USE OF LOW DOSAGE PENDIMETHALIN IN COMBINATION WITH SUPPLEMENTARY WEEDING IN MAIZE (*Zea mays* L.) AND BEAN (*Phaseolus vulgaris* L.) INTERCROP.

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A thesis submitted in part fulfilment for award of the degree of Master of Science in Agronomy in the University of Nairobi.

1984.

DECLARATION:

I declare that this thesis is my original work and has not been submitted for a degree in any other University.

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This thesis has been submitted for examination with my approval as University supervisor.

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ABSTRACT:

Field trials were designed to determine the effect of various weed control methods in maize (*Zea mays* L.) and bean (*Phaseolus vulgaris* L.) intercrop. Pendimethalin herbicide was applied at three rates i.e. 1.5, 1.0 and 0.5 kg a.i./ha on maize and bean intercrop, to determine the degree of weed control and herbicide injury on the crops. The two lower rates were combined with one supplementary weeding each, to determine weed control, reduction on weeding time and cost. Manual weed control methods were included to help compare the net monetary benefit of each weed control method. Other cropping systems namely sole maize and sole beans were studied to determine the effect of intercropping on weed control and crop yields.

According to this study, intercropping maize and beans showed no consistent effect on weed suppression, although it yielded the lowest weed dry matter of the three cropping systems. Intercropping maize and beans suppressed bean yield by 486.3 kg/ha in the short rains and 735.7 kg/ha in the long rains, but in terms of monetary benefit, was the prefered cropping system.

There were marked differences between weed control treatments. Application of pendimethalin

at 1.5 kg a.i./ha caused deformation and stunted growth on beans, often in localised spots. Both low rates, 0.5 kg a.i./ha and 1.0 kg a.i./ha, did not cause any herbicide injury on beans and did not control any of the prevalent weed species. Combined with one supplementary weeding each, however, they effected better weed control than pendimethalin alone at 1.5 kg a.i./ha.

The two low rates; 0.5 kg a.i./ha and 1.0 kg/ha combined with supplementary weeding reduced weeding time by 20.1, 21.3 man-days/ha in the short rains and 11.5, 15.2 man-days/ha in the long rains, respectively and achieved about the same degree of weed control as two hand weedings. They further reduced cost of weed control by 15.2, 8.9 US$/ha in the short rains and 9.0, 1.3 US$/ha in the long rains compared to two hand weedings, but raised cost by 3.4, 9.7 US$/ha in the short rains and 8.4, 12.2 US$/ha in the long rains compared to chemical control with pendimethalin at 1.5 kg a.i./ha. Results were, however, not consistent in the two seasons, suggesting a seasonal influence, particularly amount of rainfall received soon after application of herbicide.

The use of low dosages of herbicide plus supplementary weeding compared vary favourably with two hand weedings, the cultural method of weed control, in net benefit. They both gave higher monetary benefit than both use of herbicide alone at normal rate i.e. 1.5 kg a.i./ha and a single hand weeding. Of the two low rates, 0.5 kg a.i./ha plus a supplementary weeding was to be prefered as it gave a higher net benefit.

The use of low dosages of herbicide combined with a supplementary hand weeding in this study, as in other studies, provides an alternative method of weed control. It reduces labour requirement and cost of weed control, at the same time, gives a comparable net income to the cultural method of weed control.

I dedicate this work to my parents; my father, Misairi Obuo and my mother, Serida Itenu.

ACKNOWLEDGEMENTS

I am very grateful to the University of Nairobi for providing land on which this work was done. My sincere thanks go to my supervisor Dr. R.W. Michieka for his guidance and useful criticisms he so readily offered throughout this work. I am also grateful to Kleenway Chemicals who so kindly provided the herbicide used.

I offer my profound gratitude to the International Development Research Centre (IDRC) without whose financial support under their Fellowship Programme, this work would never have become a reality. My sincere gratitude too, goes to Prof. D.N. Ngugi, Dean, Faculty of Agriculture and Chairman, Department of Crop Science and Mr. Vincent Makumbi-Zake, Officer-in-Charge, Sorghum and Millets Unit, Serere, whose combined efforts enabled me to get the award. To them, I shall always be grateful.

Last, but not least, I thank all my friends especially Mr. Morris Ogenga-Latigo for all his help when I was in dire straights, Ms K.P. Sibuga, for all her unfailing help and advice. I thank Jane N. Mbugua for her patience in typing the thesis, and all those who assisted me in one way or other, whom I cannot mention by name.

INTRODUCTION

Intercropping is especially attractive to the small scale farmer for the sound reasons of income maximization and risk aversion. Advantages of intercropping over sole cropping can be identified as higher yields in a given season. It also gives greater stability of yields over different seasons. Higher yields in a given season are thought to be due to better use of resources and less incidence of pests, diseases and weeds. Some of the most common food crop mixtures grown in Kenya today are maize (*Zea mays* L.) and beans (*Phaseolus vulgaris* L.). Beans,often the minor crop of the intercrop is interplanted either on the same date, the maize is planted or after the latter, the main crop, has germinated. Economic constraints in the production of these crops are often land and labour. Interplanting is a wide spread response to the problem of these constraints. In the high rainfall areas farmers can produce a bean crop in addition to maize without much additional labour.

Weed control is one of the most expensive agronomic inputs facing farmers, and more human effort is devoted to weed control than any single activity. The problems that have been associated with weed control are shortage and cost of labour. Considering the fact that early planting is advocated, large areas are ready for weeding within a short space of time. This problem is compounded by the fact that the climate is highly seasonal in the tropics and all crops have to be planted in this short space of time. At the start of the rainy season, rains are intense, hence delaying time of weeding until effects of weed competition have been felt. Effects of delayed weed control on crop yields are well documented. The small-scale farmer, whose only source of labour is mainly his family, is frequently unable to carry out timely or proper weed control. This delay in weed control often leads to loss of crop yields. Often the farmer is able to manage only one late weeding.

Manual weeding is the most often employed for weed control. Manual weeding includes hand pulling of weeds and hoe weeding. Hoe weeding is the method used by most farmers and is very labour and time intensive. Hoe weeding is only economical where labour is abundant and is only effective where weeding frequency is minimal and the area to be weeded is small. To remove this constraint, a lot of work is being done to investigate the possibility of using chemical weed control. Unfortunately, chemical control requires skill and accuracy to apply the right herbicide at the right time and dosage, which many peasant farmers lack. Use of herbicides for weed control, however, has not taken a strong hold, due to the low value crops grown. At the low yield levels prevailing, few herbicides are economically suitable.

In intercropping, a further problem arises in the use of chemical control. Herbicides are often crop specific and few herbicides are technically suitable. It has so far been difficult to find herbicides that will control a broad spectrum of weeds without causing damage or injury to one or both of the crops in the intercrop. Herbicides investigated so far in maize and bean intercropping have been tolerated by maize but injurious in varying degrees to beans. Beans are very sensitive to several groups of herbicides particularly if applied at high rates.

The ability of the present day small-scale farmers to apply herbicides at the correct dosage and time is doubtful. The crops that are grown are of low value and the yields obtained are often low. There is an increased tendency by farmers to intercrop maize and beans. Beans are sensitive to herbicide injury and are an important crop in the intercrop. Considering the aforegoing circumstances, full use of chemical weed control in intercropping is not easy, both technically and economically.

This study was therefore undertaken to investigate the possibility of using pendimethalin at half its recommended dosage or even less combined with supplementary manual weeding to reduce:

a) risks of toxicity due to high dosage,

b) weeding cost, and

c) weeding time.

Further, the study was aimed at carrying out a cost analysis in terms of man-day requirement per hectare and cost of herbicide to determine the profitability of such a method of weed control as compared to manual weeding or chemical weed control alone.

LITERATURE REVIEW:

Probably the most common food crop mixtures in Kenya today are maize and beans (Laycock and Allan, 1974). According to Schonherr and Mbugua (1976), an estimated 70% of the acreage is planted in a mixture of maize and beans, and 80% of the maize is inter planted with mainly dry beans (Njeru and Kihumba, 1981). Advantages of intercropping maize and beans are well documented. In Kabete, maize yields of 2.29 t/ha and 2.22 t/ha and bean yields of 1.34 t/ha and 0.29 t/ha were obtained in pure and mixed stands respectively in the long rains of 1976 (Fisher, 1979). Yields obtained by the small scale farmers could easily be doubled by application of improved husbandry practices, especially better weed control (Laycock et. al., 1974).

The weed problem. Subsistence farmers of the tropics spend more time and energy on weed control than on any other single aspect of crop production (Terra, 1959; Kasasian, 1971; Shetty, 1979). Hand weeding, the most commonly used method for weed control, is only economical where labour is abundant, and is only effective where weeding frequency is minimal and the area to be weeded is small (Akobundu, 1978b). In some countries, such as Kenya and Nigeria (Laycock, 1974; Akobundu, 1978a), farm labour is often hard to find, and too expensive for routine farm operations. According to Young, Miller, Fisher and Shenk (1978) and Wetala (1978), manual weed control absorbs 20-50%, or higher, of the total labour requirement for crop production within traditional agricultural systems. According to Basler (1978) at International Centre of Agricultural Research for Dry Areas, ICARDA, manual weeding requires at least 60 man-days per hectare for the minimal two weedings required. In Kenya, a maize/bean intercrop requires 340 man-hours per hectare for two weedings (Anon. 1982).

The favourable temperature and light regimes in the humid tropics not only provide a scope for multiple cropping but also favour rapid multiplication of weeds. Weeds depress yields by competing for growth resources; light, water, mineral nutrients and space (Ashby and Pfeiffer, 1956; Donald, 1963). The effect of weeds on bean production can be very severe. Losses of 50% to 80% have been reported from various countries. Nieto, Brondo and Gonzalez (1968) in Mexico reported a loss of 98%. In trials carried out in Kenya, bean yield losses of various intensities were recorded, and average loss of about 40% compared with hand weeded control was found (Anon. 1974a; 1974b). Losses in mixed stands with maize are of the same order. Nieto et. al. (1968) reported that season long weed infestation reduced maize yields from a potential of 4770 kg/ha to 382 kg/ha. Crops are able to compete with weeds better if they establish quickly and if weed control is effected on time. Whether weeds take over the crop or the crop smothers weeds, the interference of weeds depends upon the farmer's managerial ability of the crop-weed balance (Rao and Shetty, 1977).

Effect of delayed weed control:

Weed competition leads to reduced crop yields (Ngugi and Kinyanjui, 1978; Allan, 1974). In Kenya as elsewhere in the tropics rainfall is highly seasonal. Most crops have to be planted within a short period of time, early in the rainy season (Parker and Fryer, 1975). The otherwise abundant labour is fully stretched in land preparation, planting and weeding operations. According to Langeman (1977), in parts of Eastern Nigeria, 60% to 80% of the total field work is carried out during the first four to five months of the year corresponding to the early rains. He also showed that 90% of the labour hired by farmers for weeding and clearing was in the early rains. Rains are often intense at this early period, making hoeing difficult and ineffective, if not impossible. Rarely are weeds removed at the optimum time, within the first 10 to 20 days, and may not be completed until 30 days or more (Parker and Fryer, 1975). In many cases farmers have to hire labour. Sometimes this labour is not hired in time, resulting in increased weed growth so that ultimately extra labour and therefore cash for weeding is needed (Versteeg and Maldonado, 1978). Druijff and Kerkhoven (1970) observed that weeding delayed by one week, increased the initial weed growth six-fold in irrigated cotton and doubled the initial labour demand. A three week delay in weeding increased the initial weed growth thirty fold and quadrupled the initial labour demand to 30 man-days per hectare. Allan (1974), working on maize in Kitale reported that unweeded plots in 1967 and 1970 gave 33% and 31% less yields respectively than clean plots. He attributed this reduced effect of weed competition to an abundance of growth factors, mainly moisture and nutrients. De Groot (1979) reported average losses in bean-maize mixtures of 40%, similar to single stands. Nieto et. al. (1968) found that when weeding was carried out one month after planting, yield reductions of 25% in maize and 53% in beans resulted. At the National Horticultural Research Station, Thika, the critical period of weed competition in maize-bean mixtures has been established at 10-20 days after emergence, while weeding 30 days after this period did not seem to increase yields. Work at Kakamega, Kisii, Thika, Katumani and Embu has shown that grain yields were influenced by the time of weeding, however, no critical periods have been conclusively determined. The general trend was in favour of early weeding for maximum yields. At Katumani, if weeds were not controlled at an early stage, the crops suffered to such an extent that even modest yields were not obtained (Anon. 1975). Time of execution was, therefore, the most significant aspect of weed control in terms of both yield and labour.

Alternative weed control methods. Miller (1976) reported that manual weed control was most economical and efficient in areas of labour abundance and on small farms with limited capital and training. However, various workers (Laycock, 1974; Akobundu, 1978 a) have reported the increasing unavailability and cost of labour in countries like Kenya and Nigeria for routine farm operations like weeding. Increased crop losses therefore in such countries is likely. The use of herbicides is potentially one of the most labour saving innovations and chemical control is the most commonly proposed alternative to traditional hand weeding in developing countries (Hammerton, 1974; Moody, 1975). Mathews (1978) reported that the use of an effective herbicide was equivalent to many man-days of hand weeding. The advantages of chemical weed control in increasing yield and decreasing labour costs in the tropics have been demonstrated (Furtick, 1970; Parker, 1972).

Introduction of chemical weed control as a complete replacement of manual weed control, for the small scale farmer, has been viewed, however, with skeptism. Chemical weed control has been reported as more expensive for the tropical small holder (Druijff and Kerkhoven, 1970). The ability of peasant farmers to apply herbicides correctly at the right dosage and time has also been doubted

(Young *et. al.*, 1978). Druijff *et. al.* (1970) also mentioned the danger of creating the more severe problem of herbicide resistant weeds.

Selected herbicides need testing with other weed control methods to develop alternative methods that are economic and feasible (Moody and Shetty, 1979). Miller (1976) and reports from International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, 1976) report a significant reduction in labour requirement for weeding and increased effect on weed control when pre-emergence herbicides are combined with hand weeding. Versteeg and Maldonado (1978) reported trials conducted in 1975 and 1976 to test the possibility of using pre-emergence soil applied herbicides at half or less than half the recommended doses with a view to support, rather than replace, manual weeding by small holders. The results showed that weed growth, before supplementary weeding, in all low dosage treatments was far less than in manually weeded plots and only slightly more than in normal dosage plots. Some problem weeds were not killed by herbicide but their initial development was less aggressive than in manually weeded plots, and so, the farmer had more time to eliminate them with supplementary weeding. The low dosage gave the farmer some protection against crop damage due to weed growth during the initial critical phase. On average the combined method with low dosage rates produced yields of the same magnitude as the other weed control methods. The labour requirements and costs also demonstrated that there were some advantages for the farmers of the combined system. Weeding costs were reduced by about 40% as compared to hand weeding or herbicide application at recommended rates. Similar results have been reported by Jennings and Drennan (1979), and ICRISAT (1976). In the highly seasonal conditions prevailing in the tropics, hand weeding cannot be done effectively on time, due to the intense rains at the start of the rainy season. On such cases chemicals can be of tremendous value as they would suppress the initial weed growth. Ogborn (1976) stated that practical application of herbicides should be to increase the maximum hoeing interval instead of replacing hoeing completely. Results he obtained indicated that pre-plant herbicide application, supplemented with hoe weeding, can reduce the effort required for weed control from 670 to 440 man-hours per hectare (Ogborn, 1978).

Weed control in intercropping. One reason that has been advanced to explain the tendency of farmers to intercrop is weed suppression. Intercrop combinations may require less weeding inputs (Moody and Shetty, 1979) than their sole crops. They indicated that the increased crop density in the intercrop resulted in greater competition against weeds and thus reduce the need for weeding. Mugabe, Sinje and Sibuga (1980) have reported similar findings. Experimental evidence, however, has tended not to always support the statement that intercrop combinations require less inputs for weed control (Norman, 1974)

Enyi (1973), stated that the more complete cover provided by intercropping reduced weed growth. This observation has been supported by other workers (Watters, 1971; Webster and Wilson, 1966). Mugabe et. al. (1980) reported that intercropping resulted in less harvestable weed dry matter than monocropping. This reduction in weed growth resulted in a reduction in the amount of labour required for weeding. Cleave (1974), reported that cropping systems may have evolved specifically to minimise the labour cost of weed control. It has generally been noted that intercropping prevents usurpation of space by weeds and instead substitutes a profitable crop. Moody (1978) observed that the growing of a number of crops in close proximity to one another, so that plant density is greater than in sole cropping, should result in greater competition against weeds, and reduce the need for weeding. However, he further noted that if the plant density of the crop is the same as for the component crops when grown singly or if both are planted at their optimal densities, there may be little advantage with respect to weed suppression from intercropping. Weed growth in the intercrop may be as great as in any other pure crops (Damodaran and Sankaran, 1974). In intercropping the total canopy, at any time,was found to be higher than in sole cropping and the ground was covered quickly due to the simultaeneous growth of two or more crops. The larger canopy thus obtained competed better for inputs, creating an environment unfavourable for weed growth (Rao and Shetty, 1977).

In Nigeria, a common practice is for farmers to sow cowpeas [*Vigna unguiculata* (L.) Walp.] into established sorghum [*Sorghum bicolor* (L.) Moench], pearl millet [*Pennisetum glaucum* (L.)

R. Br.⁄ or maize (_Zea mays_ L.) during weeding, about a month after the cereals have emerged. According to Summerfield, Huxley and Steele (1974) the spreading canopy of the cowpeas competed effectively with the weeds and made further weeding unnecessary. Moody (1977) reported that farmers in the Philippines intercrop Mexican yam beans (_Pachyrrhizus erosus_ Rich.) with maize, sowing at the same time. Weed growth can be greatly reduced in the intercrop and weeding frequencies may be reduced. In trials carried out in the Philippines (Castin, San Antonio and Moody, 1976) and Indonesia (Mahyuddin, Azzirin and Ponidi, 1976), the weight of weeds growing with the intercrop was reported to be lower than that of those growing with the sole crop. Bantilan, Palada and Harwood, (1974) and Mahyuddin _et. al._ (1976) reported that the level of weed control had little effect on the grain yield of maize when it was intercropped with mung bean [_Vigna radiata_ (L.) Wilczek]. The enhanced competition against weeds accounted for the higher yield of maize in the intercrop than in the sole crop, and the land equivalent ratios were highest under unweeded conditions. Castin _et. al._ (1976), however, observed the opposite.

At ICRISAT, intercropping of pigeon peas and sorghum reduced weed growth to an extent of 50-70% (Rao and Shetty, 1977). They further noted that within an intercrop, system, row arrangement patterns did not significantly influence the weed infestation. However, in earlier results (ICRISAT, 1978) planting more groundnut (Arachis hypogea L.) rows between pearl millet increased weed infestation in the intercrop. Hart as quoted by Moody and Shetty (1979), reported that there were no statistically significant differences in the total dry matter production from all the cropping systems that he studied. Weeds constituted 20%, 25% and 83% of the total biomass in maize, cassava (Manihot esculenta Crantz.), and bean sole crops respectively. These figures were reduced to 16% when the crops were intercropped.

The intercrop combinations need not necessarily lead to a reduction of weed weights to less than in the crops grown separately. Jereza and De Datta (1976) observed that despite a 40% reduction in weed weight in intercropped maize and mung bean, compared with the sole cropped maize, weed competition was so great in the intercrop that no yield was obtained. In Colombia, Centro International de Agricultura Tropical, CIAT (1976) there were fewer weeds growing in sole-cropped bean than in intercropped bean and maize. There were, however, more weeds in sole cropped maize than in the intercrop. Morales and Doll (1975), observed more broad leaf weeds growing in association with maize/bean intercrop and sole cropped maize than in sole cropped bean, the bean being a more effective competitor. However, in all crop combinations, only one weeding was needed for productive yields. According to Kass as quoted by Moody and Shetty (1979), the evidence for better weed control with intercropping was indirect. He further added that intercropping provided a farmer with a more effective means of utilizing resources, especially if weeding was not practiced.

Whether weed weight decreases or weed control is enhanced in intercropping depends on many factors including component crops, crop cultivars, plant population, spatial arrangement and soil fertility (Moody and Shetty, 1979; Bantilan et. al. 1974). Akobundu (1978b) states that appropriate modification of plant population and spatial arrangement have long been recognised as good weed control strategy.

<u>Weeding requirement in intercropping.</u> Moody (1978) stated that though certain crop combinations may cause a reduction in weed weight compared to the component sole crops, there was still a need in most cases to do some weeding, so that weeds present did not cause, yield reductions. According to Norman (1974) it is assumed in literature, without empirical evidence, that growing crops in mixtures resulted in a saving in labour. He further added that such reasoning has been based on the premise that weeding was less critical in intercropping. Accordingly it was assumed that intercrop combinations require less inputs for weed control. Similarly Belshaw (1979), noted, especially in row crops, that mixed cropping leads to lower labour requirements by bringing quick vegetation cover, which smothers weeds. On the other hand, Day , as cited by Moody and Shetty (1979), stated that the need for weed control in intercropping was as great as for sole cropping.

Owuor (1976), reported that significantly less labour input was required for planting and weeding operations in the pure maize stand compared with pure beans or intercropped maize and beans. According to Moody (1978), when one row of mung bean or cowpea was intercropped with one row of sorghum, no yield response to weeding was observed. However, for the sole crops and when two rows of either of the legumes were intercropped with one row of sorghum, one weeding was needed to obtain yields that were not significantly different from the weed free check. Syarifuddin, Soeharsono and McIntosh (1975), reported that it took less time to weed crops grown in intercrop combinations than when the same crops were grown sequentially as sole crops. De Groot (1979),reported that the critical period of weed competition in the intercrop was longer than in the sole crop, so that weeding operations had to be continued for a longer period of time to obtain optimum yields.

In CIAT (1976), in sole and intercropped maize and beans, one weeding was needed to give adequate control even though fewer weeds occured in the intercrop as compared to the sole cropped maize. Therefore in terms of the number of weeding operations needed, there was no advantage for intercropping. In Northern Nigeria intercrops required 29% more labour input during June-July, the peak weeding period, than sole crops (Baker and Norman, 1975).

Chemical weed control in intercropping. In intercropping a further complication in the use of chemical weed control arises. Herbicides are often crop specific, thus it has been difficult to find compounds that will control a broad spectrum of weeds without causing damage to the component crops in the intercrop combinations (Moody, 1978). The spatial arrangement of the different crops makes chemical control of weeds difficult. The same author noted that as the number of crops that tolerate a herbicide increase, so must the number of weeds that are not controlled. Technical considerations therefore severely restrict herbicide utilization in intercropping. However, Akobundu (1978b) has shown that chemical weed control is possible in mixed cropping systems and that intercropping offers an opportunity for using low dosage of herbicides to minimise early weed competition and hand weeding to control the late germinating weeds is necessary. Moody and Shetty (1979) reported that some herbicides have been identified that were suitable for use in simple crop associations. They further added that herbicide studies in intercropping should be concerned with reducing the cost of herbicide or manipulating the rate and method of application. Inspite of the fact that some advances have been made in chemical control of weeds in intercropping, generally the technology has not been adopted by farmers. Reasons advanced are unavailability of the recommended herbicides, cost, and application difficulties. Miller (1976) reported that utilizing mechanical cultivation of herbicides appeared less satisfactory for intercropped maize and bean, than for the same crops when grown separately. Problems associated with intercropping were, plant and row spacing in the intercrop, scarcity, and high cost of herbicide possessing acceptable selectivity for both crops.

In Colombia (CIAT, 1974), excellent weed control has been obtained in a maize-bean intercrop with a mixture of linuron [3-(3,4-dichlorophenyl)-1-

methoxy-1-methylurea/ and alachlor /2-chloro-2', 6'-diethyl-N-(methoxymethyl) acetanilide/, when applied alone or in combination at high rates. In another trial (CIAT, 1976) in which beans were intercropped with maize two weeks after application of pre-emergence herbicides to the maize, acceptable grass control was achieved with using chloramben /3-amino-2, 5-dichlorobenzoic acid/at 3.0 kg/ha, fluorodifen /p-nitrophenyl α,α,α - trifluoro-2-nitro-p-tolyl urea/at 3.5 kg/ha, dinitramine /N^4, N^4-diethyl-α,α,α-trifluoro-3, 5-dinitrotoluene-2, 4-diamine/at 0.75 kg/ha, Hercules 22234 /N-chloroacetyl N-(2,6-diethylphenyl) glycine ethylester/, at 3.0 kg/ha pendimethalin /N-(1-ethylpropyl)-3,4-dimethyl-2,6-dinitrobenzenamine/, at 1.5 kg/ha, trifuralin (α,α,α-trifuoro-2,6-dinitro-N, N-dipropyl-p-toluidine) at 1.5 kg/ha, butralin /4-(1,1-dimethylethyl)-N-(1-methylpropyl)-2, 6-dinitrobenzenamine/ at 1.5 kg/ha and linuron at 1.0 kg/ha. The herbicides used were slightly less effective in the control of broadleaf weeds than grasses. No bean or maize injury was observed. Butachlor /N-(butoxymethyl-2-chloro-2', 6'-diethylacetanilide)/ applied pre-emergence has been used successfully in maize/mung bean intercropping (Castin et. al., 1976) but it controlled only 35% of the broadleaf weeds. According to the same authors, butralin failed to control any of the broadleaf weeds and controlled less than 50% of the grasses in a maize/mung bean intercrop. In India, alachlor applied at 1 kg/ha gave 85% weed control when sorghum or maize were intercropped with cowpea and hyacinth bean [_Lablab purpureaus_ (L.) Sweet] (Damodaran and Sankaran, 1974). In a maize/pigeon pea intercrop, alachlor gave excellent control of weeds initially but retarded pigeon pea growth up to 4 months after treatment, however, the crop recovered later in the season (ICRISAT, 1977).

In experiments carried out at Thika, Embu and Katumani stations, pendimethalin had a slight effect on beans at emergence and some crop damage was observed especially in the dry region (De Groot, 1979). Michieka (1981) found that pendimethalin at 2.5 kg/ha gave good weed control in maize/bean intercrop. He however noted that it was weak on _Bidens pilosa_. He further noted a slight vigour reduction on beans though the bean later outgrew the injury. Other chemicals tried included linuron and combinations of metobromuron [3-(p-bromophenyl)-1-methoxy-1-methylurea] and metolachlor. Linuron effected good control of all weeds but extensive bean injury was observed.

To reduce the injurious effects of herbicides on one or both of the component crops in intercropping, the use of lower rates of herbicides has been suggested (Moody, 1977). At ICRISAT research oriented towards reducing herbicide application rates and costs compared the effects on crop yields of band application of pre-emergence herbicide followed by one hand weeding. On a sorghum and pigeon pea intercrop and a sole maize crop, terbutryne [2-(tert-butylamino)-4-(ethylamino)-6-(methylthio)-s-triazine] applied at 0.3 kg/ha in a 15 cm band over the crop rows performed at par with weed free treatments. In other field experiments, application of either atrazine [2-chloro-4-(ethylamino)-6-isoprophylamino)-s-triazine] or propazine [2-chloro-4-6, bis (isopropylamino)-2-triazine] at 0.5 kg per ha, on sorghum followed by one late hand weeding were significantly superior in efficiency and selectivity than either hand weeding or herbicides alone. These treatments also recorded highest net returns per unit area, (Sankaran and Mani, 1974). Moody and

Shetty (1979) cautioned that although crop combinations have fewer weeds, a certain rate of herbicide is needed for weed control, regardless of the number of weeds that are present. Below such a level, weed control is greatly reduced or not achieved.

The literature review shows that hand weeding in intercropping is as much as in sole cropping or even more. Intercropping effects on weed control may only be indirect. The literature review further shows that some limited initial work has been done to identify herbicides that could be used in intercropping. Attempts to apply herbicides separately as band applications on to each of the crops in the intercrop or to plant sensitive crops after application of herbicide to overcome the toxic effects of herbicides on the sensitive crops have proved not practical. Although limited progress has been made, compounds that can be used effectively on a broad range of crops are not available. Those that have been identified have not been adopted by the farmers. Reasons given include the cost of the herbicides involved, unavailability of the recommended herbicides and application difficulties.

Taking into account the low economic value of the crops commonly intercropped i.e. maize and beans, the cost of such herbicides make chemical control not economically attractive. At the same time labour is rapidly becoming scarce and expensive often leading to losses in yield. An attempt is therefore being made here to investigate the possibility of applying less than the recommended dosage of herbicide to reduce cost and minimise crop injury. This is also aimed at suppressing weeds long enough to enable the farmer spread his limited labour without risk of reduction in yield due to delayed weed control.

<u>Mode of action</u>: Pendimethalin herbicide inhibits both cell division and cell elongation in shoot and root meristems of susceptible plants. Growth is inhibited directly following absorption through the shoot (Monocotyledoneae) or through

the hypocotyl or hypocotyl hook (Dicotyledoneae). Affected plants die shortly after germination or following emergence from the soil. Germination per se is not inhibited. Specific literature on toxicity of pendimethalin on either beans or maize was not available.

Toxicology[1]: Both the technical and formulated products have a low acute and chronic mammalian toxicity. The acute oral LD_{50} for emulsifiable concentrate (500 g a.i./litre) in male and female rats is 2544 mg/kg body weight. It is practically nontoxic by skin application, with LD_{50} value being >5000 mg/kg body weight. The product is therefore safe and routine precautions are adequate.

Chemical degradation in the soil is primarily through nonbiological chemical reactions. Length of persistence in the soil will vary according to climatic conditions, particularly temperature and moisture. Generally a period of at least three

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[1] Toxicology is obtained from the manual "Stomp Herbicide" by American Cyanamid Company, Wayne, New Jersey.

months is required before sowing or resowing a sensitive crop following treatment of the soil with pendimethalin.

MATERIALS AND METHODS:

This study was conducted at Kabete, Faculty of Agriculture, University of Nairobi at an altitude of 1815 M. The study was divided into two experiments; I and II, both planted in the short rains of 1982 and the long rains of 1983.

EXPERIMENT I: Effect of cropping system on weed control method: The aim of this experiment was to investigate three weed control methods on three cropping systems. The weed control methods were; manual weeding using hand hoes, chemical control and integrated control, a combination of low dosages of herbicide with supplementary hand weeding. The three cropping systems were sole bean, sole maize and intercropped maize and beans.

The experimental design was split plot. The three cropping systems formed the main plots and six weed control treatments, derived from the three weed control methods, constituted the sub plots. Main plots measured 18 m x 9 m and sub plots measured 6.0 m x 4.5 m. Maize (var. Katumani composite) was planted at the recommended spacing of 75 cm x 30 cm and beans (var. Rose coco small) was planted at the spacing of 37.5 cm x 15.0 cm in sole bean cropping. Maize and beans, both in the intercrop and in pure stands, were planted on the same day. The spacings gave plant populations of 44,000 per hectare in sole maize and 176,000 per hectare in sole beans. In intercropping a full maize and half bean populations were obtained giving a combined plant population of 132,000 per hectare.

Six weed control treatments were imposed on each of the three cropping systems and applied to the sub plots. Ordinary hoes were used in manual hand weeding of relevant plots. The first weeding was at two weeks after crop emergence, this was in accordance with a survey conducted in the Central and Eastern Provinces of Kenya where two thirds of the farmers begin weeding maize and beans two weeks after crop emergence (Schonherr and Mbugua, 1976). According to the same survey, farmers weed maize and beans twice during the season. A second weeding for treatments requiring two weedings was done four weeks after the first weeding.

In chemical and combined use of herbicide at low dosage rates with supplementary weeding, pendimethalin 500 E, was applied pre-emergence. This herbicide was chosen for its good weed control both in maize and beans. A Cooper-Peglar (CP 3) knap sack sprayer with a water delivery of 250 litres per hectare was used for spraying of herbicide. In manual weed control and combined use of herbicides at low dosage rates with supplementary weeding, hoes of roughly similar width and weight were used for hand weeding. Workers were assigned to individual sub-plots at random to take care of individual worker variation. Time taken to weed each sub-plot in minutes was recorded and converted to hours required per hectare and days per hectare. These were termed man-hours and man-days per hectare respectively. One man-day was taken as equivalent to eight man-hours. Length of time required for application was determined by repeatedly spraying water over a specified area at uniform speed. The mean length of time was converted into hours per hectare. An addition of 20% of the spraying time was made to account for the time required for refilling of sprayer tank and resting, this was the total spraying time and was assumed constant for all herbicide treated plots. In combined use of low dosages of herbicide with supplementary weeding, this spraying time was added to the weeding time to obtain weed control time.

Cropping systems included:

A. Sole beans
B. Sole maize
C. Intercropped maize and beans.

Weed control treatments included:

1. 0.5 kg active ingredient (a.i.) pendimethalin/ha + one hand weeding.
2. 1.0 kg a.i. pendimethalin/ha + one hand weeding.
3. 1.5 kg a.i. pendimethalin/ha.
4. One hand weeding only.
5. Two hand weedings (CONTROL I)
6. No weed control (CONTROL II).

Trisuperphosphate (TSP) fertilizer was applied at the recommended rate of 200 kg/ha in beans and intercropped maize with beans, and 100 kg/ha in maize, to give 40 kg/ha and 20 kg/ha of elemental phosphorus per hectare, respectively. Calcium Ammonium Nitrate, CAN, was applied to only maize in sole maize cropping and in intercropping at the recommended rate of 190 kg/ha to give 40 kg/ha of nitrogen per hectare.

During harvest, all bean rows in sole beans were harvested only leaving four guard rows and one metre at either end of the sub plot. In intercropping, four guard rows, two rows each of beans and maize and one metre at each end of the sub plot were discarded, and in sole maize, two guard rows plus one metre at each end of the sub plot were discarded. In each of these cropping systems, the effective harvest area was 12 sq. m. (4m x 3m). After harvesting maize and beans, grain yield was calculated as kilograms per hectare at 12% and 13% moisture content for maize and beans, respectively.

EXPERIMENT II: Effect of planting pattern on weed control method:

to study the effect of two plant planting patterns in intercropping as an aid to weed control. Two spatial arrangements and three weed control methods were studied. The spatial arrangements composed of: One row of beans between rows of maize i.e. maize, beans, maize, beans (M-B-M-B); and two rows of beans between rows of maize i.e. maize, beans, beans, maize, beans, beans (M-BB-M-BB). Both of these spatial arrangements gave a full maize and half bean populations.

Experimental design was split plot. The two spatial arrangements formed the main plots and six weed control treatments formed the sub plots. The main plots measured 12.0 m x 9.0 m and the sub plots 4.0 m x 4.5 m. As in the first experiment, maize (var. Katumani composite) and beans (var. Rose coco small) were planted. The spacing for maize remained the same as in Experiment I, at 75 cm x 30 cms, but the spacing for beans varied as follows: in M-B-M-B arrangement, the bean spacing was 75.0 cm x 15.0 cm and in M-BB-M-BB arrangement, the spacing was 37.5 cm x 30 cm. These different bean spacings between the spatial arrangements were designed to give the same bean populations i.e. a full maize and half bean populations.

Six weed control treatments were imposed on each of the two planting patterns. The six treatments included:

1. 0.5 kg a.i. pendimethalin/ha + one handweeding
2. 1.0 kg a.i. pendimethalin/ha + one handweeding
3. 1.5 kg a.i. pendimethalin/ha
4. One handweeding only
5. Two handweedings (CONTROL I)
6. No weed control (CONTROL II).

Planting patterns included:

R1. One row of beans between rows of maize as maize, beans, maize, bean (M-B-M-B)

R2. Two rows of beans between rows of maize as maize, beans, beans, maize, beans, beans (M-BB-M-BB).

Diammonium phosphate fertilizer, DAP, was applied at the rate of 190 kg/ha to provide approximately 40 kg/ha of elemental phosphorus and 40 kg/ha nitrogen. At harvest, two maize guard rows and a half metre at each end of the sub plot were discarded. In M-B-M-B arrangement two bean guard rows and half metre at each end were discarded while in M-BB-M-BB arrangement four bean guard rows were discarded. In all cases the effective harvest area was nine square metres (3m x 3m). Grain yield was calculated as kilograms per hectare at 12% and 13% moisture content for maize and beans respectively. In both experiments I and II, the beans were sprayed with Daconil (75% WT/WT chlorothalonil) against bean anthracnose and Rogor L40, a 40% W/V N-mono-methylamide of dimethyldithiophosphoryl acid (dimethoate) against bean aphid infestation.

The following observations and records were maintained and recorded for both experiments: Visual weed rating was made using a scale of 0-100 where 0 meant no control and 100, complete control. Further, physical counts of total weed populations and individual weed species populations was done before and after first and second weedings. A quadrat measuring 0.5 m x 0.5 m was randomly placed at four sites within the sub plot and counts made using a tally counter. A total weed population gave the weed density and counts of each prevalent species expressed as fractions of the total weed population, gave the relative density of each species.

$$\text{Relative density (R.D.)} = \frac{\text{Density of individual species}}{\text{Total density of all weeds}}$$

The physical counts were made to help ascertain accuracy of visual rating.

Total weed dry matter yield. All weeds within the pre-determined harvest area were harvested at crop maturity. Fresh weed weights were taken in the field and representative samples from each plot were taken for drying in the oven. Samples of 1.5 kg and 1.0 kg were taken from each sub plot in Experiment I and II, respectively. The weeds were dried to constant weight at 90°C for 16 hours, and the sub plot weed dry matter yields were determined. Density, relative density and weight were then used as measures of detecting trends in weed infestation as affected by various treatments. One week after crop germination, physical counts were made for both maize and beans. This was done to determine effect of herbicide at different dosages, if any, on germination.

Further data on yield components were taken and included:

(i) Number of full bean seeds per pod

(ii) Number of pods per bean plant.

(iii) Length of maize cobs

(iv) Seed and grain yield per hectare.

Labour/input requirements. Length of time taken for application of herbicide to each sub plot was obtained by repeatedly applying water uniformly over a known area (area of one sub plot), at normal spraying speed. Time required for filling of sprayer tank and resting was taken at 20% and added to give total spraying time. The mean time in minutes was converted to hours per hectare and taken to apply to all plots sprayed. Time required for weeding was obtained by timing each worker per sub plot, from start to finish. Male workers of ages ranging from about 20 years to 28 years were used for the duration of the experiments. Times in minutes obtained were converted to hours per hectare and finally dividing by eight hours (equivalence of one man-day)[1] to give man days per hectare. Cost of herbicide required at the different rates per hectare was calculated. The price of pendimethalin was Kshs 104.20 ($8.02) per litre and this was the cost of the chemical input.

[1]This definition is usually true in the developed countries (Norman, 1972). In the absence of any figures for Kenya, this figure was used in the calculations.

The cost of labour for weeding and for application of herbicide was valued at Kshs. 15.00 ($1.15) per day. This was a compromise between Kshs 17.50 ($1.35) per day at the Faculty of Agriculture Field Station and Ksh 12.50 ($0.96) paid by farmers around Kabete, which is low.

Net benefit (income)[1]. To compute net benefit (income) a partial budget was drawn for each of the three cropping systems. Variable costs were deducted from gross field benefit to give the net benefit. Variable costs included only the cost of herbicide and labour required to apply it plus the cost of labour required for handweeding. All other costs were regarded as fixed costs as they applied to all treatments in each cropping system. Each partial budget was thus divided as follows:-

I. Benefits:

(i) Crop yield (kgs/ha)

(ii) Crop value (price/kg)

(iii) Gross benefit (kgs/ha x price/kg).

[1]Net benefit was prefered to net income as the small scale farmer who intercrops, mainly needs the beans for food. No cash income may accrue from beans and a monetary value can only be implied.

II Variable costs:-

(a) Herbicide

(i) Quantity required (litres/ha)

(ii) value (cost/litre)

(iii) Total cost (Quantity x Value)

(b) Labour for herbicide application:

(i) Amount (man-days/ha)

(ii) Value (Rate/day)

(iii) Total cost (Man-days x rate/day)

(c) Labour for handweeding:

(i) Amount (man-days/ha)

(ii) Value (rate/day)

(iii) Total cost (man-days x rate/day)

III. Total variable cost

IV. Net benefit (Gross benefit - Total variable cost)

Crop prices paid to farmers and cost of herbicide used in all calculations were those found in "Yields, Costs - Prices, 1982," a publication of the Ministry of Agriculture. The price of Rose Coco beans was Kshs 3.40 ($0.26) per kg and maize was Ksh 130 ($10.00) per 90 kg bag.

Choice of pendimethalin: This herbicide has been used for weed control in a variety of crops including maize, beans and soya beans, to name a few. The herbicide was chosen because of its crop tolerance especially in the tropics (Kirkland, 1979). It can be used in a wide range of soils and does not pose any residual problems.

Land Equivalent Ratio (LER). This is the basis that was used to compare the performance of intercropping versus sole cropping, expressed as:

$$LER = \frac{\text{Yield of maize in intercrop}}{\text{Yield of maize in sole crop}} + \frac{\text{Yield of beans in intercrop}}{\text{Yield of beans in sole crop}}$$

LER values of less than one, equal to one or greater than one meant a disadvantage, no advantage and an advantage of intercropping, respectively, at each weed control treatment.

Marginal analysis[1]. Marginal analysis was performed to show how net benefits from different weed control treatments increased as the cost of weed control increased. Marginal net benefit was the increase

[1]Adapted from "Agronomic Data to farmer Recommendations. An Economics Training Manual" by Perrin, R.K., D.L. Winkelman, E.R. Moscardi and J.R. Anderson. (CIMMYT, 1979).

in net benefit which could be obtained from a given increment of weed control cost. The marginal rate of return to a given weed control technique was obtained by dividing marginal net benefit by the marginal cost.

$$\text{Marginal rate of return} = \frac{\text{Marginal net benefit}}{\text{Marginal cost}}$$

A split plot[1] analysis of variance (ANOVA) according to Cochran and Cox (1957) was used in all the statistical analysis. Duncan's New Multiple Range Test (DNMRT) was used to separate out differences between two means. Aspects considered in analysis of variance were; weed dry matter yield, labour requirements, bean yield, number of pods per plant, number of full seeds per pod, maize yield, cob length, cost of weed control and net benefit.

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[1] Whole plots (WP) consisted of cropping system in Experiment I and planting pattern in Experiment II. Sub-plots (SP) consisted of weed control treatments in both experiments.

RESULTS:

Prevalent weed species:

Prevalent species observed in the two experimental sites included:-

1. Broadleaved:-
   Brassica napus L. (Rape)
   Datura stramonium L. (Thorn apple)
   Oxygonum sinuatum (Meisn.) Dammer (Double thorn)
   Tagetes minuta L. (Mexican marigold)
   Emex australis Steinh (Devils' thorn)
   Nicandra physaloides L. Gaertn. (Chinese lantern)
   Asystasia schimperi
   Galinsoga parviflora Cav. (Gallant soldier)
   Sonchus oleraceus L. (Sowthistle)
   Bidens pilosa L. (Black jack)
   Oxalis latifolia H.B.K.

2. Grasses:-
   Setaria verticillata L. Beauv. (Bristly fox tail)
   Pennisetum clandestinum Chiov. (Kikuyu grass)
   Cynodon dactylon L. Pers. (Star grass)

3. Others:-
   Cyperus sp. (nut grass)

EXPERIMENT I : Effect of cropping system on weed control method:

Visual weed rating (Tables 1a and b) showed that there was no effect on weed control due to cropping system in both seasons. Weed control in all six control treatments in each cropping system was better in the short rains

Table 1a. Effect of weed control on weeds and crops t 15 and 40 days after crop emergence. Short rains, 1982.

Treatment	Brna		Dast		Oxsi		Emau		Tami		Bipi		Treat. means		Crop injury Maize	Crop injury Beans
Sole bean cropping																
Pend. 0.5kg a.i./ha + supplementary weeding	46[1]	94[2]	31	94	38	94	40	94	15	94	20	94	32	94	–	0
Pend. 1.0kg a.i./ha + supplementary weeding	63	94	65	94	52	94	69	94	38	94	46	94	56	94	–	2
Pend. 1.5kg	76	48	68	46	71	49	73	49	52	37	56	38	66	45	–	5
One hand weeding	0	94	0	94	0	94	0	94	0	94	0	94	0	94	–	0
Two hand weedings	0	94	0	94	0	94	0	94	0	94	0	94	0	94	–	0
No weed control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	–	0
Mean	31	71	27	70	27	71	30	71	18	69	20	69	26	70		
Sole maize cropping																
Pend. 0.5kg a.i/ha + supplementary weeding	46	96	31	95	39	96	40	96	15	96	20	96	32	96	0	–
Pend. 1.0kg a.i./ha + supplementary weeding	63	96	64	95	52	95	68	96	40	96	46	96	56	96	0	–
Pend. 1.5kg a.i./ha	74	53	69	50	72	46	71	51	52	41	56	38	66	47	0	–
One hand weeding	0	96	0	96	0	96	0	96	0	96	0	96	0	96	0	–
Two hand weedings	0	96	0	96	0	96	0	96	0	96	0	96	0	96	0	–
No weed control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	–
Mean	31	73	27	72	27	72	30	73	18	71	20	71	26	72		
Maize/Bean intercrop																
Pend. 0.5kg a.i./ha + supplementary weeding	47	96	31	96	38	96	40	96	15	96	20	96	32	96	0	0
Pend. 1.0kg a.i./ha + supplementary weeding	63	96	68	96	53	96	67	96	40	96	46	96	56	96	0	2
Pend. 1.5kg a.i./ha	77	49	65	49	70	52	73	51	52	39	57	39	66	47	0	5
One hand weeding	0	96	0	96	0	96	0	96	0	96	0	96	0	96	0	0
Two hand weedings	0	96	0	96	0	96	0	96	0	96	0	96	0	96	0	0
No weed control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	31	72	27	72	27	73	30	73	18	71	21	71	26	72		

Brna = *Brassica napus*; Dast = *Datura stramonium*; Oxsi = *Oxygonum sinuatum*, Emau = *Emex australis*; Tami = *Tagetes minuta*; Bipi = *Bidens pilosa*.

[1] Rating at 15 days after crop emergence i.e. before first weeding.

[2] Rating at 40 days after crop emergence i.e. before second weeding.

Table 1b. Effect of weed control on weeds and crops at 15 and 40 days after crop emergence. Long rains, 1983

Weed control treatment	Barna		Dast		Oxsi		Emau		Tami		Bipi		Treat. means		Crop injury Maize	Crop injury Beans
Sole bean cropping																
Pend. 0.5kg a.i./ha + supplementary weeding	10[1]	96[2]	0	96	0	96	0	96	0	96	0	96	1	96	-	0
Pend. 1.0kg a.i./ha + supplementary weeding	32	97	29	97	20	97	31	97	0	96	0	96	19	97	-	0
Pend. 1.5kg a.i./ha	52	36	47	38	49	34	50	38	27	22	31	25	43	32	-	2
One hand weeding only	0	96	0	96	0	96	0	96	0	96	0	96	0	96	-	0
Two hand weedings	0	96	0	96	0	96	0	96	0	96	0	96	0	96	-	0
No weed control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-	0
Mean	16	70	13	71	12	70	14	71	5	68	15	68	11	70		
Sole maize cropping																
Pend. 0.5kg a.i./ha + supplementary weeding	10	98	0	98	0	98	0	98	0	98	0	98	1	98	0	-
Pend. 1.0kg a.i./ha + supplementary	32	98	29	98	20	98	31	98	0	98	0	98	19	98	0	-
Pend. 1.5kg a.i./ha	52	41	47	39	49	36	50	41	27	22	31	26	43	34	0	-
One hand weeding only	0	98	0	98	0	98	0	98	0	98	0	98	0	98	0	-
Two hand weedings	0	98	0	98	0	98	0	98	0	98	0	98	0	98	0	-
No weed control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Mean	16	72	13		12	71	14	72	5	69	55	70	11	71		
Maize/bean intercrop																
Pend. 0.5kg a.i./ha + supplementary weeding	10	98	0	98	0	98	0	98	0	97	0	97	1	98	0	0
Pend. 1.0kg a.i./ha + supplementary weeding	32	98	29	98	20	98	31	98	0	97	0	97	19	98	0	0
Pend. 1.5kg a.i./ha	52	41	47	39	49	34	50	39	27	22	31	25	43	33	0	1
One hand weeding only	0	98	0	98	0	98	0	98	0	97	0	97	0	98	0	0
Two hand weedings	0	98	0	98	0	98	0	98	0	97	0	97	0	98	0	0
No weed control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean	16	72	13		12	71	14	72	5	68	5	69	11	71		

Barna = *Brassica napus*; Dast = *Datura stramonium*; Oxsi = *Oxygonum sinuatum*; Emau = *Emex australis*; Tami = *Tagetes minuta*; Bipi = *Bidens pilosa*.

[1] Rating at 15 days after crop emergence i.e. before first weeding.

[2] Rating at 40 days after crop emergence i.e. before second weeding.

than in the long rains, although the general mean weed yield in this season was 42.97% higher than in the long rains. _Tagetes minuta_ L., _Bidens pilosa_ L., _Cyperus_ sp. and _Oxalis latifolia_ H.B.K. were not controlled by pendimethalin at all the three rates tested. At 1.5 kg a.i./ha pendimethalin had fair control on _Oxygonum sinuatum_ (Meisn.) Dammer, _Datura stramonium_ L., _Brassica napus_ L. and _Emex australis_ Steinh. At 0.5 kg a.i./ha pendimethalin had little effect on all weed species except a two day delay in weed germination. A longer delay of 4-5 days in weed germination and slight stunted growth were observed at 1.0 kg a.i./ha. An initial good weed control was observed, especially in the short rains, when pendimethalin was applied at 1.5 kg a.i./ha. Weeds, however, seemed to outgrow these effects within a short period of time. When pendimethalin was applied at 1.5 kg a.i./ha, without supplementary weeding, weeds not killed recovered, finally showing little difference in weed infestation from those treatments where no control was practiced. The experimental site was generally low on grass weed species and most of the species present were controlled by pendimethalin at 1.5 kg a.i./ha. Regrowth in hand weeded plots, especially the trial conducted during the short rains, occured within a shorter period of time, than when herbicide was used alone.

Effect of cropping system on dry weed yield: In the short rains, the cropping system had a significant effect at P = 0.05 on dry weed yield (Table 2). Sole bean cropping resulted in the highest dry weed yield and the maize/bean inter-cropping the lowest. Dry weed yield was 38.67% higher in sole beans and 10.7% in sole maize than in intercropped maize and beans. Sole bean cropping gave 31.33% higher dry weed yield than sole maize cropping, however, in the unweeded check weed yield in sole maize cropping was higher. Intercropped maize and beans reduced dry weed yield significantly (P = 0.05) compared to sole bean cropping. The difference in weed yield between intercropped maize and beans and sole maize cropping were not significant at P = 0.05.

In the long rains, the effect of cropping system on dry weed yield was not significant at P = 0.05.

No significant differences could be found in dry weed yield between cropping systems, though sole bean cropping still gave the highest dry weed yield.

Effect of weed control treatment on mean dry weed yield: Treatment effects were highly significant (P = 0.01) in both the short and long rains (Table 2). Weed yields were generally lower for all weed control treatments in the long rains. In both seasons, the highest mean dry weed yield was obtained from the no weed control treatment and the lowest from two handweedings. Two handweedings reduced mean dry weed yield by 89.02% and 72.16% in the short and long rains, respectively, compared to no weed control. Plots in which low rates of herbicide plus one supplementary weeding were used resulted in lower dry weed yields than plots where the herbicide was used at 1.5 kg a.i./ha, one handweeding only or no weed control practiced. The two low rates with supplementary handweeding, however, resulted in higher weed yield than where two handweedings were done. Plots further, showed that the combined use of herbicide at 1.0 kg a.i./ha plus one supplementary handweeding controlled weeds better in the long rains than at 0.5 kg a.i./ha plus one supplementary handweeding. Initial herbicide performance was generally better with the short rains than in the long

Table 2. Effect of weed control treatment on weed dry matter yield, kg/ha. 1982-1983

	Cropping system							
	Short rains			Long rains			Treatment means	
Weed control treatment	Beans	Maize	Maize/Beans	Beans	Maize	Maize/Beans	Short rains	Long rains
Pendimethalin 0.5kg a.i./ ha + supplementary weeding	2880ab[1]	1010b	1280a	1070a	1030ab	1530a	1730 bc	1250abc
Pendimethalin 1.0kg a.i./ ha + supplementary weeding	2450ab	1340b	1610a	1400ab	960ab	1040a	1760 bc	1130bc
Pendimethalin 1.5kg a.i./ha	4210ab	2580b	3050a	2650a	1990a	1230a	3280 ab	1960ab
One hand weeding only	4170ab	2880b	2250a	2280ab	1260ab	1450a	3100 bc	1660
Two hand weedings	720b	440b	420a	870b	310b	560a	530 c	580c
No weed control	5380a	5460a	3560a	2620a	1900a	1760a	4800 a	2090a
Cropping systems means	3300 a	2270 a	2020 b	1830 a	1240 a	1260 a	2530	1440
S.E.		880			360		510	210

[1] Means within each column followed by the same letter are not significantly (P= 0.01) different according to DNMRT.

rains. Application of herbicide alone at 1.5 kg a.i./ha resulted in a higher weed yield than all other weed control treatments, except no weed control. No significant (P = 0.01) differences could be detected in both seasons between use of pendimethalin at the two low rates plus one supplementary weeding each and pendimethalin at 1.5 kg a.i./ha alone. Two handweedings did not lower mean weed yield significantly (P = 0.01) in both seasons, than use of pendimethalin at both low rates plus one supplementary handweeding each. Two handweedings, however, lowered dry weed yield significantly compared to one handweeding alone, pendimethalin at 1.5 kg a.i./ha and no weed control treatments. Dry weed yield obtained from no weed control treatment was significantly higher than dry weed yield from the combined use of low rates of herbicide plus one supplementary weeding. It did not differ significantly from weed yields obtained from one handweeding only and application of herbicide alone at 1.5 kg a.i./ha, in both seasons, and the combined use of herbicide at 0.5 kg a.i./ha plus one supplementary handweeding in the long rains.

The effect of weed control treatment on dry weed yield within cropping system: Under sole bean cropping no statistical differences could be detected between weed control treatments in dry weed yield, except two hand weedings. This treatment yielded significantly (P = 0.01) less dry weed yield than the no weed control treatment (Table 2). In the long rains, one hand weeding gave significantly higher dry weed yield than two hand weedings.

In sole maize cropping, no weed control treatment gave significantly (P = 0.01) higher dry weed yield than pendimethalin at 0.5 kg a.i./ha and 1.0 kg a.i./ha plus one supplementary hand weeding each, in the short rains. These differences were not significant during the long rains. The difference between no weed control and two hand weedings, however, was significant at P = 0.01, in both seasons.

The maize/bean intercropping had a great stabilizing effect on mean dry weed yield. No statistical difference could be detected between weed control treatments. There was also no significant (P = 0.01) difference between two hand weedings and the no weed control treatments.

There was no significant (P = 0.01) interaction between weed control treatment and cropping system. Sole maize cropping and maize/bean intercropping suppressed weed growth better than sole bean cropping particularly in:

a) No weed control

b) Use of Pendimethalin alone at 1.5 kg a.i./ha and

c) One hand weeding only.

<u>The effect of cropping system on bean yields:</u>

Cropping system had very significant (P = 0.01) and significant (P = 0.05) effects on bean yield in the short and long rains respectively (Table 3). In the short rains, intercropping maize and beans depressed bean yield by 63.77% and 64.26% in the long rains, compared to bean yield from sole bean cropping.

<u>Effect of weed control treatment on bean yield:</u> In both seasons, the effect of weed control treatment on bean yield was significant at P = 0.01. Results (Table 3) showed that the highest bean yield in the two seasons was obtained from the use of pendimethalin at 0.5 kg a.i./ha plus one supplementary hand weeding. The lowest yield was obtained from

Table 3. Effect of weed control on bean yield in kg/ha, 1982-1983.

	Cropping System				Treatment means	
	Short rains		Long rains			
Weed control treatments	Beans	Maize/Beans	Beans	Maize/Beans	Short rains	Long rains
Pendimethalin 0.5kg a.i./ha + supplementary weeding	1112.71a[1]	378.96a	1620.73a	546.67a	745.83a	1083.70a
Pendimethalin 1.0kg a.i./ha + supplementary weeding	953.96a	394.79a	1543.96a	578.75a	674.37a	1061.36a
Pendimethalin 1.5kg a.i./ha	584.79ab	207.92a	752.92bc	208.23a	396.36ab	480.58bc
One hand weeding only	839.17ab	369.38a	1294.17ab	469.79a	604.27a	881.98ab
Two hand weedings	860.83a	264.59a	1397.29ab	531.87a	562.71ab	964.58a
No weed control	223.75b	41.88a	258.33c	119.38a	132.81b	188.54c
Cropping system means	762.53	276.25	1144.58	409.11	519.39	776.84
S.E.	144.84		158.27		103.0	111.92

[1] Means within each column followed by the same letter are not significantly (P = 0.01) different according to DNMRT.

the no weed control treatment. No herbicide injury on beans was observed at any of the two low rates in both seasons. At 1.5 kg a.i./ha, however, pendimethalin caused malformed and stunted growth in beans in localised areas. The herbicide injury was more apparent in the short rains than in the long rains. However, the bean crop seemed to outgrow the injury, though such affected sites tended to remain patchy in the short rains. Pendimethalin at 1.5 kg ai./ha gave low bean yields in both seasons. Variation among treatments was greater in the short rains than in the long rains. The use of pendimethalin at both 0.5 kg a.i./ha and 1.0 kg a.i./ha plus one supplementary hand weeding each, gave higher bean yield than all other treatments. Both one and two hand weedings gave higher bean yield than the sole use of pendimethalin at 1.5 kg a.i./ha. More bean plant damage was observed in two hand weedings than in one hand weeding alone, especially during the second weeding. At this stage the crop branching was extensive and the physical impact of the hoe caused much branch breakage and/or damage. During the short rains there was no statistical difference between the no weed control treatment and use of pendimethalin at 1.5 kg a.i./ha and two hand weedings. No significant difference at P = 0.01 could be detected among all other treatments. In the long rains the no weed control treatment was not significantly different from use of pendimethalin at 1.5 kg a.i./ha. Further, use of pendimethalin at 1.5 kg a.i./ha did not differ statistically from one hand weeding only.

The effect of weed control treatments on bean yield within cropping system: In sole bean cropping, all weed control treatments except no weed control did not differ statistically in their bean yield, during the short rains. Results in Table 3 show that during the long rains, bean yields obtained from use of herbicide alone at 1.5 kg a.i./ha and the no weed control treatments were significantly (P = 0.01) lower than those obtained from use of low rates of herbicide plus one supplementary weeding each. No weed control also gave statistically lower bean yield than both one and two hand weedings. In the maize/bean intercrop, no statistical difference was detected between all weed control treatments in both the short and long rains. During the short rains there was no statistical interaction between cropping system and weed control treatment, on yield. In the long rains, interaction was significant with a greater depression of yield in the no weed control treatment in sole bean cropping than intercropping.

Effect of cropping system on pod number per plant: Pod number per plant was influenced by cropping system significantly (P = 0.05) in the short rains (Table 4). This effect was more pronounced in the long rains. Intercropping maize and beans depressed bean pod number per plant by 19.56% in the short rains and by 16.74% in the long rains.

Effect of weed control treatment on pod number per plant: Treatment effects on pod number were significant at P = 0.01 in both seasons. The combined use of pendimethalin at the lowest rate with a supplementary hand weeding gave the highest pod number per plant and the no weed control treatment, the lowest (Table 4). Pod number varied more among weed control treatments in the long rains than in the short rains. **In** sole

Table 4. Effect of weed control on number of pods per plant. 1982-1983

	Cropping system				Treatment means	
	Short rains		Long rains			
Weed control treatments	Beans	Maize/Beans	Beans	Maize/Beans	Short rains	Long rains
Pendimethalin 0.5kg a.i./ha + supplementary weeding	9.85a[1]	7.45a	11.40a	7.28b	8.65a	9.34a
Pendimethalin 1.0kg a.i./ha + supplementary weeding	8.10a	8.05a	10.13b	8.13ab	8.08a	9.13a
Pendimethalin 1.5kg a.i./ha	7.78a	6.70ab	8.30cd	7.40ab	7.24ab	7.85b
One hand weeding	8.25a	7.05ab	7.00d	7.58ab	7.65ab	7.29b
Two hand weedings	8.58a	6.58ab	9.55bc	8.75a	7.58ab	9.15a
No weed control	6.53a	3.65b	5.33e	3.83c	5.09b	4.54c
Cropping system means	8.18	6.58	8.60	7.16	7.38	7.88
C.V.% (WP)	6.91		18.18			
C.V.% (SP)	4.46		6.70			
SE	0.84		0.35		0.60	0.24

[1]Means within each column followed by the same letter are not significantly (P = 0.01) different according to DNMRT.

bean cropping there were no statistical differences among control treatments in the short rains. In the long rains the combined use of pendimethalin at 0.5 kg a.i./ha plus one supplementary hand weeding gave significantly more pods than any other treatment. In intercropping, the response was similar to that in sole bean cropping in the long rains, for both seasons. Only in the long rains was there a significant interaction at P = 0.01 between cropping system and weed control treatment.

Effect of cropping system on seed number per pod: Intercropping maize and beans depressed seed number per pod by 16.75% in the short rains. The seed number was reduced from 4.00 full seeds to 3.33 full seeds. In the long rains there was a seed number depression of 15.36% from 3.58 to 3.03 full seeds per pod, when beans were intercropped with maize. This depression was significant (P = 0.01) in both seasons.

Effect of weed control treatment on seed number per pod: The lowest mean seed number per pod was obtained from the no weed control plots in both seasons, (Table 5). The beans in plots treated with pendimethalin

Table 5. Effect of weed control on number of seeds per pod. 1982-1983.

	Cropping system					
	Short rains		Long rains		Treatment means	
Weed control treatments	Beans	maize/Beans	Beans	Maize/Beans	Short rains	Long rains
Pendimethalin 0.5kg a.i./ha + supplementary weeding	4.38a[1]	3.45ab	4.28a	3.23bc	3.92ab	3.75ab
Pendimethalin 1.0kg a.i./ha + supplementary weeding	4.48a	3.88a	3.85ab	3.35bc	4.18a	3.60abc
Pendimethalin 1.5kg a.i./ha	3.90a	3.00ab	3.23b	2.95bcd	3.45b	3.09c
One hand weeding	4.08a	3.58a	3.60ab	2.85cd	3.83ab	3.23bc
Two hand weedings	4.38a	3.65a	4.15a	3.63a	4.01ab	3.89a
No weed control	2.80a	2.45b	2.35c	2.20d	2.63c	2.28d
Crop system means	4.00	3.33	3.58	3.03	3.67	3.30
C.V. % (WP)	4.46		3.79			
C.V. % (SP)	9.32		8.06			
S.E.	0.24		0.19		0.17	0.13

[1] Means within each column followed by the same letter are not significantly (P = 0.01) different according to DNMRT.

WP = Whole plots
SP = Sub plots

at 1.0 kg a.i./ha plus one supplementary hand weeding in the short rains appeared to have the highest seed number. In the long rains, this was obtained from two hand weedings. In both the short and long rains, no weed control treatment reduced seed number significantly (P = 0.01), in sole bean cropping. No statistical difference could be detected among all other weed control treatments in this cropping system. Lack of statistical difference was also the case in intercropping in the short rains. During the long rains, however, plots which were hand weeded twice gave more seeds per pod than all other treatments. There was no interaction between cropping system and weed control treatment in the short rains, however, in the long rains, there was an interaction between cropping system and weed control. Interaction suggested that intecropping beans and maize influenced the effect of weed control treatment on seed number per pod in the long rains season.

Effect of cropping system on maize yield:

Intercropping maize and beans did not affect maize yields in both seasons(Table 6). In the short rains, mean maize yield in the intercrop was 10.57% higher than from sole maize cropping. In the long rains maize yield was only

0.65% higher in sole maize cropping.

Effect of weed control treatment on maize yield: Weed control treatment effects (Table 6) were significant (P = 0.01) on maize yields in both seasons. In the two seasons, two hand weedings realised the highest maize yield and the no weed control treatment, the lowest. In theshort rains the combined use of pendimethalin at 1.0 kg a.i./ha plus one supplementary hand weeding gave slightly higher maize yield than the lower rate, at 0.5 kg a.i./ha. During the short rains these two rates were about equal in their maize yield. They both gave higher yield than use of pendimethalin alone at 1.5 kg a.i./ha. Both low rates combined with one supplementary hand weeding each also out yielded one hand weeding alone, in both seasons. Further, the one hand weeding treatment out yielded the use of herbicide alone at 1.5 kg a.i./ha. In the short rains, all weed control treatments except the no weed control were not statistically different from each other. No significant differences could also be detected between pendimethalin at 1.5 kg a.i./ha and no weed control treatments. In the long rains, two hand weedings gave significantly higher

Table 6. Effect of weed control on maize yield kg/ha. 1982-1983.

	Cropping system				Treatment means	
	Short rains		Long rains			
Weed control treatments	Maize	Maize/Beans	Maize	Maize/Beans	Short rains	Long rains
Pendimethalin 0.5kg a.i./ha + supplementary weeding	1585.42ab[1]	2291.46a	3044.17ab	3193.47ab	1838.44a	3118.82ab
Pendimethalin 1.0kg a.i./ha + supplementary weeding	2113.13a	2147.92a	3125.60ab	3052.05ab	2130.53a	3088.83ab
Pendimethalin 1.5kg a.i./ha	1477.29ab	1727.09ab	1911.81b	1890.49b	1603.19ab	1901.15bc
One hand weeding	1771.46ab	1848.54ab	2536.28b	2099.89ab	1810.00a	2318.09bc
Two hand weedings	2193.95a	2267.92a	3742.19a	3943.84a	2230.84a	3843.02a
No weed control	835.63b	855.83b	1502.70b	1580.25b	845.73b	1541.47c
Cropping systems means	1660.28	1856.46	3643.79	2626.66	1758.37	2635.21
C.V.% (WP)	18.08		19.77			
C.V.% (SP)	21.55		21.78			
S.E.	267.89		424.56		189.43	300.21

[1] Means within each column followed by the same letter are not significantly (P = 0.01) different according to DNMRT.

yields than all other weed control treatments except, the combined use of both low rates plus one supplementary hand weeding each. All three rates of pendimethalin and one hand weeding only did not differ statistically from each other. No weed control treatment gave significantly lower maize yield than all weed control treatments except use of pendimethalin alone at 1.5 kg a.i./ha.

Effect of weed control treatment on maize yield within cropping system: In sole maize cropping, all weed control treatments except the no weed control, did not differ significantly from each other (Table 6) during the short rains. In this season both the combined use of herbicide at 1.0 kg a.i./ha plus one supplementary hand weeding and two hand weedings treatments gave significantly higher yield than no weed control treatments. Other weed control treatments were, however, not significantly different from no weed control treatment. In the long rains two hand weedings significantly out yielded the use of herbicide at 1.5 kg a.i./ha, one hand weeding only and no weed control treatments. The combined use of herbicides at 0.5 kg a.i./ha and 1.0 kg a.i./ha with one supplementary hand weeding each, were not significantly different from these three treatments.

In the maize/bean intercrop, all weed control treatments except the no weed control, were not statistically different in maize yield in the short rains. The no weed control treatment did not lower maize yields significantly compared to pendimethalin alone at 1.5 kg a.i./ha. In the long rains, two hand weedings gave statistically higher maize yield than pendimethalin alone at 1.5 kg a.i./ha and no weed control treatments. There was, however, no statistical difference between these treatments and the rest of the weed control treatments in maize yield.

<u>Effect of cropping system and weed control on cob length:</u> No significant (P = 0.05) cropping system effects could be detected on cob length. Intercropping did not affect cob length significantly though it increased it by 5.01% in the short rains and only by 0.2% in the long rains. Results (Table 7) show that the greatest mean cob length was obtained from two hand weedings and the smallest from the no weed control treatment. The influence of weed control treatment was significant at P = 0.01 in both seasons. Results further show that no weed control treatment decreased cob length significantly in the

Table 7. Effect of weed control on cob length, (cm) 1982-1983

	Cropping System				Treatment means	
	Short rains		Long rains			
Weed control treatment	Maize	Maize/Beans	Maize	Maize/Beans	Short rains	Long rains
Pendimethalin 0.5 kg a.i./ ha + supplementary weeding	12.13ab[1]	13.85ab	16.10a	15.03abc	12.99ab	15.56bc
Pendimethalin 1.0kg a.i./ha + supplementary weeding	14.18a	13.98ab	16.35a	15.93ab	14.08a	16.14ab
Pendimethalin 1.5kg a.i./ha	13.35a	13.90ab	15.80ab	15.05abc	13.63a	15.11bc
One hand weeding alone	14.03a	13.43ab	14.23b	14.85bc	13.73a	14.54c
Two hand weedings	13.98a	14.95a	17.30a	16.65a	14.46a	16.98a
No weed control	10.90b	12.58b	11.70c	13.53c	11.74b	12.61d
Cropping system means	13.09	13.78	15.14	15.17	13.44	15.16
C.V. % (WP)	8.48		1.47			
C.V.% (SP)	5.52		4.57			
SE	0.52		0.41		0.37	0.29

[1] Means within each column followed by the same letter are not significantly (P = 0.01) different according to DNMRT.

WP = Whole plot

SP = Sub plot

short rains in sole maize cropping. Other weed control treatments did not differ statistically. In the long rains, no weed control treatment again reduced cob length significantly. One hand weeding too reduced cob length significantly compared to other weed control treatments except pendimethalin alone at 1.5 kg a.i./ha. In intercropping, effects were the same as in sole maize cropping except two hand weedings gave significantly longer cob length than the single hand weeding, in the long rains. The combined use of herbicide plus supplementary hand weeding similarly gave significantly longer cob length than the no weed control treatment. A significant interaction (P = 0.05) in the short rains and (P = 0.01) in the long rains was detected between cropping system and weed control treatment. This suggested that intercropping had strong influence on weed control treatment effect on cob length.

<u>Effect of cropping system on labour requirement:</u> Cropping system effect on labour requirement was not significant at P = 0.05 (Table 8). During the short rains, sole bean cropping had the highest labour requirement and sole maize cropping, the

lowest. Sole bean cropping required 23.57% more man-days per hectare than sole maize cropping and 3.11% more man-days than maize/bean intercropping. In the long rains, maize/bean intercropping had the higher labour requirement, taking 43.66% more man-days per hectare than sole maize cropping, which had the lowest. Sole bean cropping required 6.14% less labour than the intercrop. In both seasons, maize/bean intercropping and sole bean cropping had about the same labour requirements.

Effect of weed control treatment on labour requirement: The effect of weed control technique on labour requirement was highly significant (P = 0.01), both in the short and long rains. Results in Table 8 indicate that in both seasons two hand weedings had the most labour requirement for weed control and use of herbicide alone at 1.5 kg a.i./ha, the least. In both seasons, the combined use of pendimethalin at 0.5 kg a.i./ha and 1.0 kg a.i./ha plus one supplementary hand weeding each, required slightly less labour than both one and two hand weedings. Similarly, they required more labour for weed control than application of

Table 8. Labour requirement in man-days per ha. 1982-1983.

	Cropping system							
	Short rains			Long rains			Treatment means	
Weed control treatment	Beans	Maize	Maize/Beans	Beans	Maize	Maize/Beans	Short rains	Long rains
Pendimethalin 0.5kg a.i./ ha + supplementary weeding	18.91b[1]	14.86b	18.04b	22.48ab	10.81ab	31.49a	17.27b	21.59b
Pendimethalin 1.0kg a.i./ ha + supplementary weeding	17.27b	13.51b	17.36b	21.13b	11.06ab	21.42a	16.05b	17.87b
Pendimethalin 1.5kg a.i./ ha	0.39c	0.39c	0.39c	0.39c	0.39b	0.39b	0.39c	0.39c
One hand weeding only	20.26b	13.99b	17.88b	22.47b	16.88ab	28.16a	17.30b	22.08b
Two hand weedings	40.13a	31.44a	25.46a	40.90a	25.46a	32.65a	37.36a	33.08a
Cropping systems means	19.39	14.84	18.79	21.47	12.92	22.87	17.67	19.09
C.V.% (WP)		17.09			30.72			
C.V.% (SP)		17.70			34.47			
SE		2.21			4.65		1.28	2.69

[1]Means within each column followed by the same letter are not significantly (P= 0.01) different according to DNMRT.

WP= Whole plot

SP= Sub-plot

herbicide alone at 1.5 kg a.i./ha. Further, a combined use of pendimethalin at the higher rate of 1.0 kg a.i./ha and one supplementary hand weeding, reduced labour requirement only very slightly compared to the lower rate at 0.5 kg a.i./ha with one supplementary hand weeding. The reduction in labour obtained by use of these lower rates over one and two hand weedings was less in the long rains than in the short rains.

<u>Effect of weed control treatment on labour requirement within cropping system:</u> Results in Table 8 further show that two hand weedings in sole bean cropping, required significantly (P = 0.01) more labour than all other treatments, in the short rains. Similarly the use of herbicide alone at 1.5 kg a.i./ha, required significantly less labour compared to the rest of the treatments. All other treatments were not statistically different from each other in their labour requirements. During the long rains two hand weedings again required significantly more labour than the combined use of herbicide at low dosages and one supplementary hand weeding. In this season the use of pendimethalin

than all other treatments, except in sole maize during the long rains. In the ANOVA, no significant interaction could be detected at P = 0.05 between cropping system and weed control treatment. This indicated absence of influence of intercropping on treatments' effects on labour requirement.

Effect of cropping system on cost of weed control: No significant (P = 0.05) effect of cropping system on cost of weed control was detected in both seasons, (Table 9). Sole bean cropping had the highest cost of weed control and sole maize cropping, the lowest, in the short rains. Sole bean cropping required $ 3.44 and $26.26 more money for weed control than maize/bean intercropping and sole maize cropping respectively. In the long rains, the maize/bean intercrop had the highest cost and again, sole maize the lowest. In this season the maize/bean intercrop cost $9.77 and $57.41 more to control weeds than sole bean and sole maize cropping respectively.

The effect of weed control treatment on cost: The influence of weed control technique on cost was highly significant at P = 0.01. Data in Table 9

Table 9. Cost of weed control techniques in US $/ha[1]. 1982-1983

	Cropping system							
	Short rains			long rains			Treatment means	
Weed control treatment	Beans	Maize	Maize/Beans	Beans	Maize	Maize/Beans	Short rains	Long rains
Pendimethalin 0.5kg a.i./ha + supplementary weeding	29.83bc[2]	25.16bc	28.83bc	32.95a	20.48a	44.35a	27.94c	32.93ab
Pendimethalin 1.0kg a.i./ha + supplementary weeding	35.95b	31.61ab	36.06b	40.41a	28.80a	40.74a	34.22b	36.65ab
Pendimethalin 1.5kg a.i./ha	24.50c	24.50bc	24.50c	24.50a	24.50a	24.50a	24.50cd	24.50b
One hand weeding only	23.37c	16.14c	20.37c	25.93a	19.48a	32.50a	19.96d	25.97a
Two hand weedings	46.30a	36.28a	46.75a	46.49a	29.38a	37.96a	43.11a	37.94a
C.V.% (WP)		11.61			21.51			
C.V.% (SP)		12.03			24.21			
S.E		2.55			5.41		1.47	3.12

[1]1 US$ = Kshs.13.00

[2]Means followed by the same letter within each column are not significantly (P= 0.01) different according to DNMRT.

WP= Whole plots

SP= Sub-plots

show that during the short rains the highest cost of weed control was realised from the two hand weedings treatment and the lowest from one hand weeding only. In the long rains, the highest cost was again realised from two hand weedings but the lowest was obtained in the application of herbicide alone at 1.5 kg a.i./ha. Use of pendimethalin at 0.5 kg a.i./ha plus one supplementary hand weeding cut down on cost by 18.35% compared to application of 1.0 kg a.i./ha plus one supplementary hand weeding and 35.2% compared to two hand weedings. It however, cost 12.3% and 28.6% more than pendimethalin applied alone at 1.5 kg a.i./ha, and one hand weeding alone, respectively. A combination of pendimethalin at 1.0 kg a.i./ha plus one supplementary hand weeding reduced weed control cost only in comparison to two hand weedings. One hand weeding alone gave a lower cost of control than use of herbicide at 1.5 kg a.i./ha. In the long rains, a similar pattern followed except the use of herbicide at 0.5 kg a.i./ha and 1.0 kg a.i./ha combined with one supplementary weeding each reduced cost of weed control less compared to two hand weedings. In fact use of pendimethalin at 0.5 kg a.i./ha plus one supplementary weeding cost 16.83%

more than two hand weedings in maize/bean intercropping. At 1.0 kg a.i./ha, the combined use of herbicide plus one supplementary hand weeding cost 7.3% more than two hand weedings in the intercrop.

Effect of weed control treatment on cost within cropping system: Table 9 shows that in sole bean cropping, two hand weedings cost significantly more to execute weed control than all other treatments during the short rains. Te combined use of herbicide at both 0.5 kg a.i./ha and 1.0 kg a.i./ha plus one supplementary weeding each, did not have any statistical difference in their cost of weed control. Similarly, herbicide alone at 1.5 kg a.i./ha and one hand weeding alone did not differ significantly from each other in cost. They did not also differ significantly from the combined use of herbicide at 0.5 kg a.i./ha plus one supplementary weeding. In the long rains no significant (P= 0.01) differences were detected among all weed control treatments.

In sole maize cropping, there was no significant (P = 0.01) difference between two hand weedings and combined use of herbicide at 1.0 kg a.i./ha with one supplementary weeding, in the short rains. At 0.5 kg a.i./ha, the combined use of herbicide plus one supplementary hand weeding did not differ statistically from one hand weeding alone and pendimethalin alone at 1.5 kg a.i./ha. They all cost significantly less than two hand weedings. In the long rains there were no significant differences at P = 0.01 among all weed control treatments in their weed control cost.

In maize/bean intercropping, a similar response as that in sole bean cropping was obtained in the short rains. In the long rains no significant (P = 0.01) difference could be detected between weed control treatments. In this season, however, the combined use of 0.5 kg a.i./ha and 1.0 kg a.i./ha plus one supplementary weeding cost more than two hand weedings. No significant (P = 0.05) interaction could be detected between cropping system and weed control treatment, on cost of weed control, in both seasons. This showed that intercropping maize and beans did not influence weed control treatment to affect cost of weed control.

<u>The effect of cropping system on net benefit</u>: Effect on monetary benefit was only

significant (P = 0.05) in the short rains but not in the long rains. The highest net benefit was realised in the maize/bean intercrop during the two seasons research. Sole maize cropping gave the lowest net benefit in the short rains and sole bean cropping the lowest net benefit in the long rains. The maize/bean intercrop gave 31.43% and 35.75% higher net benefit than sole bean and sole maize cropping respectively, in the short rains. Sole bean cropping realised 6.3% higher net benefit than sole maize cropping. For this season the maize/bean intercrop realised significantly (P = 0.05) higher net benefit than either sole bean or sole maize cropping. The maize/bean intercrop realised 26.58% and 25.90% higher net benefit than sole bean and sole maize cropping respectively, in the long rains. Sole maize cropping gave only 0.92% higher net benefit than sole bean cropping. There were no significant differences between all cropping systems in net benefit in this season.

Effect of weed control treatment on net benefit: The influence of weed control treatment on net benefit was highly significant (P = 0.01) in both seasons. Results in Table 10 show that the combined application of herbicide at the lowest rate i.e. 0.5 kg a.i./ha with one supplementary hand weeding gave the highest net benefit, in the short rains. The lowest net benefit in the same season was obtained from no weed control treatment. The combined use of pendimethalin at 0.5 kg a.i./ha plus one supplementary weeding was the most profitable technique of weed control in this season, giving higher net benefit than all other weed control treatments. At 1.0 kg a.i./ha the combined use of pendimethalin plus one supplementary weeding was the second highest in both profitability and net benefit. The use of pendimethalin at 1.5 kg a.i./ha alone was only better than the no weed control treatment in net benefit. One single hand weeding alone was found to give a higher net benefit than two hand weedings. The following ranking from highest to lowest could be observed in net benefit in the short rains; Pendimethalin at 0.5 kg a.i./ha plus one supplementary weeding > pendimethalin at 1.0 kg a.i./ha plus one supplementary weeding > one hand weeding only > two hand weedings > pendimethalin at 1.5 kg a.i./ha > no weed control. Two hand weedings gave the highest net benefit compared to all other weed

Table 10. Effect of weed control treatment on net benefit, US $/ha[1], 1982-1983.

	Cropping system						Treatment means	
	Short rains			Long rains				
Weed control treatment	Beans	Maize	Maize/Beans	Beans	Maize	Maize/Beans	Short rains	Long rains
Pendimethalin 0.5kg a.i./ ha + supplementary weeding	216.19a[2]	151.00a	324.89a	389.93a	317.76ab	453.46ab	245.69a	387.05a
Pendimethalin 1.0kg a.i./ ha + supplementary weeding	213.54ab	203.18a	305.85a	363.40ab	318.49ab	449.74ab	240.86a	377.21a
Pendimethalin 1.5kg a.i./ha	130.37ab	139.65a	221.78ab	172.42bc	187.93ab	240.02bc	163.93ab	200.12a
One hand weeding only	196.10ab	179.02a	281.63a	312.55ab	262.33ab	323.70bc	225.33a	299.52a
Two hand weedings	178.84ab	207.47a	274.44a	318.95ab	386.42a	539.35a	220.25a	414.91a
No weed control	58.52b	92.85a	106.05b	67.56c	166.97b	206.80c	85.80b	147.11b
C.V.% (WP)		19.74			29.32			
C.V.% (SP)		27.61			23.99			
S.E		38.24			51.68		22.08	29.84

[1] 1 US$ ≡ Kshs. 13.00

[2] Means within each column followed by the same letter are not significantly (P = 0.01) different according to DNMRT.

WP = Whole plots

SP = Sub-plots

control treatments in the long rains. Like in the short rains, the combined use of pendimethalin at 0.5 kg a.i./ha plus one supplementary weeding gave higher net benefit than the same technique of control but at the higher rate of 1.0 kg a.i./ha. It was also found to give higher net benefit than use of pendimethalin alone at 1.5 kg a.i./ha, one hand weeding alone and no weed control treatments. Net benefit in the long rains could be ranked from highest to lowest as follows: two hand weedings > pendimethalin at 0.5 kg a.i./ha plus one supplementary weeding > pendimethalin at 1.0 kg a.i./ha plus one supplementary weeding > one hand weeding only > pendimethalin at 1.5 kg a.i./ha > no weed control. The no weed control treatment gave significantly low net benefits for both seasons, compared to all other treatments, except pendimethalin at 1.5 kg a.i./ha. The use of pendimethalin at 1.5 kg a.i./ha did not differ significantly from no weed control treatment in the short rains. However, it gave significantly higher net benefit than the no weed control treatment in the long rains.

<u>Effect of weed control treatment on net benefit within cropping system:</u> In sole bean cropping,

the combined use of pendimethalin at 0.5 kg a.i./ha plus one supplementary hand weeding in the short rains gave significantly higher net benefit than no weed control treatment. It did not, however, differ significantly from other weed control treatments, which in turn were not significantly different from no weed control treatment. A similar response was obtained in the long rains except the combined use of pendimethalin at 0.5 kg a.i./ha plus one supplementary weeding gave statistically higher net benefit than both use of herbicide at 1.5 kg a.i./ha and no weed control treatments.

In sole maize cropping, no statistical differences existed among all weed control treatments in net benefit, during the short rains. In the long rains, however, two hand weedings gave significantly higher net benefit than no weed control treatment. No significant differences could be detected between these two controls and other weed control treatments.

In maize/bean intercropping, the no weed control treatment gave a significantly lower net benefit than all other treatments except use of pendimethalin at 1.5 kg a.i./ha, in the short rains.

All other treatments were not significantly different. Two hand weedings gave statistically higher net benefit than both use of pendimethalin at 1.5 kg a.i./ha and no weed control treatments, in the long rains. The difference in net benefit between one hand weeding and two hand weedings was uniquely significant in this cropping system during this season. There was no significant interaction at P = 0.05 detected between cropping system and weed control treatment in both seasons. This suggests that the influence of weed control treatment is the main factor influencing net benefit.

Marginal analysis of weed control treatment in the maize/bean intercrop: A marginal analysis was performed to determine the marginal rate of return to investment for each of the weed control treatments in the maize/bean intercrop. In the short rains only use of pendimethalin at 0.5 kg a.i./ha with one supplementary weeding and one hand weeding only were found to be economically viable (Table 11a). Other weed control treatments were considered dominated alternatives as for each of them there was another alternative technique of

Table 11a. Dominance analysis of weed control response in the maize/bean intercrop, short rains, 1982.

Net benefit (US $/ha)	Method of weed control	(US $/ha) Weed control cost
325.66	0.5kg a.i./ha pendimethalin + One weeding	28.83
305.85	1.0kg a.i./ha pendimethalin + One weeding	36.06*
281.63	One hand weeding only	20.37
274.44	Two hand weedings	46.75*
221.78	1.5 kg a.i./ha pendimethalin	24.50*
106.05	No weed control	0

*Dominated treatment which is that treatment for which there is another alternative treatment with a higher net benefit and a lower weed control cost. Dominated treatments were not considered economically viable weed control techniques.

Table 11b. Dominance analysis of weed control response in the maize/bean intercrop, long rains, 1983.

Net benefit (US $/ha)	Method of weed control	(US $/ha) Weed control cost
539.35	Two hand weedings	37.96
453.46	0.5kg a.i./ha pendimethalin + one weeding	44.35*
449.74	1.0kg a.i./ha pendimethalin + one weeding	40.74*
323.70	One hand weeding only	32.49
240.02	1.5kg a.i./ha pendimethalin	24.50
206.80	No weed control	0

*Dominated treatment which is that treatment for which there is another alternative treatment with a higher net benefit and a lower weed control cost. Dominated treatments were not considered economically viable weed control techniques.

weed control with a higher net benefit at a lower cost of weed control. In the long rains (Table 11b) both the use of pendimethalin at 0.5 kg a.i./ha and 1.0 kg a.i./ha plus one supplementary weeding were dominated alternatives. Considering the mean net benefit and variable cost for each weed control treatment for the two seasons, the only dominated treatment was the use of pendimethalin at 1.0 kg a.i./ha plus one supplementary weeding. The mean marginal rates of return to mean weed control cost for the two seasons can be seen in Table 12. Use of pendimethalin at 1.0 kg a.i./ha with one supplementary weeding was not included as it was not considered economically viable.

The effect of planting pattern on dry weed yield: In a follow up experiment on effect of planting pattern on weed suppression, it was found out that the highest dry weed yield was obtained in planting single rows of beans between maize rows in the M-B-M-B (1:1) pattern. In the short rains the mean dry weed yield from 1:1 pattern was 25.1% higher than in the M-BB-M-BB (1:2) pattern. In the long rains, this was 13.06% higher. While this difference in dry weed yield

Table 12. Marginal analysis of undominated weed control data US $/ha (Averaged data for 1982-1983).

	Net benefit	Weed control method	Viable cost	Change from next highest benefit: Marginal increase in net benefit	Marginal increase in variable cost	Marginal rate of return %[1]
1.	406.90	Two hand weedings	42.36	17.73	5.77	307.40
2.	389.17	0.5kg a.i. pendimethalin/ha + one supplementary hand weeding	36.59	86.51	10.16	851.58
3.	302.16	One hand weeding only	26.43	71.76	1.93	3709.50
4.	230.90	1.5 kg a.i. pendimethalin/ha	24.50	74.47	24.50	304.03
5.	156.43	No weed control	0	-	-	-

[1]Large percent marginal rates of return were recorded mainly because of the sensitivity of net benefit to changes in variable cost. A small change in variable cost as a result of change of weed control technique was accompanied by a large change in net benefit.

between planting patterns was significant at P = 0.05 during the short rains, it was not in the long rains. Planting pattern did not alter the influence of weed control treatment on dry weed yield as there was no detectable planting pattern and weed control treatment interaction.

EXPERIMENT II

Effect of planting pattern on bean yield: Planting pattern had significant effect (Tables 13a and b) on bean yield in both seasons. Two rows of beans between the maize rows in the 1:2 pattern increased bean yield significantly in the two seasons giving 20.9% higher bean yield in the short rains. This was 15.23% higher in the long rains than in the 1:1 pattern. Weed control treatment effect on bean yield differed among the planting patterns. In the short rains no significant (P = 0.01) differences existed between weed control treatments in the 1:1 pattern. In the 1:2 pattern, one hand weeding alone gave significantly higher bean yield than both two hand weedings and no weed control treatments. During the long rains there was no influence of planting pattern on the effect of weed control treatment on bean yield.

Effect of planting pattern on maize yield: In both the short and long rains, planting pattern did not have any significant effect on maize yield (Tables 13a and b). In the short rains, two rows of beans interplanted between maize rows, reduced maize yield by only 2.48% and by 16.54% in the long rains. This differences were not significant at P = 0.05. There was no significant interaction between planting pattern and weed control treatment. However, it was observed that yields were higher in all weed control treatments in the 1:2 pattern in the short rains.

Effect of planting pattern on labour requirement and cost of weed control: The effect of planting pattern on labour requirement and cost of weed control was not significant (Tables 13a and b). Labour requirement for weed control was slightly greater in the 1:2 pattern. This pattern required 6.23% and 14.97% more labour than the 1:1 pattern in the short and long rains respectively. Further, plot workers prefered weeding in the 1:1 pattern as it was easier. No significant interaction was detected between planting pattern and weed control treatment on labour requirement.

The 1:2 pattern raised the cost of weed control by 4.19% and 11.49% in the short and long rains respectively. These differences were, however, not significant. No significant interaction could also be detected between cost of weed control treatment and planting pattern in the two seasons. This lack of interaction implied that planting pattern did not influence weed control treatment in determination of labour requirement and cost for weed control.

Effect of planting pattern on net benefit: The effect of pattern on net benefit was significant (Tables 13a and b) in the short rains and not significant in the long rains. The 1:2 pattern increased net benefit by 11.92% in the short rains and only 4.42% in the long rains. In the long rains significant (P = 0.01) interaction between planting pattern and weed control treatment was detected. The combined use of herbicide at both 0.5 kg a.i./ha and 1.0 kg a.i./ha plus one supplementary weeding gave higher net benefits in the 1:2 pattern than in the 1:1 pattern.

Table 13a. Effect of planting pattern on various parameters short rains, 1982.

	M-B-M-B	M-BB-M-BB	(±) S.E. between patterns	% C.V. main plots	% C.V. sub-plots
1. Weed dry yield, kg/ha	1560.0a	1168.4b	10.53	13.27	26.74
2. Bean yield kg/ha	537.04b	546.55a	41.57	11.84	23.68
3. Maize yield kg/ha	1186.04a	1156.60a	80.76	11.94	23.88
4. Labour, man-days/ha	19.30a	20.58a	1.41	3.75	19.23
5. Cost, US/$/ha	31.97a	33.37a	1.10	3.38	13.53
6. Net benefit $/ha	245.72b	278.99a	13.88	6.33	22.61

Means along the same horizontal line followed by the same letter are not significantly (P = 0.05) different according to DNMRT.

Table 13b. Effect of planting pattern in various parameters long rains, 1983.

	M-B-M-B	M-BB-M-BB	(±) S.E between patterns	% C.V. main plots	% C.V. sub-plots
1. Weed dry yield kg/ha	1209.5a	1051.5a	29.17	44.70	46.04
2. Bean yield, kg/ha	546.32a	463.10b	31.38	11.99	28.00
3. Maize yield, kg/ha	1880.00a	2252.48a	163.30	13.69	26.58
4. Labour, man-days/ha	23.30a	27.41a	3.56	22.19	28.22
5. Cost, $/ha	36.50a	41.24a	4.10	16.70	22.65
6. Net benefit $/ha	321.35a	336.29a	16.26	8.56	21.81

Means along the same horizontal line followed by the same letter are not significantly (P = 0.05) different according to DNMRT.

DISCUSSION:

Visual weed rating showed that best weed control was obtained by use of low dosage of herbicide in combination with supplementary weeding. The combined use of herbicide at both low rates with one supplementary weeding each were superior to all other weed control treatments. Ratings further showed that there was suppression of weed growth in these two weed control treatments right from the time of crop germination and throughout the seasons. Several reports (Nieto et. al., 1968; Anon., 1975; De Groot, 1979) have shown that early weed competition as critical on crop yields. During the short rains, pendimethalin at both low rates had a noticeable effect on weeds. In the long rains, however, little or no herbicide effect was observed at all the three rates, this was probably due to the high amount of rainfall, that was received soon after application of herbicide. In the short rains, 6.5mm of rainfall was received the day prior to spraying of herbicide and 65.6 mm in the next seven days. In the long rains, 10.9 mm was received the day before spraying and 203.0 mm in the next seven days. This was considered the main factor for the lower rating and poor weed control in this season. Walker and Bond (1977) have reported that at 25^{o}C, the half life of pendimethalin increased with a decrease in soil moisture among seven soils they studied. Gebhart (1981) also observed that the effect of the combined use of a pre-emergence herbicide and cultivation was not the same from year to year. The weed control response of these variables seem to be influenced by differences in rainfall and available soil moisture. The high amount of rainfall received in the long rains during this short period, possibly led to the apparent in-effectiveness of the herbicide in this season.

Effect of intercropping on dry weed yield: The results on the effect of intercropping on dry weed yield were not conclusive. In the short rains, intercropping maize and beans significantly reduced dry weed yield, compared to sole bean cropping, this was not the case, however, in the long rains. Several workers (Bantilan and Harwood, 1973; Bantilan *et. al.*, 1974; Castin *et. al.*, 1976; Mahyuddin *et. al.*, 1976; Rao and Shetty, 1977; Mugabe *et. al.*, 1980) have reported a low or generally lower weed weight in intercropping than in sole cropping. The extent to which intercropping suppresses weed growth appears to be dependent on the initial weed infestation. The general mean dry weed yield in the short rains was 42.97% higher than in the long rains. Intercropping effect on weed growth was more easily identified. Hart as quoted by Moody and Shetty (1979), reported that there were no statistically significant differences in the total dry matter production from all systems that he studied. He, however, found that weeds constituted 20% and 83% of the total biomass in maize and bean sole crops and 16% when these crops were intercropped. In the three cropping systems, in this study, sole beans seems to have the least suppressive effect on weeds possibly due to the more openness of its canopy. According to Moody and Shetty (1979) and Shetty and Rao (1979), one of the situations that can be observed in the comparative ability of intercrops and sole crops in competing with weeds, is when the intercrop is superior to one of the component crops. This study showed that the maize/bean intercrop is superior to the sole bean cropping. According to the same authors, some of the factors that influence a crop's competitive ability are spreading growth and canopy structure.

The Rose Coco (small) beans variety that was grown is a non-spreading, compact variety, giving a non-continuous canopy. The Katumani Composite maize, however, despite its short structure gave a nearly continuous canopy in a short period of time. This probably explains why there was little difference between intercropped maize and beans and sole maize cropping in their dry weed yields. Due to the growth habit of Rose Coco (small), additional effectiveness of this maize/bean intercrop could be realized by planting double rows of beans between maize rows. Moody (1978) observed that growing of a number of crops in close proximity to one another so that the plant density is greater than in sole cropping should result in greater competition against weeds. Webster and Wilson (1966) and Watters (1971), add that a more complete cover reduces weed growth by competition. A marked decrease in weed dry matter was observed in the 1:2 pattern compared to the 1:1 pattern. The 1:2 pattern depressed weed growth significantly in the short rains but failed to do so in the long rains, though a decrease was still noted. Results from ICRISAT (Ann.Peport1978), indicated that a row arrangement in pearl millet/groundnut intercropping influenced weed infestation.

<u>Effect of weed control treatment on dry weed yield:</u> The response of dry weed yield to weed control treatment was the same across the cropping systems. Results further show that in both seasons there were no statistical differences between weed control treatments in intercropping. The performance of the combined use of herbicide at both low rates with one supplementary weeding each in relation to hand weedings, in their dry weed yields is in close agreement with a report by Sankaran and Mani (1974). They reported that pre-emergence application of atrazine or propazine at 0.5 kg/ha followed by one late season weeding, in their dry weed weights, were superior to all other weed control treatments, except three repeated hand weedings. The results show that pendimethalin at 0.5 kg a.i./ha and 1.0 kg a.i./ha gave poor or no control of the majority of the prevalent weed species mainly; <u>Datura stramonium</u> L., <u>Brassica napus</u> L., <u>Oxygonum sinuatum</u> (Meisn.) Dammer; <u>Tagetes minuta</u> L.; <u>Emex australis</u> Steinh. and <u>Nicandra physaloides</u> L. Gaertn., prior to the supplementary weeding. They were still superior

to all other treatments. Weeds not controlled by the low dosages of herbicide were controlled by the supplementary hand weeding. Versteeg and Maldonado (1978), observed that pre-emergence herbicides applied at half the recommended rates or less resulted in far less initial weed growth than in manually weeded plots and only slightly more than in normal dosage plots. Akobundu (1978b), observed that integrated weed control is one of the best options for weed control in the tropics. According to him, herbicide rates used in sensitive crops fail to provide effective control and hand weeding to control late germinating weeds is necessary. Pendimethalin at 1.5 kg a.i./ha gave fair control initially, however, Tagetes minuta and Bidens pilosa were not controlled. Michieka (1981), too observed that pendimethalin was rather weak on Bidens pilosa. Other weed species which were initially suppressed, outgrew their injury and quickly established themselves especially during the long rains. In one or two hand weedings, weed control was only obtained from the second week after crop-emergence and soon a progressive regrowth occured. In one hand weeding alone, this regrowth could not be checked up to harvest time but in two hand weedings, the second weeding four weeks later removed any regrowth that had occured. This was why high and low dry weed yields were obtained from one hand weeding and two hand weedings respectively.

Effect of intercropping on bean yield:

The results showed that cropping system had very significant (P = 0.01) and significant (P = 0.05) effect on bean yield in the short and long rains respectively. Intercropping maize and beans depressed bean yield by 63.77% in the short rains and 64.26% in the long rains. Fisher (1977, 1979); Edje and Laing (1980); Hasselbach and Ndegwa (1980) and Nadar (1980), have reported a decrease in bean yield in maize/bean intercropping. Considering that only 50% of the population is obtained in intercropping the real reduction is probably lower. The real reduction could therefore be about 32%, this tallies with a reduction of 36% obtained by Nadar (1980), which he got from 50% of the bean population. The decrease in bean yield is reflected in the lower pod number per plant and lower seed number per pod. Intercropping maize and beans depressed pod number per plant by 19.56% in the short rains and 16.74% in the long rains. Nadar (1980), reported a 12-18%

decrease in pod number per plant.

Similarly, 16.75% and 15.36% fewer seeds/pod in intercropping were recorded in the short and long rains respectively. Further, planting of beans in double rows between maize rows gave a higher bean yield than obtained in single rows, despite similar populations. This was thought to be due to the better weed suppression obtained in the 1:2 planting pattern at all levels of weed control, due to the improved ground cover. Bean yield in the short rains was generally lower in both sole and intercropped beans. This could have been due to the higher weed growth in the short rains site, since rainfall did not seem a limiting factor. Conversely rainfall could have been a factor in the short rains, especially when much of it was received during flowering, possibly leading to the fewer number of pods/plant observed in this season.

Effect of weed control treatment on bean yield: The influence of weed control treatment on bean yield was significant (P = 0.01). The highest bean yields were obtained from use of pendimethalin at 0.5 kg/ha and 1.0 kg/ha with one supplementary weeding each. In both seasons there was a wide variation in bean yield among weed control treatments in sole bean cropping while in intercropped maize and beans variation was minimal with all control treatments not statistically different. The level of weed control had little effect on bean yield when intercropped with maize. This could be seen in the correlation coefficients. Bean yield and dry weed yield were negatively correlated, r= -0.75 in sole beans and r = -0.52 in maize/bean intercropping. This implied that in sole bean cropping,bean yield was more sensitive to the amount of dry weed yield resulting from each weed control treatment than in intercropping. The higher bean yields obtained in use of pendimethalin at 0.5 kg/ha and 1.0 kg/ha with one supplementary weeding over other weed control treatments could be attributed to the early suppression of initial weed competition in pure bean stands i.e. at 10-40 days after crop emergence. This was the same in intercropping except the the critical period was shorter. Versteeg and Maldonado (1978), as discussed in the literature review reported that weed growth in low dosage treatments was far less than in manually weeded plo before the supplementary weeding and their initial development less aggressive. At 1.0 kg/ha stunting effects of pendimethalin start to show in sole bean cropping, this is seen in the slightly lower bean yield that was obtained at this rate compared to 0.5 kg/ha pendimethalin with one supplementary weeding. Due to the high quantity of rainfall received after spraying of herbicide in the long rains, these effects were not marked in the long rains. Michieka (1981); Wanjala and Michieka (1981) and De Groot (1979), have reported a reduction in bean vigour by pendimethalin. In intercropping, due to the overall improved weed control, the bean yield at 1.0 kg/ha with one supplementary weeding was higher than in pendimethalin at 0.5 kg/ha with one supplementary weeding. Bean yield from plots sprayed with pendimethalin at 1.5 kg/ha was low due to a possible combined effect of herbicide injury and poor weed control. This was especially the case in the short rains when more herbicide injury at this rate was observed. One hand weeding gave the same bean yields as two hand weedings.

Effect of intercropping on maize yield:

Intercropping maize and beans had no effect on maize yield, this is in agreement with earlier findings

(Fisher, 1977; 1979; Francis and Sanders, 1978). This is reflected in the absence of statistical differences in cob lengths and maize yield between intercropped and sole cropped maize. Beans did not compete for growth resources with maize, indeed a slight increase in yield was realised from intercropped maize. Bantilan et. al. (1974); Mahyuddin et. al. (1976) and Fisher (1979), have reported similar findings. Slightly longer cobs in the intercropped maize due to better weed control in intercropping could possibly be the reason. Planting two rows of beans between maize rows in a 1:2 pattern did not affect maize yield.

Effect of weed control treatment on maize yield: Results indicate that weed control treatments had very significant ($P = 0.01$) effect on maize yield with the best yields obtained from two hand weedings and the lowest from no weed control. Unlike in beans, use of low dosages of herbicide in combination with supplementary weeding does not improve yields better than two hand weedings. At 1.0 kg a.i./ha with one supplementary hand weeding, pendimethalin gave better weed control than at 0.5 kg a.i./ha with one weeding. This is probably why the former rate gives higher maize yields. The control of initial weed growth by application of lower rates of pendimethalin is not particularly an advantage over two hand weedings in maize. This is because maize is fast growing soon outcompeting weeds. Before the first and second hand weedings are executed, weed competition has not been felt much by the maize crop.

Land Equivalent Ratios (LER): These ratios were calculated in order to put the different crops and situations into a comparable basis and to give a measure of the yield advantage. Land Equivalent Ratio values of less than one, equal to one and greater than one, indicate, respectively no yield advantage, no difference and a yield advantage. The LER values for the two seasons (Appendix VIII) indicate that in all weed control methods there was a yield advantage in intercropping maize and beans. The highest LER in the short rains was in the use of pendimethalin at the lowest rate combined with a supplementary hand weeding. No weed control had the lowest, but in the long rains, this had the highest LER. Nadar (1980), reported that the maize/ bean intercropping system consistently showed a ratio above one, for four seasons. Mahyuddin et. al. (1976) reported having obtained the highest LER value in no weed control treatment. In this study, this was only true for the long rains. It was thought that the very high initial weed infestation in the short rains did not allow the advantage of intercropping to be realised in no weed control. A certain degree of weed control was therefore required. However, maize yield was still higher in the intercrop implying that bean suffered more from weed competition both in the intercrop and sole bean crop. In the lighter weed infestation during the long rains, the situation allowed the advantage of intercropping in weed control to be felt hence the high LER value obtained in this season in no weed control.

The effect of weed control treatments on labour requirement and cost: Results of this study indicated that intercropping maize and beans required more labour for weed control than sole maize cropping and about the same as sole bean cropping. The differences in labour requirements between the three cropping systems, however were not statistically significant. Several authors (Webster and Wilson, 1966; Cleave, 1974; Lageman, 1977; Moody, 1978); have reported that intercropping leads to reduced labour requirement for weeding. The findings in this study are in agreement with reports by Moody (1977); Baker and Norman (1975); Norman (1974) and Moody and Shetty (1979) that labour requirement is not always low in intercropping. Day as quoted by Moody and Shetty (1979) states that labour for weed control is just as great in intercropping as in sole cropping. Owuor (1976), reported that significantly less labour input for planting and weeding was required in sole maize cropping than in either intercropped maize and beans or sole beans. This was the case in this study. Both inter and intra row spacing of component crops seems an important determinant of labour requirement. The reduced inter row spaces between maize rows by planting of bean rows in a maize/bean intercrop leads to the increased labour requirement in intercropping compared to sole cropped maize. A saving in labour in intercropping seems to occur only if there is a reduction in weed weight in the crop combination compared to the sole crops. This was the case in the short rains when intercropping reduced weed weight significantly (P=0.05) compared to sole beans. Norman (1974), remarked "the reasoning that intercropping requires less labour than sole crops, has been based on the premise that some operations such as planting of the second crop and weeding of the first can be combined". Further Syarifuddin et. al.,(1975) reported that it only took less time to weed crops grown in intercrop combination than when the same crops were sequentially grown as sole crops. Norman (1974), noted that although theoretically, labour should be saved by intercropping, quantitative evidence does not support this. When double rows of beans are planted between the maize rows, a noticeable increase in labour requirement is observed. This is particularly so due to the even further reduced inter row spacing making hand weeding slower.

According to this study, use of reduced dosages of pendimethalin at both 0.5 kg/ha and 1.0 kg/ha with supplementary weeding each required less labour for weeding than two hand weedings. At 1.0 kg a.i./ha labour requirement was even less than in one weeding only but about equal to that used with pendimethalin at the lower rate. The two rates too did not differ statistically from each other. Jennings and Drennan (1979); Versteeg and

Maldonado (1978), reported a reduction in labour when a low dosage of herbicide was combined with a supportive hand weeding. ICRISAT (1976) reported that in treatments that received a minimal amount of herbicide at the rate of 0.75 kg/ha alachlor, only 10 woman-days/ha were required for the supportive weeding compared to the average of 48 woman-days normally required for hand weeding. Ogborn (1978) found that a pre-plant herbicide application reduced weeding effort from 84 man-days per hectare to 55 man-days/ha. Akobundu (1978b), stated that a pre-emergence herbicide would be appropriate not only for minimizing early weed competition but also to reduce the workload during peak periods. The use of pendimethalin at low dosages with one supplementary weeding each reduced cost of control compared to two hand weedings but cost more than one hand weeding only. At 0.5 kg/ha with one supplementary weeding, pendimethalin reduced weed control cost by 35.2% in the short rains and 13.22% in the long rains. At 1.0 kg/ha with one supplementary weeding pendimethalin reduced weed control cost by 20.61% in the short rains and only 3.41% in the long rains compared to two hand weedings. Versteeg et. al.

(1978) reported a reduction of 40% on hired labour cost by use of reduced dosage of herbicide with supplementary weeding, in farm sizes of 3-5 hectare in Brazil and Okigbo (1978) reported a 34% reduction in Nigeria. In this study pendimethalin at 0.5 kg/ha with one supplementary weeding compared very favourably with these reports, during the short rains. There was a marked seasonal difference between the short and long rains in labour requirements. In the short rains the difference in cost between the combined herbicide and hand weeding methods of weed control and two hand weedings were significant in the maize/bean intercrop and not statistically significant in the long rains. This could have been due to the high amount of rainfall received during and after application of herbicide in the long rains reducing or cancelling out benefit that should have accrued from its use, leading toin increased cost.

<u>Profitability of use of reduced rates of pendamethalin in combination with supplementary weeding.</u>

<u>Effect of intercropping on net benefit</u>: Results showed that intercropping maize and beans gave the highest net benefit.

Though the yield of beans was depressed, maize yield remained fairly steady. The additional yield obtained from beans was therefore the main contributor to the higher gross benefit obtained from intercropping, Norman (1974) noted that although yields of individual crops may be depressed when grown in mixtures rather than in sole stands, the presence of yields from other crops in the mixture more than compensated for this decrease. Similarly, Castin et. al.,(1976) reported the superiority of intercropping in yield. Several authors have generally concluded that crop mixtures result in greater returns per unit area (Munro, 1960; Grimes, 1962; Evans and Streedharan, 1962; Rao et. al., 1979; Nadar, 1980; Nnko and Doto, 1980). Intercropping had a higher labour requirement for weed control than sole bean cropping in the short rains and the highest in the long rains. The higher labour input for weed control in intercropped maize and beans was compensated by the higher gross return that resulted, hence giving the higher net benefit obtained. An important factor that determines the profitability of a maize/bean intercrop is the prevailing prices of these crops (Francis and Sanders, 1978; Rao et. al., 1979). The former authors observed that below a price ratio of 4:1 for beans: maize, a maize/bean intercropping is profitable and sole bean cropping becomes profitable above the ratio. In this study, the prevailing price of US$ 0.26 per kilogram of beans and $10.00 per 90 kilogram bag of maize gives a bean:maize price ratio of 2.4:1, this is well below the 4:1 price ratio. Intercropping maize and beans is therefore more profitable. Further, Francis et. al. (1978) reported that monoculture beans are profitable over a wide range in relative prices, only if the farmer is able to introduce an intensive package of technology. In this study a deliberate attempt was being made to reduce weed control costs by use of reduced dosages of herbicide with one supplementary hand weeding. The higher net benefit from intercropping in the study confirm these workers' report that the profitability of attaining a consistent income with relatively lower investment is highest in the maize/bean associated cropping. Nadar (1980) reported that in the economic analysis of intercropping, it is not economical to grow beans as a monocrop and if growing beans and maize is desirable it is better to grow them intercropped. This study further indicated that a higher net benefit is obtained from growing double rows of beans between maize rows instead of single rows. This is due to the improved weed control and higher gross benefit despite increased labour requirement and cost of weed control. During the short rains the net benefit from maize/bean intercrop was significantly ($P = 0.05$) higher than in sole bean or maize cropping, but no significant difference could be detected in the long rains. Francis et. al. (1978) reported a non-significant difference in net income between monoculture beans and the maize/bean intercrop. The significance during the short rains was thought to be due to the higher initial weed infestation probably leading to more pronounced advantage of intercropping. The greater severity of weed infestation in the short rains affected bean yields most in the sole bean cropping. Results showed beans to suppress weeds least. The low bean yields obtained in the short rains and the high cost of weed control in the sole beans could explain the presence of the significant difference in net benefit between sole bean cropping and intercropped maize and beans.

The effect of weed control treatment on net benefit: This was found to be significant at P = 0.01, in both seasons. The use of the two low rates of pendimethalin in combination with one supplementary hand weeding, gave net benefits that were of the same magnitude as obtained in two hand weedings and no statistical difference could be detected. Versteeg *et. al.*, (1978) and Akobundu (1978b) attributed this to the protection offered by the low dosages of herbicide against weed competition during the critical phase. Sankaran and Mani (1974), noted that the pre-emergence application of either atrazine or propazine at 0.5 kg/ha followed by one late season weeding gave control of grass weeds equal to three repeated weedings and they obtained the highest return over control from use of propazine at 0.5 kg/ha with one late season weeding. During the long rains a very high amount of rainfall was received the week of herbicide application. It is possible that a high loss of herbicide especially at the low rates must have resulted, leading to loss of protection against the initial weed growth. The higher labour requirement, cost of weed control and lower bean yield observed from use of 0.5 kg/ha and 1.0 kg/ha with one supplementary weeding each, in the long rains in relation to one or two hand weedings, could explain why two hand weedings gave higher net benefit than pendimethalin at these two rates with one supplementary weeding each in this season. The effect of rainfall in the long rains could also be seen in the poorer control of weeds observed from application of pendimethalin at 1.5 kg/ha. This was responsible for the significantly low net benefit obtained from chemical control compared to two hand weedings in the long rains. In a situation where initial weed infestation is high, there appears to be a definite advantage in the use of low dosages of herbicide as the initial growth is suppressed enough to allow the supplementary hand weeding give good weed control. Moody (1977), cautioned that a certain rate of herbicide application is needed for weed control, below this level, weed control is greately reduced. Rates should therefore not be lowered to a level where weed control is no longer achieved or is greatly reduced.

The factors that determine the profitability of the combined use of reduced dosages of herbicide and supplementary hand weeding in the intercrop appear to be; degree and cost of weed control, yields of component crops and the maize and bean prices. This method required less labour for weed control than both one and two hand weedings. Only at 0.5 kg ai./ha did this combined method require slightly more labour than a single hand weeding only. Though cost of weed control at the two low rates was higher than for the single hand weeding, crop yields obtained were higher. This, resulted in higher net benefits for the two treatments. Akobundu (1978 b), observed that saving labour is at least as important economically as the prevention of production losses. Though there is a considerable saving of labour in the sole use of herbicide at normal dosage, there is both poor weed control and crop injury to beans causing unacceptably low net benefit. In the maize/ bean intercrop, prices of these crops becomes an important factor. Where bean yield is reduced either due to crop injury as in the use of herbicide at 1.0 kg a.i./ha in the short rains, and 1.5 kg a.i./ha in both seasons or poor weed control as in one hand weeding in the short rains and herbicide at 1.5 kg a.i./ha in both seasons, net benefit is likely to be low. At the prevailing price ratio of 2.4:1, beans:maize, bean yield is therefore an important factor in the profitability of method of control.

In the marginal analysis of net benefits of method of control in the short rains, only the combined use of herbicide at 0.5 kg a.i./ha with one supplementary hand weeding and one hand weeding alone were undominated. Only these two methods could be economically acceptable. The higher cost of weed control realised in the other methods with lower net benefits, made them uneconomically viable. In the long rains, the combined use of herbicide at the two low dosages with one supplementary weeding each were not economically viable as they were both dominated. However, the marginal analysis of net benefit and variable cost for the two seasons, showed that only the use of herbicide at 1.0 kg a.i./ ha witn one supplementary weeding was uneconomic. The increase in cost realised from the use of the extra litre of herbicide per hectare at this rate, over the lower rate of 0.5 kg a.i./ha could not be justified by increase in crop yield. Perrin, Winkelmann, Moscardi and Anderson (1979), have stated that as a general rule farmers will not want to make an investment unless the average rate of return to investment is at least 40% per crop season. In this study all control methods gave over 40% returns and could be economically viable, except, the combined use of pendimethalin at 1.0 kg a.i./ha with one supplementary weeding. High percent marginal rates of return to investment were observed because of the high marginal increases in net benefit and the low marginal increases in variable cost. The main factor therefore in choice of weed control method is the resources (capital) available at ones disposal. The two methods that gave the highest mean net benefit were two hand weedings and the combined use of pendimethalin at 0.5 kg a.i./ha with one supplementary weeding. The use of the latter method especially in the double bean rows between the maize rows, might be the more desirable alternative. According to Ngugi and Kinyanjui (1978) and Laycock (1974), labour unavailability and cost are limiting factors in weed control in Kenya. For this reason use of pendimethalin at 0.5 kg a.i./ha with one supplementary weeding is especially desirable, in comparison to two hand weedings. In the two seasons, this rate of herbicide plus one supplementary weeding required an average of 24.76 man-days per hectare while two hand weedings required 36.59 man-days per hectare. A saving of 11.83 man-days is realised per hectare, with only a loss of US $17.73 in net benefit from two hand weedings. In a situation such as this where labour is a limiting factor, this 11.83 man-days saved per hectare can be chanelled to other farm activities with possibly higher marginal return to investment. Plucknett, Rice,Burrill and Fisher (1976), have emphasized the need to find a suitable agro-socioeconomic situation in the trade-off between labour (number of hoeings) and capital (rates of herbicide). In this study it was noted that only at the rate of 0.5 kg/ha pendimethalin was there an economic trade-off between these limiting factors; labour and capital. A saving in labour was realised in the use of herbicide at this rate over two hand weedings which offered the highest mean net benefit, with a relatively low loss in net benefit. Armstrong, Leasure and Corbin (1967), observed that the choice of weed control method should take into account factors such as cost and return relationships, timeliness and the alternative uses of labour in addition to the effectiveness of control method. The use of pendimethalin at 0.5 kg a.i./ha with a supplementary weeding certifies these requirements.

CONCLUSION:

This study has shown that intercropping maize and beans is more profitable at the existing price ratio than either sole bean or sole maize cropping. If growing of either crop is desired then preference should be to grow them intercropped. This is inspite of having as high cost of weed control as sole bean cropping. Further, intercropping maize and beans did not necessarily aid in weed suppression, however, results were inconclusive.

The study further still shows that there is scope for use of pendimethalin at reduced dosages in combination with supplementary hand weeding. This reduces labour requirement needed for weed control, compared to the traditional two hand weedings. In the short rains the combined use of pendimethalin at 0.5 kg a.i./ha plus a supplementary hand weeding, reduced labour requirement by 55.5% in the maize/bean intercrop. At the higher rate of 1.0 kg a.i./ha plus a supplementary weeding, the reduction on labour requirement was 57.2%. This was in comparison to two hand weedings. During the long rains, reduction in labour requirement was not so good. At 0.5 kg a.i./ha plus one supplementary weeding the reduction in labour requirement was only 3.6% while at 1.0 kg a.i./ha plus a supplementary weeding the reduction was 34.4%. Both reductions were again in comparison to two hand weedings. The seasonal differences were believed to have been influenced by the amount of rainfall received soon after application of herbicide in each season. Further both reduced rates of herbicide cut down on cost of weed control in the intercrop during the short rains. Use of pendimethalin at 0.5 kg a.i./ha plus a supplementary weeding, cut down on cost by 38.3% in the short rains but failed to do so in the long rains. Infact, raising cost of weed control by 14.4%. At 1.0 kg a.i./ha plus a supplementary weeding, reduction in cost of control, compared to two hand weedings was 22.9%, in the short rains. It, however, raised cost by 6.8% in the long rains. This was again thought to be due to the high rainfall received, soon after herbicide application during the long rains. The high amount of rainfall could have led to herbicide loss by leaching or in run-off. This cancelled out any advantage on suppression of early weed growth that could have accrued from the reduced herbicide dosage. The herbicide at these low dosages was literally wasted thus the higher labour requirement and cost of weed control for these two treatments, in the long rains.

Use of low dosages of herbicide gave crop yields of nearly the same magnitude as in two hand weedings, even better for the bean yield. The two herbicide rates plus supplementary weedings, caused no herbicide injury on beans. Both treatments gave net benefit that was better than use of herbicide alone at 1.5 kg a.i./ha in the two seasons and even two hand weedings, during the short rains. Use of pendimethalin at 0.5 kg a.i./ha plus a supplementary weeding gave a higher net benefit than use of the herbicide at 1.0 kg a.i./ha plus a supplementary weeding, in the two seasons. Results have shown that the advantages of using low dosages of herbicide in combination with one supplementary weeding appear to be dependent on rainfall received at time of application.

<u>Specific conclusions from this study include:</u>

a) Use of reduced dosages of herbicide both at 0.5 kg a.i./ha and 1.0 kg a.i./ha plus a supplementary weeding each did not cause any herbicide injury to beans. Further, both low rates only suppressed the initial weed growth but failed to control certain weed species.

b) This combined techniques of control gave crop yields that were apparently better than either use of pendimethalin at 1.5 kg a.i./ha oe one hand weeding alone.

c) In the short rains, the combined technique of control reduced both labour requirement and cost of weed control compared to two hand weedings. This difference was not clear in the long rains.

d) Use of pendimethalin at 0.5 kg a.i./ha plus a supplementary weeding was the most beneficial in terms of net benefit.

Future research: from the conclusions, future research should focus mainly on;

a) Testing other herbicides with better weed control than pendimethalin but with known toxic effects on beans, at reduced dosage plus supplementary hand weeding.

b) Investigate the effect of rainfall on herbicide performance and amount lost at a reduced dosage.

c) Test pendimethalin in a site which has a mixed weed population i.e. grasses and broadleaf weeds.

d) Determine labour input in sequential herbicide application.

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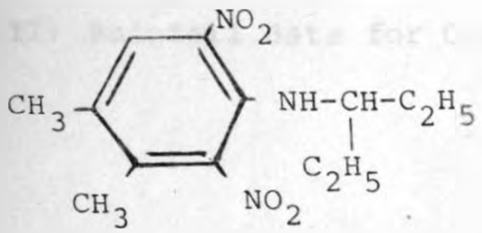
APPENDICES:

Appendix I:

Molecular structure of pendimethalin :



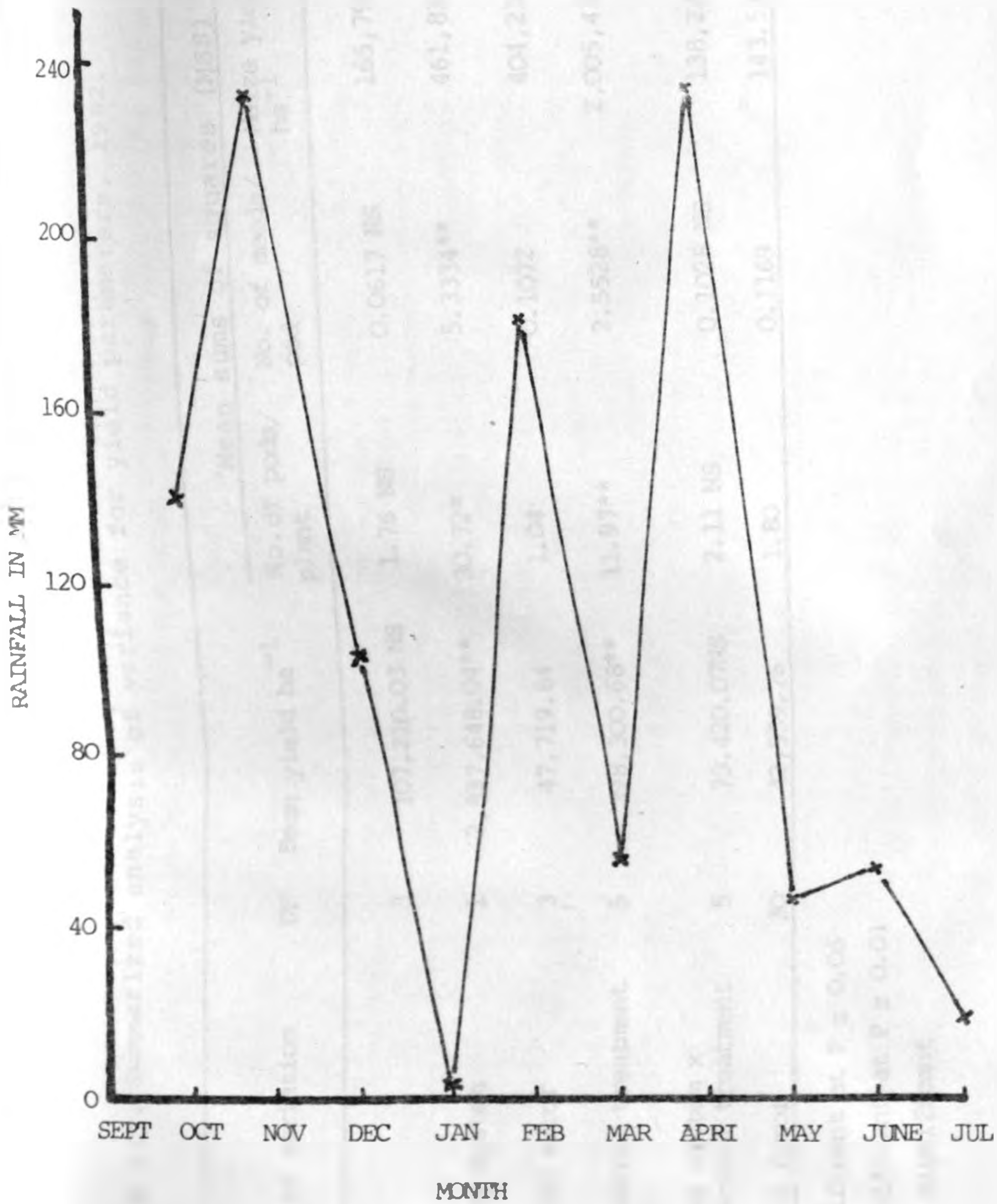
The formulation used was an emulsifiable concentrate designated as 500-E.

Active ingredient (a.i.) is that portion of the herbicide which effects weed kill.

Amount of herbicide used per sub plot was calculated using the following formula,

$$\frac{\text{Rate(g/ha)} \times \text{Area of sub plot } (M^2) \times \text{ml}/\ell}{\text{a.i. E.C. (g/kg)} \times \text{Area of 1 ha } (M^2)} = \text{millilitres}$$

Appendix II: Rainfall data for October 1982-July, 1983.



Appendix III. Summarized analysis of variance for yield parameters, 1982.

Source of variation	DF	Mean sums of squares (MSS)				
		Bean yield ha^{-1}	No. of pods/ plant	No. of seeds/ pod	Maize yield ha^{-1}	Cob length (cms)
Block	3	107,210.03 NS	1.76 NS	0.0617 NS	165,796.53 NS	2.22 NS
Cropping system	1	2,837,648.04**	30.72*	5.3334**	461,837.20 NS	5.67 NS
Main plot error	3	47,719.84	1.04	0.1072	404,214.07	5.19
Weed control treatment	5	398,300.68**	11.97**	2.5528**	2,005,431.94**	7.47**
Cropping system x weed control treatment	5	73,420.07NS	2.11 NS	0.1028 NS	138,227.38 NS	1.84*
Sub-plot error	30	42,539.76	1.80	0.1169	143.532.22	0.55

* significant at P = 0.05

** significant at P = 0.01

NS Not significant

Appendix IV. Summarised analysis of variance for yield parameters, 1983

Source of variation	DF	Mean sums of squares (MSS)				
		Bean yield ha^{-1}	No. of pods/ plant	No. of seeds/ pod	Maize yield ha^{-1}	Cob length (cms)
Block	3	915,069.63 NS	0.95 NS	0.4058 NS	251,068.35 NS	2.19*
Cropping system	1	6,490,684.56*	24.94**	3.5209**	3,520.03 NS	0.012 NS
Main plot error	3	364,182.14	0.20	0.0625	1,085,266.53	0.20
Weed control treatment	5	1,047,861.63**	27.03**	2.7823**	5,974,578.92**	18.07**
Cropping syst. x Weed control Treatment	5	233,778.34**	4.92**	0.2113*	105,404.47 NS	2.20 **
Sub plot error	30	50,100.54	0.28	0.0708	360.496.63	0.48

* significant at P = 0.05

**significant at P = 0.01

NS not significant

Appendix V. ANOVA, Weed yield, short rains, 1982.

	DF	SS	MS	Fcal
Block	3	139,616.32	46,538.77	
Cropping system	2	221.000.79	110,500.40	3.00 NS
Main plot error	6	93,078.65	15,513,11	7.12*
Treatment	5	1,352,927.76	270,585.55	
Crop syst. x Treat	10	119,626.21	11,962.62	17.43**
Sub plot error	45	698.614.24	15,524.76	0.77 NS

ANOVA Weed yield, Long rains, 1983

	DF	SS	MS	Fcal
Block	3	27,487.62	9,162.54	
Cropping system	2	53,455.05	26,727.52	2.11 NS
Main plot error	6	75,890.05	12,648.34	
Treatment	5	193,112.82	38,622.56	14.60**
Crop syst. x Treatment	10	43,013.39	4,301.34	1.63N
Sub plot error	45	119,068.59	2,645.97	

* significant at P = 0.05

** significant at P = 0.01

NS not significant

Appendix VI. ANOVA Cost of control[1], short rains, 1982

Source of variation	DF	SS	MSS	F-value
Block	3	8,061.40	2,687.13	0.33 NS
Cropping system	2	55,086.43	27,543.21	3.36 NS
Main plot error	6	49,240.21	8,206.70	
Treatment	4	664,847.34	166,211.84	75.43**
Crop syst. x Treatment	8	27,017.14	3,377.14	1.53 NS
Sub plot error	36	79,324.15	2,203.45	

ANOVA, Cost of control[1], Long rains, 1983

Source of variation	DF	SS	MSS	F-value
Block	3	528,509.43	176,169.81	5.64*
Cropping system	2	258,608.17	129,304.09	4.14 NS
Main plot error	6	187,289.57	31,214.93	
Treatment	4	303,558.09	75,889.52	37.68**
Crop syst. x Treatment	8	153,803.90	19,225.49	1.86 NS
Sub plot error	36	356,102.63	9,891.74	

* significant P = 0.05

** significant P = 0.01

NS Not significant.

[1] In analysis of variance for cost of control, the no weed control treatment was not included since it had no cost value and was the same for all cropping systems.

Appendix VII. ANOVA, Net benefit, short rains, 1982

Source of variation	DF	SS	MSS	Fcal
Block	3	2,808,588.70	936,196.23	0.93 NS
Cropping system	2	19,683,501.70	9,841,750.85	9.73*
Main plot error	6	6,067,792.3	1,011,298.72	
Treatment	5	38,057,584.2	7,611,516.84	15.40**
Crop.syst. x Treatment	10	6,677.002.7	667,700.27	1.35 NS
Sub plot error	45	22,243,283.4	494,295.19	

ANOVA Net benefit, long rains, 1983

Source of variation	DF	SS	MSS	Fcal
Block	3	19,771,241.0	6,590.413.67	1.22 NS
Cropping system	2	22,821,416.79	11,410,708.39	2.12 NS
Main plot error	6	32,262,234.96	5,393,705.83	
Treatment	5	119,121,469.5	23,824,293.90	26.39**
Crop.syst. x Treatment	10	16,761,719.65	1,676,171.97	1.86 NS
Sub plot error	45	40,621,791.1	902,706.47	

* significant at P = 0.05

** significant at P = 0.01

NS Not significant.

Appendix VIII. Land equivalent ratios 1982-1983

Weed control treatments	Land equivalent ratios	
	Short rains	Long rains
Pendimethalin 0.5 kg a.i./ha + supplementary weeding	1.79	1.39
Pendimethalin 1.0 kg a.i./ha + supplementary weeding	1.43	1.35
Pendimethalin 1.5 kg a.i./ha	1.53	1.27
One hand weeding only	1.48	1.19
Two hand weedings	1.34	1.43
No weed control	1.21	1.51