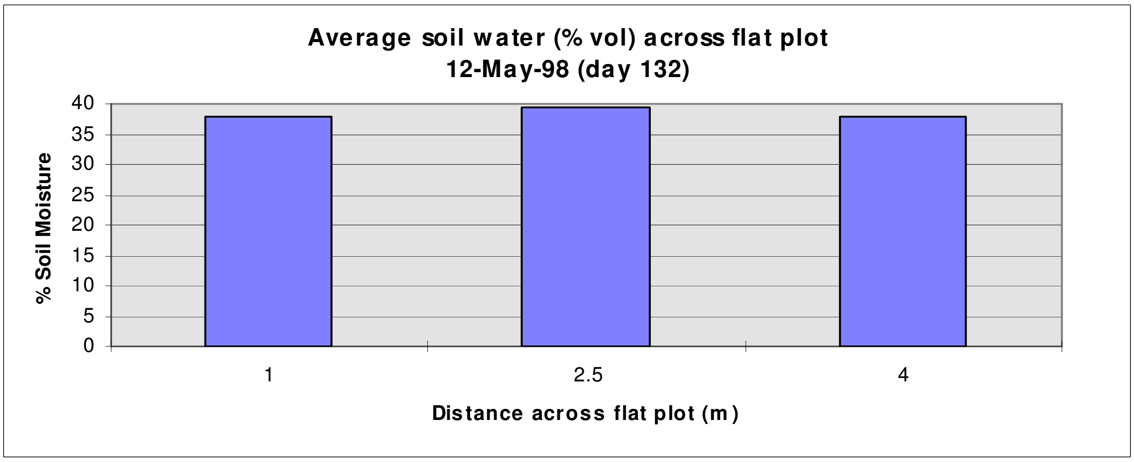


Fig. 19. Soil moisture retention curves of Vertisol samples from ARS Kpong

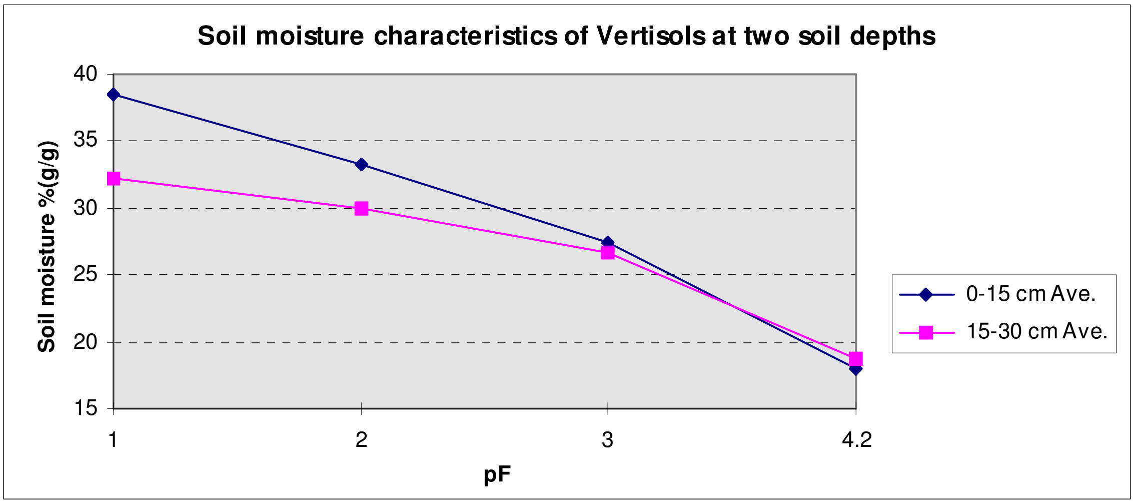


Fig. 20. Tension measurements showing how moisture available to the crop (CAM) is least on top and greatest in the trough (furrow) of a camber bed

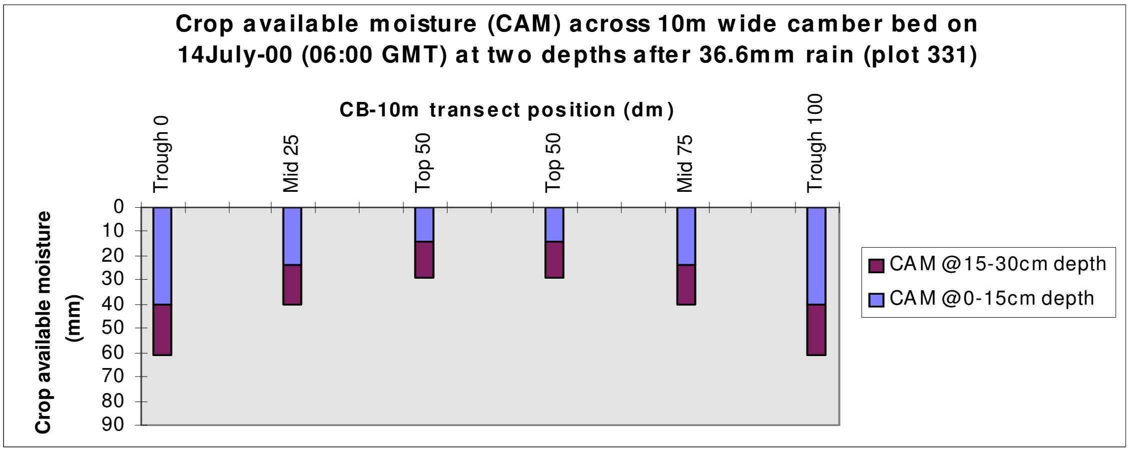


Fig. 21. Drying curves after rainfall over a 30-hour period in the furrow, middle and top of a camber bed (note that the top is the driest part of the camber bed)

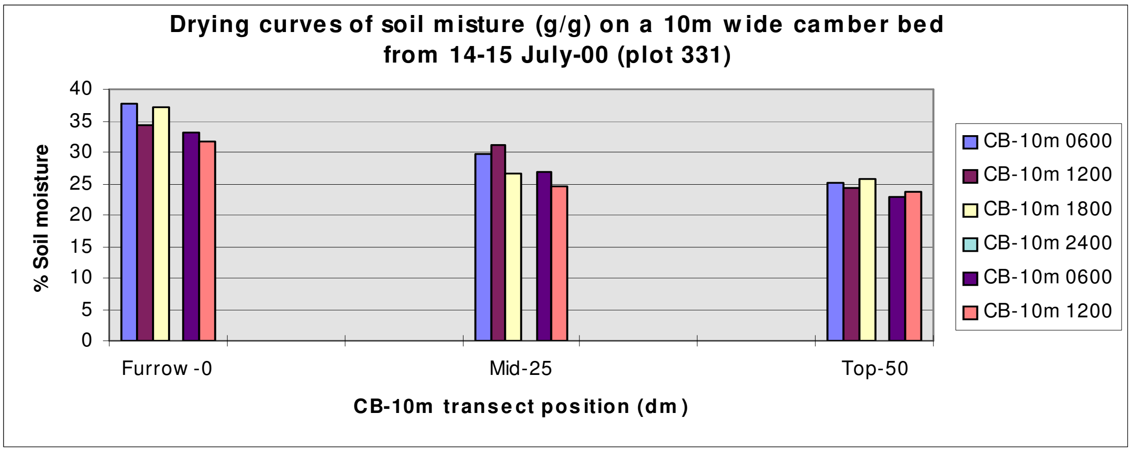
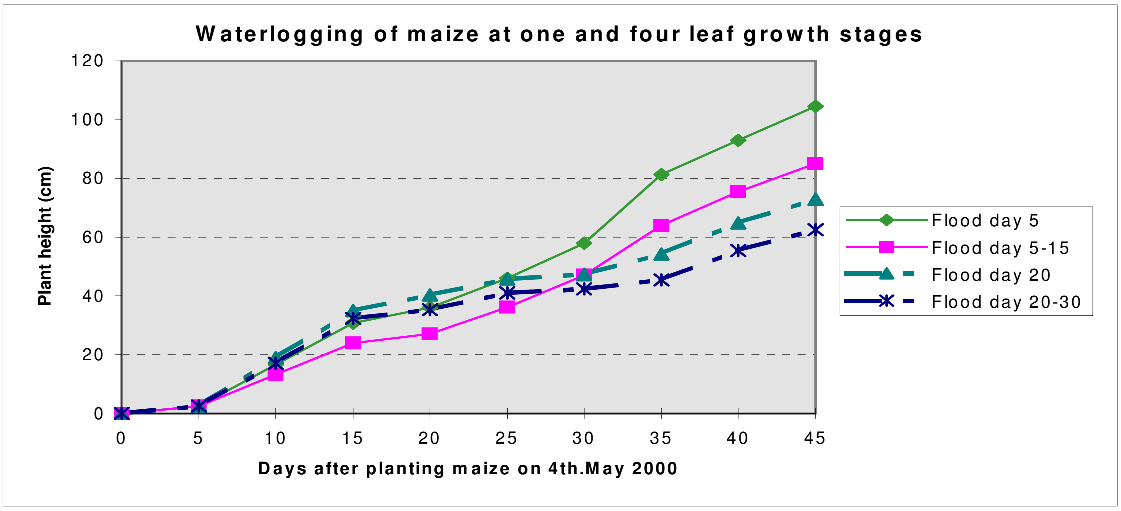


Fig. 22. The effect of waterlogging on maize



4.7 On-farm trials

There were large differences between farms but glyphosate treatments gave significantly (P<0.001) higher maize grain yields than hand-weeded plots (Fig. 23). Diligent hand-weeding could probably give comparable yields to those achieved by weed management with herbicides but, in the case of Vertisols, the land is very difficult to weed by hand when the soil is wet and problem species, such as *C. rotundus*, are not effectively controlled. The yield differential between glyphosate and hand-weeded plots was less on farmers' fields than on the research station, indicating, perhaps, that the farmers were more effective at maintaining their hand-weeded plots than the research station. Although yields on farms appeared to be higher on flat plots in the dry 1998 major season, they did not differ significantly (P>0.05) from camber beds. In 1999, camber beds gave significantly higher maize yields, confirming the trend found on the research station for better yields when rainfall is near average.

In the 1998 minor season, cowpea yields were significantly (P<0.001) higher on glyphosate treatments than on hand weeded plots (Fig. 24). Camber beds also gave significantly (P<0.001) higher yields than flat plots this season. The significantly higher yields of glyphosate treatments were repeated in 1999 but the apparently higher yields on flat plots compared with camber beds were not significant (P>0.05).

Fig. 23. Mean grain wt of maize from hand weeded and glyphosate treatments on farms with 5m camber beds in 1998 and 1999

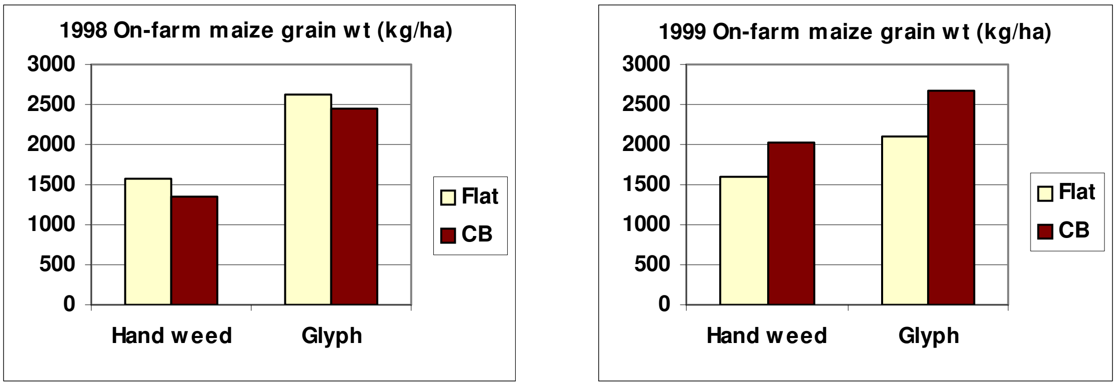
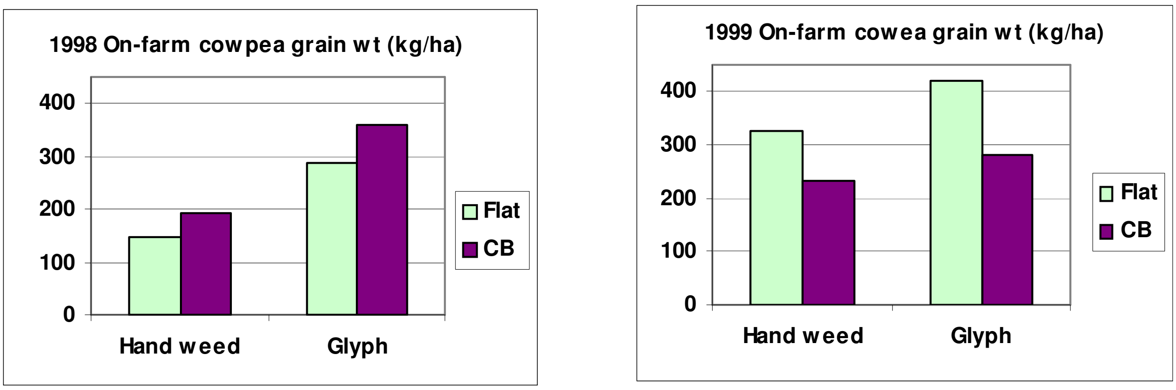


Fig. 24. Mean grain wt of cowpea from hand weeded and glyphosate treatments on farms with 5m camber beds in 1998 and 1999



It was encouraging to note that farmers said they would continue to use glyphosate and that the camber beds had allowed them to use waterlogged, low lying land that they could not otherwise use.

4.8 Biological control of *Cyperus rotundus*

4.8.1 Mycobiota of *C. rotundus* in Ghana

The fungi collected and/or isolated from *C. rotundus* during the surveys are listed and described in Table 12; only documented or suspected plant pathogens are included here. Over 20 taxa were delimited, most of which had never previously been reported from *C. rotundus*. Six of the species are of especial interest since they are either rare or new to science at the species/or generic level. Given the relatively short sampling period and the pantropical distribution of this high profile weed, which has been the subject of previous mycological investigation in several countries over many years, the richness of the associated mycobiota in Ghana was unexpected. This lends support to the hypothesis that *C. rotundus* may have evolved in Africa rather than in India based on collections in Sudan, "Other potentially useful pathogens may be discovered if systematic surveys are undertaken in the suspected native range of *C. rotundus* (possibly Sudan)."

The results from the early season survey indicated that there were significant differences between the fungi recorded within the different geographic regions. It appeared that the rust (*Puccinia canaliculata*) was more common and damaging in the south (Greater Accra, Eastern Region), whilst leaf and tuber blight, possibly caused by *Phytophthora*, replaced the rust in the Northern Region. However, the follow-up survey showed these differences to be due to seasonal variation, rather than geographic, since rust epiphytotics were subsequently recorded in the Northern Region.

The disease observation plots also showed a similar pattern: the rust being cryptic during the initial part of the rainy season (May - June), with a slow build-up of infection over the following months and reaching epidemic proportions only towards the end of the rainy season (October); almost certainly too late to have a significant impact on tuber production. Paradoxically, the rust itself is subject to heavy suppression by natural enemies in the form of at least two hyperparasitic fungi, which may, in part at least, explain why *C. rotundus* populations "explode" even when apparently damaging natural enemies, such as the rust, occur within the ecosystem.

4.8.2 Pathogenicity studies

The following potential pathogens were screened: *Coelomycete* sp.; *Dactylaria higginsii*; *Leptosphaeria* sp.; *Phytophthora* sp.; *Pseudrallescheria fusoidea*. The first three species induced leaf symptoms on *C. rotundus* and *C. esculentus*, with necrotic streaking and death of older leaves, particularly pronounced on purple nutsedge although the plants regenerated through the production of new shoots.

4.8.3 Discussions and conclusions

The surveys revealed that a significant proportion of the co-evolved pathogens of *C. rotundus* already occur in Ghana and that classical biological control as a long-term management strategy is not relevant. Preliminary results from the albeit limited pathogenicity studies, suggest that there may be potential for the inundative strategy but, clearly, more screening of the material collected is necessary in order to reach a firm conclusion. Based on taxonomic uniqueness and affinities, at least 10 of the isolates/species listed in Table 12 merit at least a preliminary if not a full evaluation.

Table 12. Actual/potential fungal pathogens recorded on or associated with *Cyperus rotundus* in Ghana (May-Oct 1997)

FUNGUS	DISTRIBUTION	ASSOCIATED DISEASE AND TAXONOMIC OBSERVATIONS
Basidiomycotina *Puccinia canaliculata* (Schw.) Lagerh.	All Regions	Highly specific pathogen, epiphytotics towards end of wet season, Ubiquitous and damaging; initial chlorosis, coalescing lesions leading to necrosis and leaf death. Rust consistently hyperparasitised by *Sphaerellopsis filum* and *Penicillium*.
Cintractia limitata Clint.	Ashanti and Northern Regions	Sporadic occurrence, heavy infection; black powdery smut spores replace inflorescences. Specific to genus *Cyperus* (Ling, 1950).
Thanatephorus cucumeris (Frank) Donk (= *Rhizoctonia solani* Kuhn)	Ashanti and Volta Regions (IMI 376065)*	Probably common, especially in dense populations with humid microclimate, leaf die-back and herbicidal - like symptoms induced by toxin; non-specific (plurivorous) root and stem pathogen.
Ascomycotina *Leptosphaeria* sp.	Volta region (IMI 377927)	Uncommon, not previously recorded from *C. rotundus* (Barreto & Evans, 1995); associated with black, irregular spreading leaf lesions leading to leaf death; large genus of root and stem rot pathogens, usually host-based.
Cochliobolus lunatus Nelson & Haasis (= *Curvularia lunata* (Walker) Boed.)	Ashanti Region (IMI 376069)	Associated with root necrosis and tuber rot; general graminicolous pathogen (Sivanesan, 1987).
Pseudallescheria fusoidea (Arx) McGinnis *et al*.	Ashanti Region (IMI 376068)	Isolated from tuber rot; genus contains animal rather than plant pathogens (Arx *et al*., 1988)
Deuteromycotina *Colletotrichum* sp.	Northern Region (IMI 376074)	Isolated from greyish-black, coalescing leaf lesions; intermediate between *C. capsici/C. dematium* complex and the one centred on *C. graminicola*; however, the wide conidia, the presence of sclerotia and the variable appressoria "distinguish it from any known species" (Report, P. Cannon).
Coelomycete ***sp***	Eastern Region (IMI 376075)	Isolated from leaf spots on necrotic leaves; on agar producing black, sphaerical sclerotia - like aggregations "not recognised as belonging to any of the known Coelomycete genera" (Report. G. Kinsey).
Curvularia fallax Boed.	Northern Region (IMI 377930)	Isolated from tubers of yellowing/dying plants; a plurivorous, graminicolous pathogen (Sivanesan, 1987).
Dactylaria higginsii (Luttr.) M.B. Ellis	Ashanti and Volta Regions (IMI 377924)	Orange, elliptical leaf lesions, spreading and becoming grey when sporulation heavy; type described from *C. rotundus* in the UDA (Luttrell, 1954) and considered to have good potential as a biocontrol agent (Evans, 1987); first record from West Africa (Barrto & Evans, 1995).
Fusarium sp.	Ashanti Region (IMI 377931)	Isolated from black sclerotia around base of dying plants: "this strain does not fit easily into any described species" (Report. D.

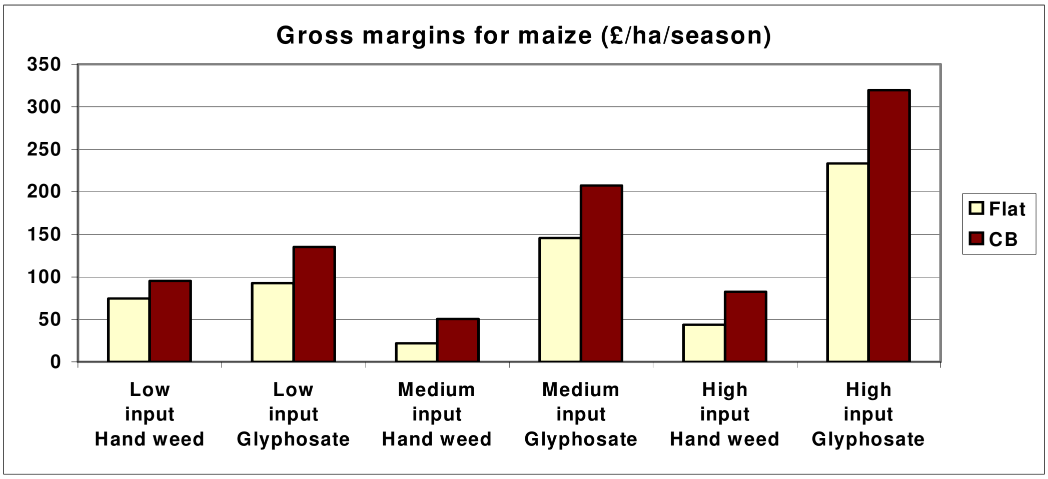
		Brayford), and, obviously, therefore, represents a new toxin.
Hyphomycete sp.	Northern Region (IMI 377932)	Isolated from leaf spots and necrotic lesions, associated with a declining population of *C. rotundus*; "I have never seen anything like it before, and am not aware of any genus in which it could be put" (Report. D. Minter).
Neottiosporina masonii Sutton	Volta Region (IMI 377926)	Isolated from black powdery bodies within leaf surface, possible biotrophic association as leaf still green (non-necrotic); "*Until now only known from the type specimen* on *Pinus caribaea* from Tanzania, [Sutton & Marasas, 1976]. The present specimen is therefore an important addition to the knowledge of this species" (Report. G. Kinsey). Pathogenic status unknown.
Phoma sorghina (Sacc.) Boer *et al*.	Northern Region (IMI 376066)	Coalescing leaf lesions, black fructifications on dead leaves; common opportunistic pathogen, particularly of grasses in the tropics (Boerema, 1993).
Phoma sp (close to *tropica*)	Northern Region (IMI 3779290	Associated with die-back; common saprophyte in the tropics. "The present specimen differs in that it is slow-growing and produces grey mycelium without greenish tints" (Report. G. Kinsey).
Pyrenochaeta sp. (close to *rubi-idaei*)	Northern Region (IMI 376070)	Uncommon; associated with water-soaked leaf lesions; identification tentative because this species has only been reported from *Rubus* (Schneider, 1979), no spp. recorded on *Cyperus* previously; poorly studied genus but contains some important plant pathogens (e.g. tomato brown rot).
Coniothyrium sp. *Fusarium oxysporum* Schlect. *Fusarium solani* (Mart.) Sacc.	Ashanti Region	All regularly isolated from tubers collected from dead/dying plants in Disease Observation Plots; probably saprophytic and/or opportunistic pathogens associated with prior insect damage.
Chromista *Phytophthora* sp.	Northern and Volta Regions	Black leaf spots coalescing to produce wet rot at stem/root interface; typical *Phytophthora* - like culture successfully isolated from one specimen only, but mature diagnostic sporangia not produced on standard media; IMI, therefore, unable to confirm identity.

* IMI Culture Collection Number

4.9 Economics

Using a cost-benefit model (Annex 4), the economics of using glyphosate compared very favourably to hand weeding (Fig. 25). Gross margins for glyphosate treatments are higher than for hand weeding because of the greater yields and reduced labour costs for weed control. For glyphosate treatments on camber beds, they can be £320/ha, compared with £75/ha for low-input farmers using hand weeding on flat plots. These are not dissimilar to gross margins of $132/ha (*c.* £88) where farmers used no fertiliser and $332/ha (*c.* £221) where fertiliser had been used on flat plots in the Accra Plains (Ellenbroek *et al.*, 1997). Kwadzo (1995) reported net returns of $112/ha (*c.* £75) for maize grown in the same area. Gross margins for low-input farms using hand-weeding are higher than for the medium- and high-input farms because they are assumed to have no labour costs for planting, weeding and harvesting due to the use of their own, or family, resources. The low-input farmer can benefit from using glyphosate but it seems to be imperative that the medium- and high-input farmers use glyphosate, or another herbicide, to alleviate the high labour costs and to maximise the benefits from other inputs. The use of fertiliser without effective weed control will worsen the economic situation, as it will promote prolific and damaging weed growth.

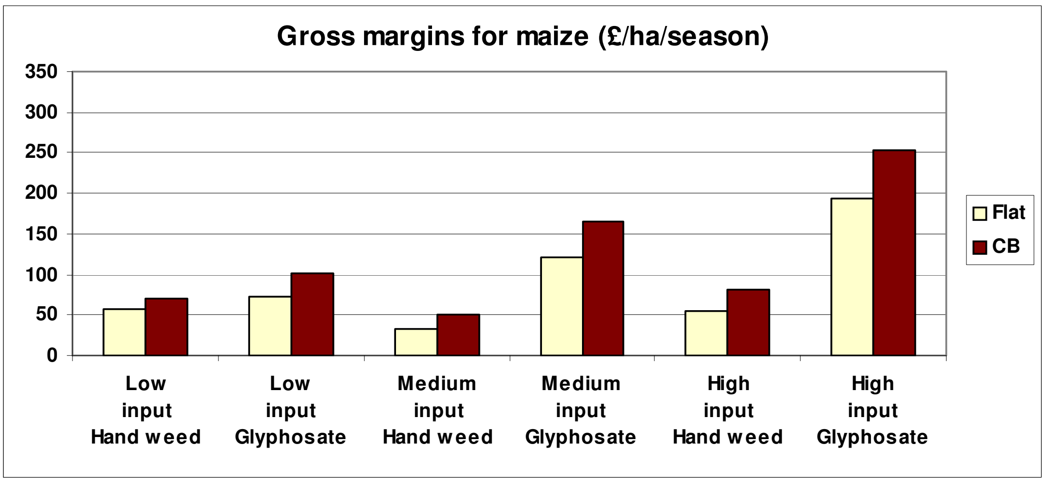
Fig. 25. Gross margins (£/ha) for glyphosate and hand weeded treatments averaged over ten seasons. (£1 = Cedis 4,300. See Table 3 for descriptions of low, medium and high input systems)



The gross margins for 5m-wide camber beds are positive over a period of ten maize-growing seasons. Costs of preparing camber beds reduce the gross margins in the first year of deployment but they are still more profitable than flat plots in a typical wet season. In exceptional seasons, when rainfall is well below average (i.e. for one year in ten when rainfall is less than 80% of the average), yields and gross margins are better on flat plots and on wider camber beds.

Gross margins change with fluctuations in the value of the Ghanaian Cedi. Those calculated for Fig. 25 were at a time when £1 = Cedis 4,300. By August 2000, the exchange rate for one pound was Cedis 9,340 but gross margins were still positive (Fig. 26).

Fig. 26. Gross margins (£/ha) for glyphosate and hand weeded treatments averaged over ten seasons. (£1 = Cedis 9,340. See Table 3 for descriptions of low, medium and high input systems)



The rationale for this research was that cost-effective and practical strategies could be demonstrated for managing weeds (particularly *C. rotundus*) and Vertisols in Ghana. It has certainly shown the feasibility and profitability of using glyphosate and also confirmed the value of camber beds in normal rainy seasons. The question is, will farmers use this technology? A socio-economic study (Ellenbroek *et al.*, 1997) revealed that 79% of land in the Accra Plains is ploughed by tractor, and harrows are used on 21% for subsequent seedbed preparation. Only 20% of cropped fields are prepared by manpower only. These mechanical resources are sufficient for creating camber beds but some training would be needed for the drivers of the hired tractors. Most weed control is done manually with a hoe or cutlass but Ellenbroek *et al.* (1997) found that glyphosate was used as a spot spray by 14% of the farmers and 18% had knapsack sprayers, mainly for insecticide application. So, although herbicide use is not widespread, there is an awareness of the technology and, moreover, herbicides and spraying equipment are available in local markets.

Maize production in the Accra Plains is very variable: Kwadzo (1995) reported yields of 1,125 to 2,500 kg/ha; Ellenbroek *et al.* (1997) found ranges of 280 to 1,010 kg/ha in the absence of fertiliser, and 450 to 1,350 kg/ha where fertiliser had been used. The yields from on-farm trials reported in this paper varied from 582 kg/ha to 3,563 kg/ha at the same location (Block Farms, Somanya) in 1998, providing a clear indication of the potential for improving production. Many farmers participating in the research programme have been very satisfied with the results and will continue using glyphosate and camber beds. Hence, there is reasonable cause for optimism that farmers around Kpong and in other areas will adopt the technology demonstrated in this research for improved use of Vertisols.

5. Contribution of Outputs

5.1 Contribution of outputs to project goal

The project goal was, "To identify methods for the control of *Cyperus rotundus* which enable more effective utilisation of Vertisols and similar clay soils by smallholder farmers". This was achieved by:

- ❑ Developing techniques based on glyphosate herbicide, to give over 99% control of *Cyperus rotundus* within three years.
- ❑ Demonstrating the yield benefits of using camber beds in seasons of normal and above average rainfall.
- ❑ Using technologies that farmers are already using and/or for which they have affordable access. Demonstrating methods in on-farm trials that farmers have indicated they are willing to adopt.

5.2 Achievement of outputs stated in the project memorandum

Most outputs, as indicated by ❑, were achieved but two outputs, as indicated by ❍, were not achieved for the reasons stated.

❑ "*An understanding of farmers' perceptions of weeds and their capacity to manage them on Vertisols and vertic clay soils*." This was achieved in a socio-economic survey in the first year of the project and through working with farmers on participatory trials and by two open days.

❑ "*Researcher-managed and farmer-participatory trials will produce results on various weed management options*." On-farm trials were done in six seasons with up to 24 participating farmers. Complementary studies were done on the research station over seven seasons. A practical method for controlling *Cyperus rotundus* was demonstrated, based on the integration of glyphosate herbicide into traditional farming systems and in systems based on camber bed land forms to control water.

❑ "*Recommendations for the management of Cyperus, on Vertisols and vertic clay soils*." A guide book for farmers and the extension service will be completed by December 2000.

❑ "*Dissemination of recommendations through publications, the extension service, student training and open days for farmers.*" Posters and papers were presented at two international weed conferences. One paper has been submitted to an international journal and at least two more are planned. The extension service has been involved with on-farm trials and an open day. An open day for farmers was broadcast twice to an audience of three million TV viewers in Ghana. Post-graduate students have been employed on the project to gain work experience and to contribute to the research.

❑ "*Necrotrophic pathogens of C. rotundus isolated and identified, together with preliminary assessments of their pathogenicity.*" Eighteen pathogens were isolated and tested for their pathogenicity. More time was needed for this research but additional funding was not approved.

❍ "*An assessment of the potential of Ghanaian farmers and extension workers to manipulate or incorporate a biocontrol agent within the local farming system.*" This was not possible in the absence of an identified pathogen.

❍ "*Long-term feasibility of exploiting indigenous and/or exotic fungi for the control of C. rotundus*." It was not possible to achieve this during the 18-month lifetime of this aspect of the project.

5.3 Contribution to DFID's development goals

DFID's development goals are articulated in the logframe of the CPP High Potential Production System, i.e.:
Goal: "Livelihoods of poor people improved through sustainably enhanced production and productivity of RNR systems".
Purpose: "Benefits for poor people generated by application of new knowledge on crop protection to High Potential production systems". The relevant indicator of achievement is, "By 2003, management strategies for the major pest constraints in maize-based cropping systems adopted in one country".

The project addressed a specific pest problem, i.e. *Cyperus rotundus*, reputedly the worst weed in the world, on land with difficult to manage Vertisols and vertic clays occupied by poor farmers. Whilst these farmers were not the "poorest of the poor", they lack the resources, security and quality of life that DFID and other donor agencies seek to improve. Although the project was based in Ghana, the research was relevant to many other developing countries, because *C. rotundus* is such an important and ubiquitous weed in smallholder farming systems and farmers in many countries are not able to fully utilise Vertisols.

Control of *C. rotundus* by glyphosate was first demonstrated over 30 years ago and, soon after, it became a practical management strategy for use by commercial farmers. The high price of glyphosate virtually excluded it from use by most farmers in developing countries until quite recently, when the price of this herbicide began to fall. The promotion of pesticide use for Third World farmers is generally not supported by development agencies but herbicides offer one of the few options for relieving the drudgery of weeding and releasing labour for more productive activities. In many respects, glyphosate is an ideal herbicide for farmers in developing countries because it has low mammalian toxicity, it is environmentally benign and it is a very reliable and effective product. The challenge for this project was to introduce glyphosate to farmers in such a way that it complemented their systems of crop production. This was achieved, making it possible to suppress and/or remove *C. rotundus* and other weeds from notoriously difficult-to-cultivate Vertisols where hoe weeding is difficult and not very effective. Combining weed management with the practice of raised land forms (camber beds) has made it feasible to cultivate large areas of Ghana and other developing countries that hitherto have been under utilised.

Having developed and demonstrated the technology, the question is, "Will farmers adopt it?" Glyphosate is available in local markets, as also is the spraying equipment for its application. Camber beds can be constructed with the equipment used by the contractors who plough and harrow land for farmers, some instruction will be needed. Cost-benefit models show the profitability of using glyphosate. Farmers who participated in the trials were very happy with the results and many, including some of their neighbours, indicated that they would continue to use the technology developed by the project. With these positive indicators, it is hoped that the technology will be widely adopted in the near future.

5.4 Promotion pathways to target institutions and beneficiaries

The project has reached stage 'F' (Application and replication of results in target institution programmes) on the 'A-H uptake pathway'. The next step is to promote the technology. The project has sought to aid this process by involving extension workers in the on-farm trials, publicising its work in a national TV programme (Plate 7) and by producing literature that can be used by the extension service and farmers. If these promotion activities are successful in encouraging the uptake of the outputs, the project will have contributed to the DFID programme purpose indicator of "*adopting management strategies for the major pest constraints in maize-based cropping systems adopted in one country by 2003*".

Plate 7. Filming a farmers' field day for broadcasting to three million viewers of the Ghana TV programme, *Agrolink*

5.5 Follow up action/research to promote findings

Further publications are planned. These include a guide to the management of *Cyperus rotundus* on Vertisols for farmers and extension officers (in preparation) and at least two publications in peer-reviewed journals.

A project proposal on the management of water and weeds on Vertisols is being considered for submission to the NRSP after encouraging comments from the programme manager, Dr M Quin. It is anticipated that a new project will be compatible with the Agricultural Services Improvement Program (AGSIP) in Ghana.

Dr E O Darkwa, Director of ARS Kpong, has been in negotiations with the Benson Agriculture and Food Institute in Prove, Utah to develop a proposal, based on the outputs of the project. This will assist and encourage the people of Okewnya and beyond, who cultivate soils dominated by *Imperata cylindrica* and other perennial weeds, to replace grasslands with agro-forestry.

Mrs Christiana Amoatey from the University of Ghana has secured a Commonwealth Academic Staff Scholarship to do a PhD on *Cyperus rotundus* at the University of Reading from 2001.

5.6 Publications

5.6.1 Conference proceedings and posters

Title pages of published and submitted papers are given in Annex 2. Full reports are available from the authors.

DARKWA, E.O., JOHNSON, B.K., NYALEMEGBE, K., TERRY, P.J. and WILLCOCKS, T.J. (1999) Control of *Cyperus rotundus* on Vertisols and vertic clays in Ghana. pp. 373-378. In: *Proceedings of the 1999 Brighton Conference*. (Edited proceedings and poster)

TERRY, P.J., DARKWA, E.O., JOHNSON, B.K., YANGYUORO, M. and WILLCOCKS, T.J. (2000) Weed management on Vertisols for small-scale farmers in Ghana. pp192-193. In: *Abstracts, Third International Weed Science* Congress, Foz do Iguassu, Brazil. (Abstract and poster)

TERRY, P.J. (Ed.) (1999) International Crop Protection: Achievements and Ambitions. *Proceedings 1999 BCPC Symposium No. 73*, Brighton. 150 pp. (Edited proceedings)

WILLCOCKS, T.J., DARKWA E.O., JOHNSON, B.K., NYALEMEGBE, K., TERRY, P.J. and YANGYUORU, M. (1999) How can the production potential of Vertisols and vertic clays contribute to the demand for more food? Presentation at Tropical Agriculture Association Biennial Residential Seminar, *Can sustainable agriculture feed the population of tropical countries for the next 25 Years?* Edinburgh, 25 – 26 September 1999. *TAA Newsletter,* 20 (1): 29-30. (Peer reviewed paper)

5.6.2 Paper submitted to peer-reviewed journal

DARKWA, E.O., JOHNSON, B.K., YANGYUORU, M., OTI-BOATENG, C., WILLCOCKS, T.J. and TERRY, P.J. Weed management on Vertisols for small-scale farmers in Ghana.

5.6.3 Internal Reports

(a) Back-to-Office reports following visits to Ghana

1996	October	P J Terry & T J Willcocks
1997	Feb/March	T J Willcocks
“	May	P J Terry & T J Willcocks
“	November	T J Willcocks
1998	March	P J Terry
“	March	T J Willcocks
“	October	P J Terry & T J Willcocks
1999	March	P J Terry
“	March	T J Willcocks (with technical annex)
“	July	P J Terry & T J Willcocks
2000	February	P J Terry
“	March	T J Willcocks (with technical annex)
“	August	T J Willcocks
“	Aug/Sept	P J Terry

(b) Annual and quarterly reports

1996-1999 - Four annual reports
1996-2000 - 12 quarterly reports

(c) Other internal reports

Title pages of other internal reports are given in Annex 2. Full reports are available from the authors.

DARKWA, E.O., JOHNSON, B.K., NYALEMEGBE, K., YANGYUORU, M., OTI-BOATENG, C. WILLCOCKS, T.J. and TERRY, P.J. (1999) Weed management on Vertisols for small-scale farmers in Ghana. University of Ghana, Legon. (Project publicity handout)

ELLENBROEK, W.E.T., KWADZO, G.T-M. and EGYIR, I.S. (1997) Smallholders' arable farming systems on Vertisols and vertic clay soils in Ghana, October 1997. Report of Natural Resources Institute, Chatham. 57 pp.

EVANS, H.C. (1998) Final report of the IIBC component of NRIL project ZA0055. Report of CABI Bioscience, Ascot. 7 pp.

5.6.4 Other dissemination of results

DARKWA, E.O., JOHNSON, B.K., NYALEMEGBE, K., and TERRY, P.J.(2000) Management of the perennial weed *Cyperus rotundus* on Vertisols and vertic clay soils. Block Farms, Somanya, Ghana. 31 August 2000. [Field day for 35 farmers and extension workers]

DARKWA, E.O., OTENG, J., JOHNSON, B.K., NYALEMEGBE, K., OTI-BOATENG, C., TERRY, P.J. and WILLCOCKS, T.J. (1999) Management of the perennial weed *Cyperus rotundus* on Vertisols and vertic clay soils. Agricultural Research Station, Kpong and Block Farms, Somanya, Ghana. 22 July. [Field day for 70 farmers, extension workers and academics from the University of Ghana]

DARKWA, E.O., OTENG, J., OTI-BOATENG, C., TERRY, P.J. and WILLCOCKS, T.J. (1999) Control of *Cyperus rotundus* on Vertisols. *"Agrolink" Ghana Television.* 2 August (18:30) 15 minutes. Ghana (national). Twi and English. (Television, audience of 3 million)

5.6.5 Plans for future dissemination

A handbook for farmers and extension officers is being prepared and will be published by December 2000. At least two papers will be prepared and submitted to peer-reviewed journals by March 2001.

6. ACKNOWLEDGEMENTS

It is a pleasure to acknowledge the co-operation and friendship of our collaborators at the Agricultural Research Station Kpong, particularly the Director, Dr John Oteng, and Dr Ed Darkwa, the project leader in Ghana and now head of ARS Kpong. We are also grateful for the support and interest of the University of Ghana, Legon, especially Professor Seth Danso who generously loaned a vehicle before the project acquired its own transport and provided laboratory facilities for the analysis of soils. Professor Yaw Ahenkora and Professor K B Laryea of the Department of Soil Science have demonstrated their support during the project.

Dr Harry Evans of CABI Bioscience and his collaborators at the Crops Research Institute, Kumasi did original research on the biological control of *C. rotundus*. This had no immediate impact on the control of *Cyperus* during the life of the project but their studies have contributed to knowledge on pathogens with the potential to control this important weed.

Wim Ellenbroek, from the Natural Resources Institute, and his collaborators at the University of Ghana did a socio-economic study of the Accra Plains which proved valuable for justifying the need for the project and for interpreting the outputs.

The project Landrover was inherited from an ODA cotton project in Egypt and we thank Dr Anthea Cook for facilitating its transfer from the Natural Resources Institute, Chatham. Having done a high mileage before we received it, this vehicle needed quite a lot of maintenance and we thank Mr Kwame in the workshops of the British High Commission for his successful endeavours.

Lastly, we thank many farmers for their participation in our on-farm trials and for their kind words of appreciation for our efforts to alleviate their weed burdens on the Vertisols of Ghana.

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ANNEX 1

ANNUAL RAINFALL AT ARS KPONG, GHANA

ANNUAL RAINFALL AT ARS KPONG, GHANA

1996	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Total	0.00	175.90	129.90	217.50	244.85	167.15	94.40	53.25	22.25	104.40	13.85	35.10	1258.55

1997	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Total	41.00	18.10	187.35	174.75	143.35	272.00	142.35	72.75	72.10	161.85	68.75	27.25	1381.60

1998	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Total	1.80	1.75	48.00	12.40	178.75	207.00	36.55	4.41	138.60	245.80	26.75	5.80	907.61

1999	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Total	2.90	25.80	57.80	83.10	64.60	325.70	74.30	80.20	122.80	119.10	109.50	4.10	1069.90

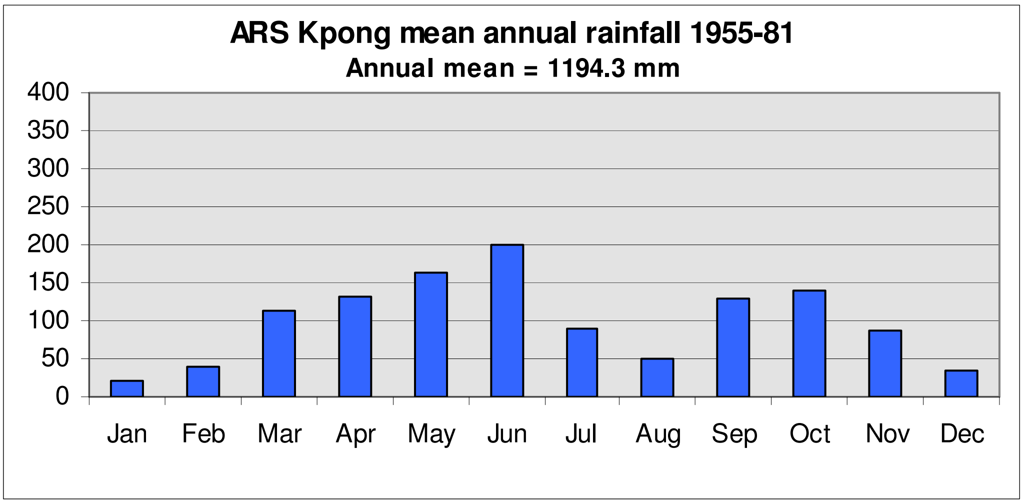
2000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Total	30.00	8.10	42.10	116.80	127.20	121.30	137.80	15.50	0.00	0.00	0.00	0.00	598.80

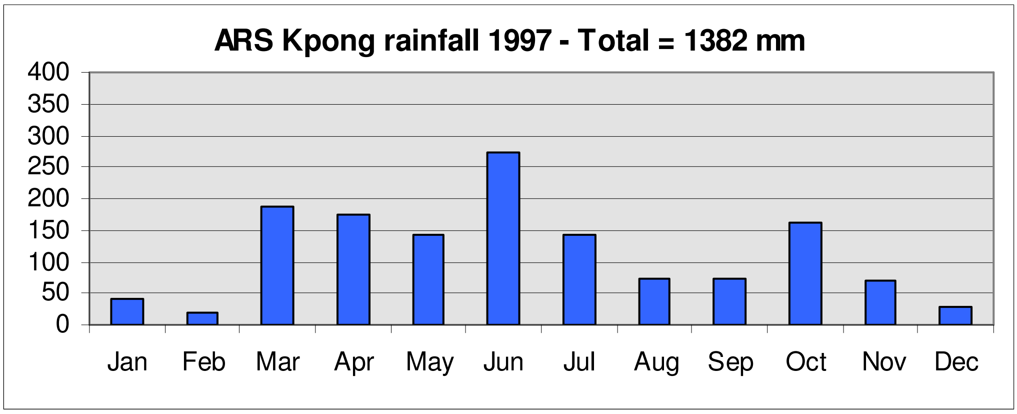
YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Mean 55-81	21.6	39.1	112.0	130.5	163.0	201.2	88.5	51.3	127.9	138.5	87.5	33.2	1194.3

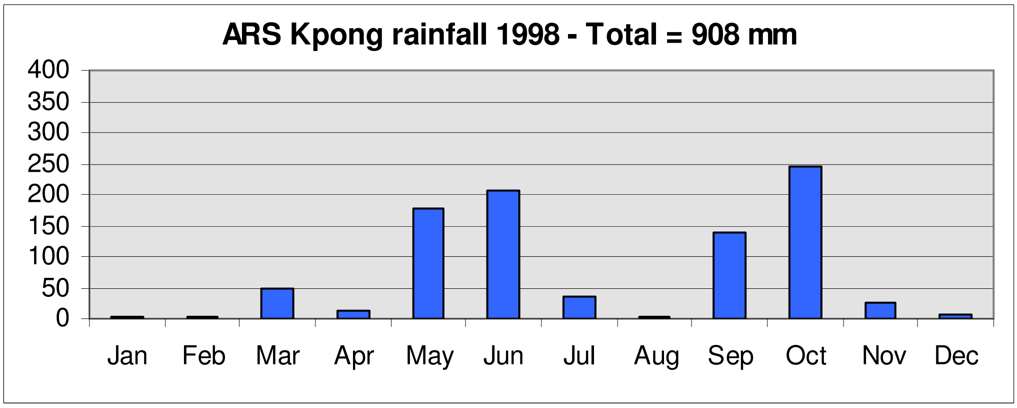
Year	Major	%	Minor	%
1996-97	1083	137.85	217	52.99
1997-98	1011	128.65	332	81.16
1998-99	489	62.23	420	102.72
1999-00	712	90.57	386	94.31
2000-01	569	72.40		
1955-81	786	100.00	409	100.00

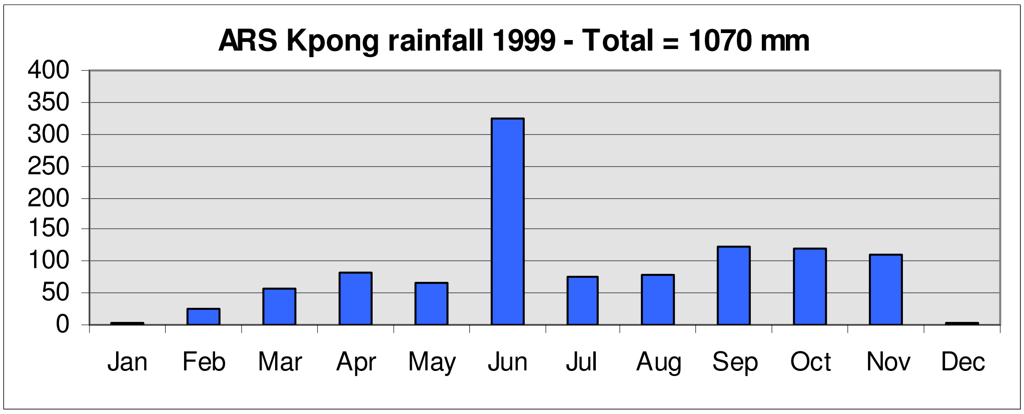
Major season

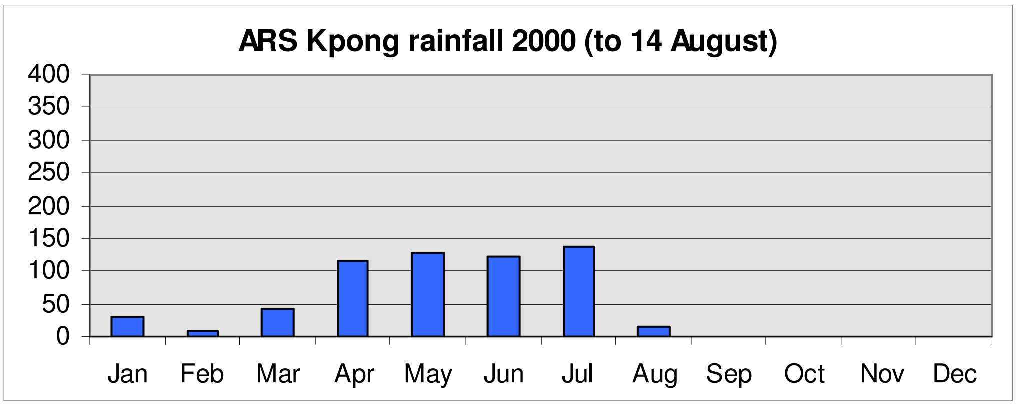
Minor season




ARS Kpong rainfall 1997 - Total = 1382 mm
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


ARS Kpong rainfall 1998 - Total = 908 mm
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


ARS Kpong rainfall 1999 - Total = 1070 mm
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


ARS Kpong rainfall 2000 (to 14 August)
400
350
300
250
200
150
100
50
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

ANNEX 2

TITLE PAGES OF PROJECT PUBLICATIONS

Control of *Cyperus rotundus* on Vertisols and vertic clays in Ghana

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ABSTRACT

Field trials on Vertisols in Ghana showed that 1.8 kg a.e./ha glyphosate reduced tuber populations of *Cyperus rotundus* L. by 95% after being applied at the beginning of four cropping seasons during 1997 and 1998. Yields of maize grown during the major seasons of these years were significantly increased by use of the herbicide treatment. Camber beds (4.8 m-wide raised beds) appear to increase crop growth in typical wet seasons, compared to flat seed beds, but not in seasons that are much drier than average. The combination of camber beds for land drainage and glyphosate for controlling *C. rotundus* and other weeds is appropriate technology for small scale farmers in the Accra Plains of Ghana.

INTRODUCTION

It is estimated that 308 million ha of the earth's surface are composed of Vertisols (Coulombe *et al.*, 1996), including 90 million ha in Africa (Willcocks, 1989) with 180,000 ha in Ghana (Ahenkorah, 1995). Vertisols are montmorillonitic clays, representing valuable resources as they hold more water and are generally more fertile than the sandy soils that cover much of Africa. They are, however, difficult to manage as they are hard and cloddy when dry and very sticky when wet. These properties of Vertisols mean that the windows of opportunity for land preparation, sowing and early weeding are small. Vertisols are hard to cultivate when dry and too sticky for tractor operations and limit human access when wet. However, since these montmorillonitic clays shrink when dry and expand when wet, they are self-loosening. Hence, their physical properties make these soils ideally suited to reduced systems of tillage as there is little need to loosen them by mechanical tillage to grow crops.

Options for managing Vertisols in Ghana were explored during a three year project during 1992-95 which showed that raised land forms gave superior crop yields to those obtained on traditional flat beds (Ahenkorah, 1995). Camber beds, 4.8 m wide and 0.3 m high, were the most successful land form studied, increasing crop yields by 90% compared with flat beds.

Weed management on Vertisols for small-scale farmers in Ghana

P J TERRY[1], E O DARKWA[2], B K JOHNSON[2], K NYALEMEGBE[2], M YANGYUORU[2] & T J WILLCOCKS[3]

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Summary

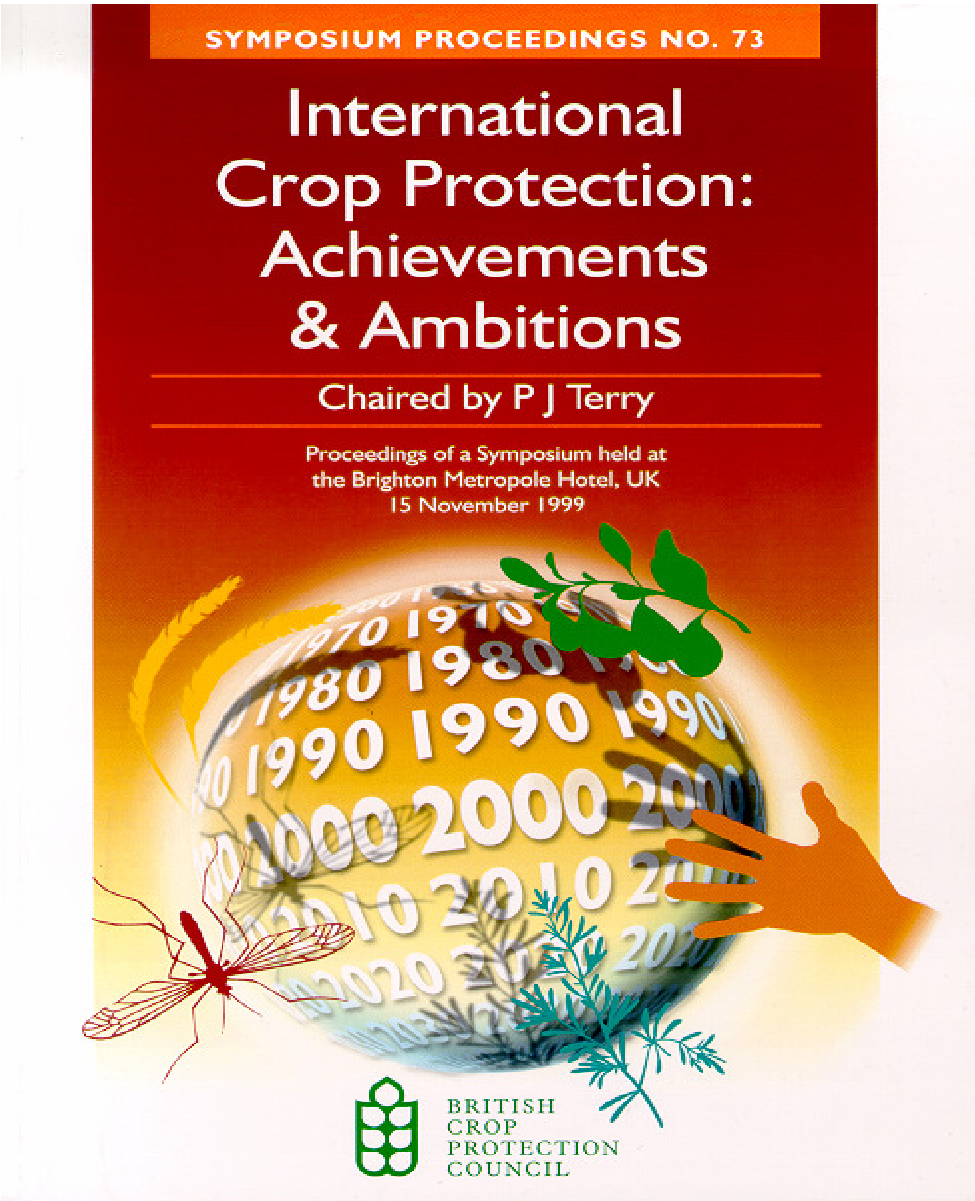
Vertisols and vertic clays represent a vast crop production resource (300 million hectares world-wide) that is underutilised, mainly because of problems with soil physical characteristics (particularly relating to water) and weeds. These montmorillonitic clays are generally more fertile and have higher water holding capacities than many tropical soils, but they are difficult to manage as they are very sticky when wet and hard and cloddy when dry. Research in Ghana has shown that it is technically possible to increase crop yields by 90% in normal wet seasons by using raised (camber) beds to control water, but further increases in yield potential are prevented by high populations of *Cyperus rotundus* L. and *Imperata cylindrica* (L.) Raeuschel. These challenges have been addressed by research on farms and on a research station to determine the effectiveness of glyphosate and camber beds for weed and water management and crop production in maize-based farming systems. Field trials have shown that tuber populations of *C. rotundus* could be reduced by 95% after glyphosate at 1.8 kg. a.e./ha was applied at the beginning of four cropping seasons during 1997 and 1998. The combination of glyphosate for weed control and camber beds to shed excess water produced maize grain yields of 3.5 t/ha - a significant increase over the typical yields of about 1.0 t/ha with traditional methods of hoe weeding on flat land. Economic evaluations have shown that the returns to small-scale farmers could be considerably increased by the use of glyphosate for weed control.

Introduction

Vertisols and vertic clays have generally not been regarded as a significant resource for food production because they are difficult to manage, being very sticky when wet and hard and cloddy when dry. These montmorillonitic clays, however, are generally more fertile and have a higher water holding capacity than many tropical soils. They represent, therefore, a vast underdeveloped crop production resource as it is estimated that there are about 308 million ha in the world (Coulombe et al., 1996), of which 90 million ha are in Africa (Willcocks & Browning, 1986), including 180,000 ha in Ghana (Ahenkora, 1995).

The development of effective management systems for Vertisols will make significant progress when the focus is on the control of water and weeds. 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 impact of precipitation and its damaging effects on crops. Options for managing Vertisols in Ghana were explored during a three-year project which showed that raised land forms gave superior crop yields to those obtained on traditional flat beds (Ahenkorah, 1995).

BCPC Symposium Proceedings No. 73, 1999



'How can the production potential of Vertisols and vertic clays contribute to the demand for more food ?'

Theo J Willcocks[1], Ed O Darkwa[2], B K Johnson[2], Ken Nyalemegbe[2], P John Terry[3] and Macarius Yangyuoru[2]

INTRODUCTION

It is estimated that there will be an additional two billion mouths to feed by the year 2025 and it is clearly evident that we are struggling to effectively feed the current global population of six billion. Members of the Tropical Agriculture Association (TAA) are aware of the challenges that we face in endeavoring to increase food production by at least 30% and to develop and implement strategies that will be more effective for the equitable distribution of food. Clearly we all have different roles to play in this global challenge and, in our quest to be more effective, we give due consideration to the factors affecting world food supplies, as summarized by Smith (1999), and the need to carefully evaluate the reliability of available data as highlighted by Young (1999). Such an approach should allow us to focus on those areas where we can make a meaningful contribution towards solving some aspects of these seemingly insurmountable problems.

Increased land area combined with improved production systems are urgently needed but where will we find the 'spare land' to grow and meet these vast food requirements? As far back as 1955, Kettlewell in Malawi reported: "All the good arable land and most of the second best is already under cultivation …. in a manner which is exposing it to erosion and depleting fertility". Research and development focus in agriculture has been on improving the productivity of high potential and marginal land areas and this has included projects to improve semi-arid and hillside crop production systems with the emphasis on traditional field crops.

Vertisols and vertic clays have generally not been regarded as a significant resource for food production because they are difficult to manage, being very sticky when wet and hard and cloddy when dry. These montmorillonitic clays, however, are generally more fertile and have a higher water holding capacity than many tropical soils. Therefore, they represent a vast underdeveloped crop production resource as it is estimated that there are about 300 million hectares in the world, of which 90 million hectares are in Africa (Willcocks & Browning, 1986). This paper refers briefly to some on-farm research and development work that is being undertaken in Ghana where there are about 180,000 hectares of these soils.

Paper submitted to the International Journal of Pest Management in 2000

Weed management on Vertisols for small-scale farmers in Ghana

(*Keywords: Cyperus rotundus*, Ghana, maize, gross margins, Vertisol)

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Abstract. Vertisols and vertic clays represent a vast crop production resource (300 million hectares world-wide) that is underutilised, mainly because of problems with soil physical characteristics (particularly relating to water) and weeds. These montmorillonitic clays are generally more fertile and have higher water holding capacities than many tropical soils, but they are difficult to manage as they are very sticky when wet and hard and cloddy when dry. Research in Ghana has shown that it is technically possible to increase crop yields by 90% in normal wet seasons by using raised (camber) beds to control water, but further increases in yield potential are prevented by high populations of Cyperus rotundus L. and Imperata cylindrica (L.) Raeuschel. These challenges have been addressed by research on farms and on a research station to determine the effectiveness of glyphosate and camber beds for weed and water management and crop production in maize-based farming systems. Field trials have shown that tuber populations of C. rotundus could be reduced by 95% after glyphosate at 1.8 kg. a.e./ha was applied at the beginning of four cropping seasons during 1997 and 1998. The combination of glyphosate for weed control and camber beds to shed excess water produced maize grain yields of 3.5 t/ha - a significant increase over the typical yields of about 1.0 t/ha with traditional methods of hoe weeding on flat land. Economic evaluations have shown that the returns to small-scale farmers could be considerably increased by the use of glyphosate for weed control.

1. Introduction

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The development of effective management systems for Vertisols will make significant progress when the focus is on the control of water and weeds. 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 impact of precipitation and its damaging effects on crops. Options for managing Vertisols in Ghana were explored during a three-year project which showed that raised land forms gave superior crop yields to those obtained on traditional flat beds (Ahenkorah, 1995). Camber beds, 4.8 m wide and 0.3 m high, were the most successful land form studied, increasing crop yields by 90% compared with flat beds.

Internal report, CABI Bioscience

Final Report of IIBC Component of NRIL Project ZA 0055

Reporting Period:	**April 1997 - March 1998**
Project Scientist:	**H. C. Evans**
Organisation:	**International Institute of Biological Control (Now incorporated into CABI Bioscience)**

Internal report, Natural Resources Institute

SMALLHOLDERS' ARABLE FARMING SYSTEMS ON VERTISOLS AND VERTIC CLAY SOILS IN GHANA

Willem E.T. Ellenbroek
George T-M Kwadzo
Irene S. Egyir

October 1997

Natural Resources Institute
Central Avenue
Chatham Maritime
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United Kingdom

Project C0965

WEED MANAGEMENT ON VERTISOLS FOR SMALL-SCALE FARMERS IN GHANA

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[1]University of Ghana Agricultural Research Station Kpong, Ghana, [2]Natural Resources for Development, Bedfordshire, UK and [3]IACR-Long Ashton Research Station, UK

1. Introduction

Vertisols and vertic clays are difficult to manage as they are very sticky when wet and hard and cloddy when dry. Research has shown that raised (camber) beds are beneficial for shedding excess water from Vertisols but *Cyperus rotundus* L. can be a problem on these land forms (Fig. 1). Repeated applications of glyphosate can be used to control this weed, so trials were done to compare its efficacy on flat plots and camber beds on Vertisols in the Accra Plains of Ghana.

Fig. 1. Maize infested with Cyperus rotundus

2. Materials and methods

Field trials were done on small-scale farms and a research station. Two land forms (camber beds and flat plots) and two weed control treatments (glyphosate and hand-weeding) were compared on plots arranged in a 2x2 factorial design. Camber beds were 4.8 to 5-m wide by 30-cm high. Glyphosate was applied to actively growing *C. rotundus* at a dose of 1.8 kg a.e./ha prior to planting maize at the beginning of the major rainy seasons in 1997, 1998 and 1999. Tuber densities of *C. rotundus* were determined to depths of 30-cm using 0.2-m^2 quadrats. Maize was harvested from areas of 48 or 50-m^2 within treated plots.

3. Results

After four seasons of glyphosate use, tubers of *C. rotundus* were reduced by 95% (Fig. 2).

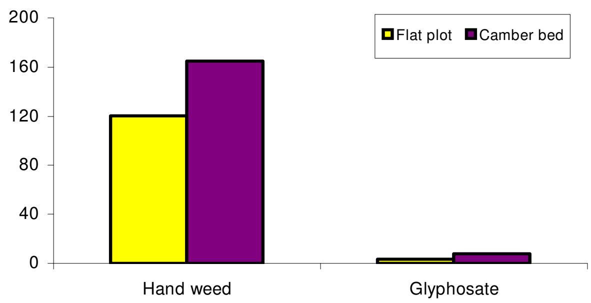

Fig. 2. Tuber densities per 0.2-m^2 after four seasons of glyphosate use

Mean grain yields of maize from the research station in 1998 and 17 on-farm trials in 1999 are shown in Fig. 3. They show the negative effect on yield of camber beds in poor rains (38% below average) in 1998 compared with yields in a season of normal rainfall in 1999. In both years, grain yields were significantly higher where glyphosate had been used to control *C. rotundus* and other weeds.

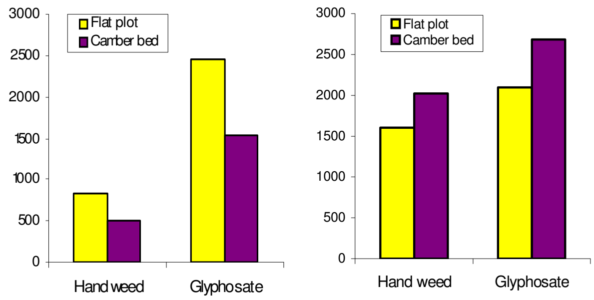

Fig. 3. Maize yields (kg/ha) on research station in 1998 (left) and farms in 1999 (right)

The profitability of growing maize was determined from a model that integrated input costs with the value of the crop (Fig. 4). Gross margins are shown for three types of farmer: (a) low-input farmer, i.e. a farmer with little cash who uses family labour, (b) medium-input farmer, i.e. a farmer who can make modest purchases of inputs, and (c) high-input farmers who grow maize on a semi-commercial scale.

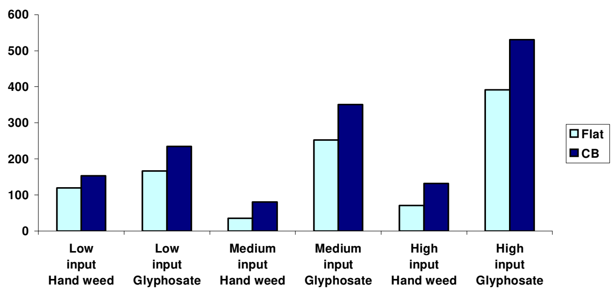

Fig. 4. Gross margins (US$/ha) for three types of farmer

4. Summary

Camber beds increased maize yields on Vertisols in a normal wet season but reduced yields, compared with flat plots, when rainfall was well below average. Glyphosate applied in four cropping seasons reduced tuber densities of *C. rotundus* by 95% and increased crop yields. Gross margins for using glyphosate in combination with camber beds was US$530/ha/year for high input farms.

5. Acknowledgements

This project (R6737) was supported by funds from the UK Department for International Development.