Maize–weed competition and soil erosion in unweeded maize

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Received June 1981

Weeding is one of the most labour-demanding phases of the production of maize (*Zea mays* L.) by village farmers in Africa. Because herbicides may not be appropriate, the possibility of using the maize crop itself to control weeds was investigated. Four experiments were conducted in two years in central Malawi to determine the influence of plant arrangement, population density, maize vigour, and fertilization practices on the maize–weed competition. The effects of weeding on soil and water conservation were also studied. Weed dry matter production was negatively correlated with maize population density. Maize grain yields of 12.12 t ha^{-1} were produced on totally unweeded plots where 120 kg N and 22 kg P were applied and 80 000 hybrid maize plants were grown per hectatre. Clean-weeded plots produced a yield of 13.66 t ha^{-1}. With 20% as much fertilizer and an open-pollinated variety of maize, yields were much lower, both absolutely and in relation to clean-weeded control plots. The effect of plant arrangement on maize yields depended on maize density. The highest yields at 20 000 plants ha^{-1} occurred with equidistant spacing but at 80 000 plants ha^{-1} the greatest yields were associated with the widest row spacing. The weedy ground cover reduced soil erosion losses from 12.1 t ha^{-1} on the weeded plots to 4.5 t ha^{-1} on the unweeded plots.

Keywords: *Zea mays* L; Weed control; Soil erosion

Hoeing weeds is one of the most labour-demanding phases in the production of maize (*Zea mays* L.) by African village farmers. On the larger, more mechanized farms weed control is also expensive in terms of machinery, fuel, labour and herbicide costs. In Malawi, as in much of central Africa, maize is the staple food of the people. For this reason, and because of the substantial effect of planting date on grain yields, maize is generally the first crop to be planted with the onset of the rainy season (Lungu, 1971). The critical time for controlling weeds in maize is during the first six weeks after planting when the maize is becoming established and its canopy does not yet effectively shade out inter-row weeds (Klingman, 1961; Vega & Obien, 1965). The traditionally recommended practice in Malawi is to weed the maize fields three times during this period. Work by the Malawi Ministry of Agriculture indicated that reducing this to two timely weedings did not significantly affect yields (Malawi Government, 1977).

Peanuts (*Arachis hypogaea* L.), beans (*Phaseolus vulgaris* L.), and tobacco (*Nicotiana tabacum* L.) are other major crops grown by villagers in the region to diversify their diet or to obtain a cash income. The period of field preparation and planting of these crops coincides with the critical period for weeding maize. Thus, there tends to be a competition for the available labour between the staple food crop, maize, and these other important food and cash crops. The acreage of the latter may be limited by the necessity of weeding the former. Herbicides have not been found to be an appropriate solution to this problem because they are uneconomic, ineffective and/or dangerous when used by untrained village farmers (Parker, 1972; Brown & Beaty, 1970).

This study investigates the possibility of using the maize crop itself to control weeds through vigorous competition. Little work has been published that directly studies the competitive ability of maize with respect to weeds. However, it is recognized that 'crop competition is one of the cheapest and most useful methods (of weed control) farmers can use' (Klingman, 1961). Research on the intercropping of other crops with maize generally has shown that maize is an aggressive competitor. Eplee & Kingman (1968) investigated the influence of maize planting density on the effectiveness of simazine (2-chloro-4, 6-*bis*(ethylamino)-s-triazine) in controlling weeds. They found that the competitive ability of maize had a synergistic effect with the herbicide. Simazine had little effect on the production of weeds where no maize was grown and the percentage weed control obtained increased greatly as the density of the maize stand was increased.

The main objective of the work reported here was to study maize–weed competition as influenced by management level, fertilizer placement, plant arrangement and population density. A secondary objective was to determine the effects of weeding on soil erosion and run-off.

Materials and methods

The experiments were conducted during the 1977/78 and 1978/79 growing seasons at the research farm of Bunda College of Agriculture, University of Malawi. This site is located approximately 30 miles southeast of Lilongwe at an elevation of 1100 m above sea level and latitude 14 °S. The soil used is the Lilongwe series, a member

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0041-3216/82/030207-07 $3.00

Table 1 Effects of maize population density and row width on the yields of maize and weeds in unweeded plots

Row width cm	Maize density, plants ha^{-1}	Maize grain, ** t ha^{-1}	Dry matter produced, t ha^{-1} Maize	Weeds	Total	Maize dm,† %
91	31 000	6.8a*	13.7a	4.9a	18.6a	74a
91	52 000	10.6b	18.2b	2.9b	20.9a	87b
91	57 000	11.1b	18.6b	3.0b	21.5a	87b
60	75 000	12.5b	22.0b	1.4c	23.4a	94c
60	77 000	10.9b	20.0b	1.1c	21.2a	95c

* Mean followed by the same letter do not differ significantly at the 0.05 level according to Duncan's New Multiple Range Test
** Maize grain at 15.5% moisture.
† Maize dry matter as percentage of total dry matter produced

of the oxic rhodustalfs. Some properties of the plough layer (0–15 cm) of this soil are: organic matter = 4.3%; C.E.C. (NaOAc) = 14.7 meq/100 g; pH (H_2O) = 5.4; sandy clay texture (40% clay). Mean annual rainfall at the site is 1046 mm; more than 80% of this occurs in the four-month period December–March. The average growing season, based on moisture availability to maize, is 144 days (Hay, 1981).

In experiment 1 the soil was disc-ploughed to 20 cm, and rolled to crush clods during the dry season. Once the soil was moistened by the first rains, ridges were built up with hand hoes and fertilizer was band-applied at the rate of 45 kg ha^{-1} N and 19 kg ha^{-1} P. One week later, on 6th December, 1977, maize (hybrid SR 52) was hand-planted at several population densities (Table 1) on ridges approximately 40 cm high and either 91 or 60 cm apart. No attempt was made to control weeds and the plots were not entered again until harvest, except on 11th January 1978, when a side dressing of 56 kg ha^{-1} N (as calcium ammonium nitrate) was applied by the dollop method. The 4 × 6 m plots were replicated four times and arranged in a randomized complete block design.

Experiments 2 and 3, conducted in 1978/79, were similar to each other in design, except that in experiment 2 maize was grown at a high management level typical of the more productive farms in Malawi, i.e. a maize hybrid (SR 52) with 120 kg ha^{-1} N and 22 kg ha^{-1} P, whereas in experiment 3 a lower level of management, more typical of village farmers, was used, i.e., an open pollinated cultivar (U.C.A.) with 24 kg ha^{-1} N and 4.4 kg ha^{-1} P. Tillage and planting were done before the first rains of the season had moistened the soil enough to germinate any weed seeds. This gave a severe test of the competitive ability of the maize as not even the first generation of weeds was killed. In these experiments no ridges were built up; the maize was planted on a flat seedbed. All of the P and 42% N were applied at planting time by placing an appropriate quantity of fertilizer in a dollop 5 cm to the side and 5 cm below each maize seed planted. The remaining N was

Table 2 Yields of maize and weeds as affected by plant spacing and weeding in experiment 2

Treatment number	Maize plant spacing, cm	Dry matter yields, t ha^{-1} Weeds	Maize	Total	Weed dm** %	Grain,† t ha^{-1}	Maize dm, g plant^{-1}
1	70 × 70	6.74	10.57	17.32	38	5.77	333
2	86 × 57	6.17	11.34	17.51	36	6.32	383
3	99 × 50	6.62	7.48	14.11	46	4.18	260
4	121 × 40	5.67	7.59	13.3	42	4.43	263
5	140 × 35	7.16	6.45	13.6	51	3.86	239
Means for 20 000 plants ha^{-1}		6.47a*	8.69c	15.16b	43a	4.92c	296a
6	50 × 50	4.38	14.09	18.47	24	8.88	252
7	61 × 41	3.69	16.38	20.06	18	10.24	276
8	71 × 35	4.08	16.27	20.35	19	9.12	279
9	87 × 29	3.99	11.74	15.73	25	7.56	216
10	100 × 25	4.72	13.06	17.78	26	8.13	235
Means for 40 000 plants ha^{-1}		4.71b	14.31b	18.48a	22b	8.78b	252b
11	35 × 35	2.24	15.77	18.01	12	9.40	149
12	43 × 29	2.33	14.79	17.12	16	8.80	134
13	50 × 25	2.05	16.78	18.84	11	10.25	153
14	61 × 20	1.90	18.31	20.21	9	10.47	177
15	70 × 18	2.00	20.27	22.25	9	12.12	194
Means for 80 000 plants ha^{-1}		2.1c	17.19a	19.29a	11c	10.21a	162c
16	87 × 29	—	19.64	19.64	—	11.47	327
17	32 × 35	—	22.30	22.30	—	13.66	208
18	Weeds only	11.13	—	11.13	100	—	—
S^2		2.48	4.68		15.72	2.88	36

*Means followed by the same letter do not differ at the 0.05 level of significance according to Duncan's New Multiple Range Test
**Weed dry matter as percentage of total dry matter produced
†At 15.5% moisture

applied as a side dressing 24 days after emergence. The plot treatments consisted of three population densities (20 000, 40 000 and 80 000 plants ha^{-1}) with five row widths within each population, two weed-free controls (hand-weeded), and a weed-only treatment in which the seedbeds were prepared and fertilized but no maize was planted (Table 2). Experiments 2 and 3 thus included 18 treatments each. The treatment plots were 5 × 8 m and were arranged in randomized complete block designs, with four replications in each experiment.

Experiment 4 was designed to test the influence of fertilizer placement and ridging on the yield of unweeded maize. Hybrid maize (SR 52) was planted in 60 cm wide rows at the rate of 83 000 plants ha^{-1}. Four treatment factors (ridged seedbed, flat seedbed, dollop fertilizer application and broadcast application) were combined in a 2 × 2 factorial arrangement. These plots were unweeded. Two completely hand-weeded and ridged treatments were also included, one with dollop-applied fertilizer and the other with broadcast fertilizer application. The dollop application method was the same as described for experiments 2 and 3. For the broadcast fertilizer application treatments, a basal dressing was broadcast on the soil surface prior to ridging and worked into the top 15 cm of soil. The side dressed N (as calcium ammonium nitrate) was broadcast at 24 days post emergence. These six treatments were applied to 4 × 6 m plots laid out in a completely randomized design with four replications.

In experiments 2 and 3 two 0.25 m^2 quadrants from each plot were sampled for weed and maize dry matter and maize plant height at 23 and 42 days after maize emergence. In all experiments maize and weed above-ground parts were harvested and weighed in the field after the maize had matured and samples were dried for 72 h at 70 °C to determine the moisture contents. Maize grain, cobs, husks, stover and weeds were harvested separately. The principal weed species encountered are listed in Table 3.

Run-off losses of water and soil losses by erosion were measured in experiment 2 on the plots for treatments 9 (unweeded) and 16 (weed-free). This was done by means of micro-catchments such as that shown in Fig. 1. These were constructed from galvanized sheet steel with the run-off and sediment

Table 3 Weed species encountered and their mean densities in unweeded plots of maize

Local name	Latin name	Plants m^{-2}
Chinsangwi	*Eleusine indica* (L.) Gaertn.	1235
Dosa	*Nicandra physaloides* Gaertn.	44
Khobvani	*Commelina benghalensis* L.	28
—	*Dactyloctenium aegyptium* (L.) Beauv.	13
Chisoso	*Bidens* sp.	7
Kapanthi	*Vernonia* sp.	6
Msonthi	*Rottboellia exaltata* (L.) L.F.	4
Mzinga Mphiri	*Rhynehelytrum* sp.	3
Therere	*Hibiscus* sp.	1
Kalasawere	*Acanthospermum hispidum* D.C.	0.6

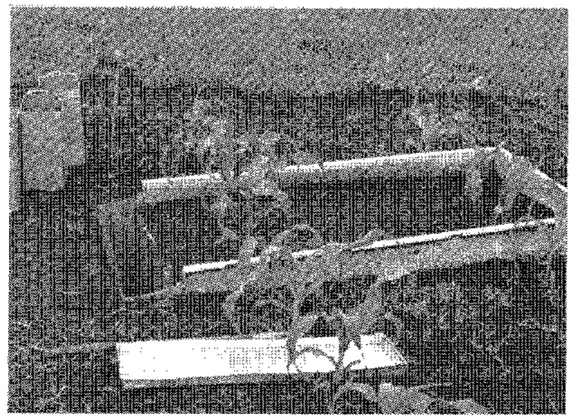

Fig. 1 Microcatchment used to measure run-off water and soil erosion losses. Shown in weed-free plot (treatment 6) with 10-litre collecting tanks (background) and collecting tank cover (foreground) removed

from a 1 m^2 catchment area (1.41 × 0.71 m) being collected in three removable 10-litre tanks. These tanks were housed in a sheet-metal container which was buried so that its upper lip was flushed with the soil surface. The soil surface in these catchments was graded to a uniform 6% slope, which was within 1% of the natural slope of the land. The collection container was fitted with a sloping cover to prevent the direct entry of rain water. A rain gauge was set up in the centre of the experimental area and read daily throughout the 1978/79 rainy season. The volume of run-off water collected in the tanks was measured after each 24-hr period during which there had been measurable rainfall. A 200 ml sample was taken from the run-off water and filtered to determine the suspended solids. Sediment was removed from the emptied tanks with a rubber spatula and a stream of water. The dry weight of this sediment and the filtered suspended solids were summed to arrive at a value for soil lost by erosion.

The data were analysed statistically by the method of Steel & Torrie (1960) for analyses of variance, Duncan's multiple range tests (where significant *F* values were found), planned comparisons by *F*-test, and linear correlations. Statistical Analysis Systems Institute (SAS Institute, 1979) programmes were used for the computations.

Results and discussion

Yields of maize and weeds

Yield data for maize and weeds in experiment 1 are shown in Table 1. In general, the maize yields were excellent, among the best recorded at the Bunda College Research Farm, despite the fact that no weed control was practised and weed growth was ranked early in the season. More than 10 t ha^{-1} of grain were produced at all but the lowest maize density of 31 000 plants ha^{-1}. This density followed the currently recommended planting rate of one seed per 30 cm of row with rows 91 cm apart (germination was ≈86%.)

Weed dry matter at harvest time tended to decrease as the maize density increased. This suppression of weed growth by the maize crop is clearly shown in Fig. 2 as a negative linear correlation between maize density and weed dry matter. It is

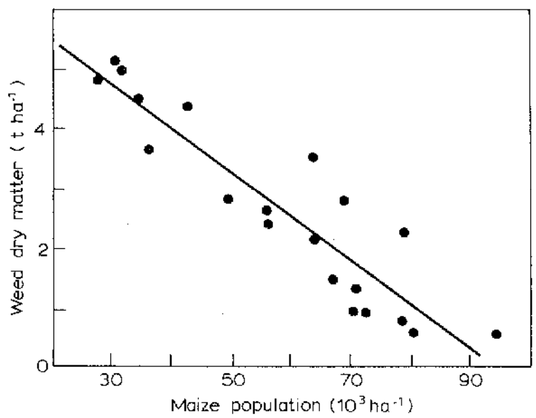

Fig. 2 Relationship between maize population density and weed dry matter produced on individual plots. $Y = 6.97 - 0.074\ X\ r = -0.91$

interesting to note from Table 1 that the sum of the maize and weed dry-matter yields was constant among maize density treatments and probably reflects the maximum biomass production possible in the environment. The main factor affecting maize yields, then, was the proportion of weeds in the total biomass produced. This decreased from 25% at the lowest maize density to 5% at the highest maize density.

Table 2 presents data from experiment 2 and confirms the potential for producing high maize yields without weeding. Several of the unweeded treatments produced >10 t ha^{-1} of grain. Comparisons with the weed-free control plots indicate that the reduction in maize yields due to weed competition may have been considerable, however. If the grain yields of the weed-free controls (treatments 16 and 17) are compared with the unweeded treatments having the corresponding plant densities and arrangements (i.e. treatments 9 and 11) there are statistically significant reductions in yield resulting from weed competition of 34 and 31%, respectively. However, if these control yields are compared with the yields of the best yielding plant arrangement within each density (i.e. treatments 7 and 15), then the reductions are a statistically non-significant 11%.

Statistically significant differences occurred among the various combinations of maize density and planting pattern. The analysis of variance showed a significant main effect of maize density on the yields of both maize and weeds. Comparing the mean yields for the 20 000 and 80 000 plants ha^{-1}, maize densities, maize grain and dry matter increased by a factor of two with the more dense planting, while weed yields dropped off by a factor of three. As a proportion of the total dry matter produced, weeds decreased from 43% at the lowest maize density to 11% at the highest.

Theoretically, in treatments such as these, the planting pattern, as well as the overall plant density, would be expected to influence the inter- and intraspecies competition in a maize field. Where soil moisture and fertility are not limiting, light, as influenced by interplant shading, would be a major factor in this competition and an equidistant planting arrangement might be expected to give the best results. Interference between adjacent maize plants is postponed as long as possible in this arrangement, whereas complete shading of the interrow spaces (and presumably most of the weeds) is achieved at the earliest possible date. Any deviation from the equidistant pattern to a more rectangular planting arrangement might be expected to decrease early maize interference with weed growth whilst increasing competition between adjacent maize plants. Fig. 3 illustrates this concept with vertical views of plants in treatments 11 and 15, having within- to between-row spacing ratios of 1 and 4, respectively.

There was no significant main effect of planting pattern on any of the variables measured when averaged across the three maize densities. This can be explained by the highly significant maize density × plant arrangement interaction shown in Fig. 4. Analysis of the data, however, revealed some effects of planting pattern within maize densities. At 20 000 maize plants ha^{-1}, the expected trend occurred with maize dry-matter yields decreasing from 10.57 t ha^{-1}, where plants were spaced equidistantly, to 6.45 t ha^{-1} where the distance between rows was 4 times the distance between plants within the row. The opposite trend occurred at 80 000 maize plants ha^{-1}. At the middle density of 40 000 plants ha^{-1} (not shown in Fig. 4), maximum yields were obtained at the between- to within-row spacing ratios of 1.5 and 2.0. It is difficult to explain why yields at the highest density were best where the maize plants were crowded together in relatively wide rows. A possible

Fig. 3 Maize and weed growth where the ratio of within-row to between-row maize spacing is 4.0 (treatment 15 top) and 1.0 (treatment 11, bottom). Scale in decimeters

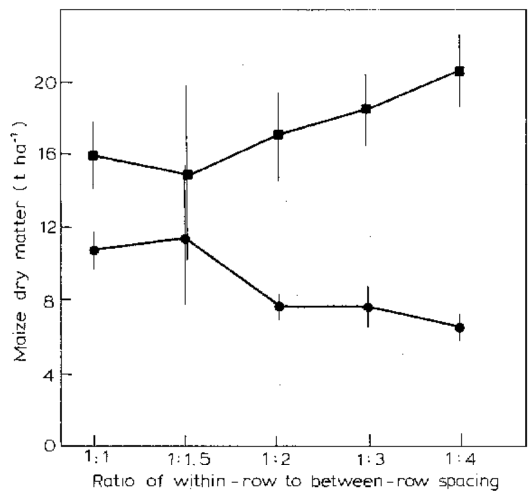

Fig. 4 Interaction of maize planting pattern and plant density as it affects maize dry matter yields. ■—■, 80 000 plants ha^{-1}; ●—●, 20 000 plants ha^{-1}

explanation would be that mutual competition between the closely-spaced maize plants resulted in taller plants during the early part of the season when weed competition is so critical. However the data do not support this hypothesis: there were no significant differences in the plant height measurements taken three and six weeks after planting. Also, the mechanism for the effects of plant arrangment probably had no relation to weed competition since there were no significant differences in weed dry-matter yields among plant arrangements within a given maize density (see Table 3).

Experiment 3 was identical in design with experiment 2, except that experiment 3 was carried out using a lower level of fertilizers and an open-pollinated cultivar (U. C. A.) more typical of village farming situations. The results are presented in Table 4. It is clear that under these conditions the crop was much less productive and less able to compete against the weeds than in experiment 2. Unlike in experiment 2, the maize grain yields in experiment 3 did not respond favourably to a population density >40 000 plants ha^{-1}. In the weeded plots, grain yields declined significantly from 6.79 to 4.54 kg ha^{-1} when the population increased from 40 000 to 80 000 plants ha^{-1}. However, the denser planting did seem to improve the competitiveness of the unweeded maize which, when averaged across all planting patterns, showed a slight, non-significant increase in grain yields (2.34 *versus* 2.96 t ha^{-1}) and a significant increase in dry matter yields (5.79 *versus* 8.93 t ha^{-1}). There was no significant main effect of planting pattern and no significant interaction between planting pattern and maize density with respect to any of the variables measured. Weeds were suppressed by the denser maize plantings, accounting for 38% of the total dry matter with 80 000 maize plants ha^{-1}, and 53% with 40 000 maize plants ha^{-1}. These values are > three times the respective weed contributions to total dry matter in experiment 2. A non-statistical comparison of the two adjacent experiments reported in Tables 2 and 4 reveals nearly identical yields in the weeds-only plots (11.13 and 10.84 t ha^{-1}, respectively) suggesting little if any reponse to the 5-fold greater fertilizer application to the former. The comparison of weed yields at the various maize density levels also indicates that maize vigour as well as planting density is important in suppressing weed growth.

The effects of fertilizer placement and type of seedbed were tested in experiment 4; the main results are presented in Table 5. Fertilizer rates and maize hybrid were the same as in experiment 2. The

Table 4 Yields of maize and weeds as affected by plant spacing and weeding in experiment 3

Treatment number	Maize plant spacing, cm	Dry matter yields, t ha^{-1} Weeds	Maize	Total	Weed** dm, %	Grain,† t ha^{-1}	Maize dm, g plant^{-1}
1	70 × 70	7.76	4.29	12.05	65	1.89	141
2	86 × 57	7.00	5.00	12.07	58	1.90	166
3	99 × 50	6.25	3.64	9.89	64	1.05	123
4	121 × 40	6.20	4.38	10.58	62	1.85	150
5	140 × 35	6.20	5.14	10.85	55	1.96	172
Means for 20 000 plants ha^{-1}		6.62a*	4.42b	11.05b	61a	1.72b	148a
6	50 × 50	7.38	3.94	11.31	67	1.17	68
7	61 × 41	7.27	4.91	12.18	59	1.67	85
8	71 × 35	4.92	4.56	9.44	52	2.02	77
9	87 × 29	4.93	7.28	12.21	43	3.11	130
10	100 × 25	6.42	7.97	14.39	44	3.67	141
Means for 40 000 plants ha^{-1}		6.18a	5.79b	12.04ab	53a	2.34a	101b
11	35 × 35	4.80	4.22	8.96	54	1.09	39
12	43 × 29	5.64	10.05	15.68	38	3.50	93
13	50 × 25	4.61	9.55	14.15	33	2.75	88
14	61 × 20	4.12	10.02	14.14	35	3.88	92
15	70 × 18	4.03	9.87	13.40	34	3.12	90
Means for 80 000 plants ha^{-1}		4.64b	8.93a	13.50a	38b	2.96a	82b
16	87 × 29	—	14.30	14.30	—	6.79	240
17	35 × 35	—	12.70	12.70	—	4.54	116
18	Weeds only	10.84	—	10.84	100	—	—
S^2		2.0	4.20		18	2.06	66

*Means followed by the same letter do not differ at the 0.05 level of significance according to Duncan's New Multiple Range Test

**Weed dry matter as percentage of dry matter produced

†At 15.5% moisture

Table 5 Effects of weeding, fertilizer placement and type of seedbed on yields in experiment 4

Treatment no.	Weeding	Seedbed	Fertilizer placement	Weed dm, t ha^{-1}	Maize dm, t ha^{-1}	Maize grain,† t ha^{-1}	Maize grain,† g plant^{-1}
1	Yes	Ridge	Broadcast	—	23.6a	13.4a	143a
2	Yes	Ridge	Dollop	—	21.1ab	11.9a	129a
3	No	Ridge	Broadcast	2.3a*	15.8b	7.5c	83c
4	No	Ridge	Dollop	1.9a	18.4ab	9.1bc	99bc
5	No	Flat	Broadcast	2.4a	15.4b	8.8bc	97bc
6	No	Flat	Dollop	3.0a	16.5b	9.4b	102b

* Means in one column followed by the same letter do not differ significantly by Duncan's New Multiple Range Test ($P \leqslant 0.05$)

† At 15.5% moisture

83 000 plants ha^{-1} density in experiment 4 gave maize and grain yields very similar to those achieved with the 80 000 plants ha^{-1} density in experiment 2 (compare Tables 2 and 5). Weeds in experiment 4 appeared to reduce grain yield by 24 and 44 %, respectively, with dollop and broadcast fertilizer applications. Broadcast application was more effective than dollop on the weed-free plots. However, on the unweeded plots the dollop application gave 13% better yields (significant at P = 0.05) than the broadcast method. Apparently, it was quite important to place the fertilizer where the maize roots could easily reach it but most of the weeds could not. Effects due to type of seedbed were not significant by either Duncan Multiple Range Test or planned comparison F tests, despite the fact that it might be expected that planting on ridges would give the maize an early height advantage over the inter-row weeds.

Erosion and run-off losses

Two of the benefits of the no-weeding method of maize culture used in this study were the considerable reductions in soil erosion and run-off water losses as compared with the conventionally hand-weeded maize plots. Fig. 5 presents the rainfall, run-off, and soil loss data for the plots during the 1978-79 season. Total rainfall for the season was 886 mm. This was 15% below normal, mainly because of an extended dry period in January during which, for 16 days, there was no significant rainfall, and, for 24 days, no rainfall great enough to produce measurable run-off. During this dry period, the maize in the high fertility experiment did not show visible signs of moisture stress, while that in the low fertility experiment did. This was probably due to the less extensive root systems of the latter. Weeds may have transpired considerable amounts of soil moisture early in the season before the maize canopy closed. However, once the weeds covered most of the soil surface they also had the effect of conserving water by allowing a greater percentage of the rainfall to infiltrate the soil during a given rain event. One month after the onset of the rains, weeds in the unweeded plots gave almost 100% ground cover, and run-off from these plots virtually ceased (Fig. 5b). Averaged over the entire season, run-off losses were 28% rainfall on the weed-free plots and 15% on the unweeded plots. This represents a difference of 114 mm in run-off losses (significant at $P \leqslant 0.01$) between the two treatments.

As with run-off losses, soil losses for the weeded and unweeded plots were about the same until a weedy ground cover became establised in mid-December (Fig. 5a). After that time erosion ceased on the unweeded plots, but continued on the weeded plots to cause serious losses with major rain events. Total soil loss for the season was 12.1 t ha^{-1} from the weed-free plots and 4.5 t ha^{-1} from the unweeded plots (difference significant at $P \leqslant 0.01$).

Conclusions

This study has demonstrated that excellent yields of maize can be produced without weeding. The

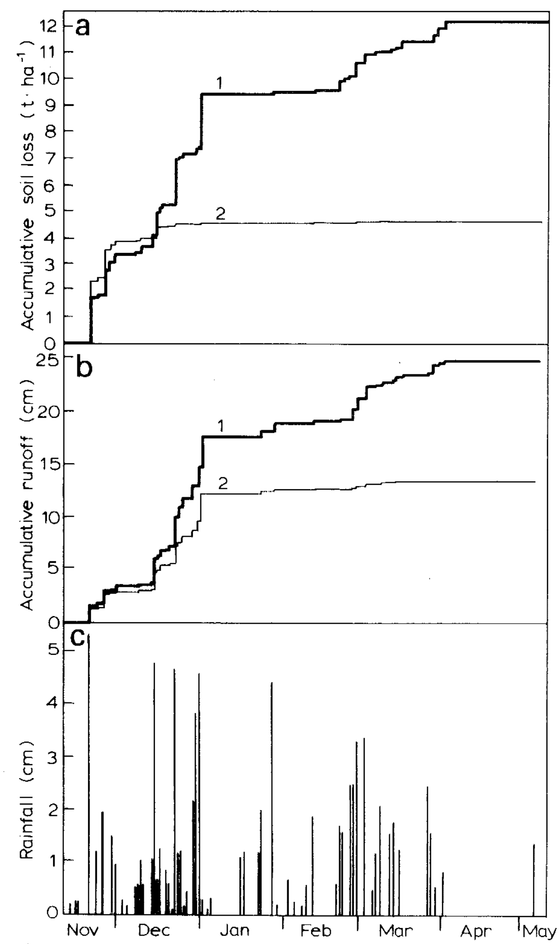

Fig. 5 (a) Soil lost by erosion; (b) run-off water losses; (c) rainfall during the 1978/79 growing season at Bunda College, Malawi. 1, weeded; 2, unweeded

benefits of the unweeded maize system in terms of labour demands and soil conservation were considerable. The annual saving of ≈8 t ha^{-1} of soil would seem to be of potentially great enough benefit to offset yield reductions in the long run. The system used in these experiments was simple and adaptable by village farmers as long as the seed and fertilizer inputs were available. The field labourers who cultivated these experimental crops were themselves village farmers and were able to execute this system of culture without apparent difficulty.

Certainly some questions remain unanswered and much more research experience must be gained before this system could be generally adopted in areas where environmental conditions are similar to those in the study area. One potential problem is that of weed adaptation to the altered competitive conditions. With a greater number of weeds reaching maturity, weed seed production and subsequent infestations might become more serious. Also the competitive pressure of the maize crop might select for taller, faster growing weeds. Although neither of these problems was evident during the two years of this study, they should be investigated over a longer period. It is likely that rotating a given field to other (weeded) crops in sequence with maize would minimize these potential problems.

Overall, the yield reductions caused by weeds in this study averaged between 11–25% in the high management level experiment, and 30–70% in the lower management level experiment. Using the lower fertilizer rates and open-pollinated variety of experiment 3, unweeded maize culture was clearly impracticable. However, excellent grain yields were produced and yield reductions were kept to ≈10% by optimum plant spacing at the 40 000 and 80 000 plants ha^{-1} densities, provided the vigorous hybrid and moderately high fertilizer rates of experiment 2 were used.

Acknowledgements

The author thanks the Research and Publications Committee of the University of Malawi for part of the funding for this study and Dr S.K. Banarjee for help in identifying the weed species.

References

Brown, R.H. and Beaty, E.R. (1970) Influence of row width and plant population on yield of two varieties of maize, *Agron. J.* **62** 767–770

Donald, C.M. (1963) Competition among crop and pasture plants, *Advan. Agron.* **15** 1–118

Duncan, W.C. (1969) Cultural manipulation for higher yields in: *Physiological aspects of crop yield*, (Eds. J.D. Eastin *et al.*) Madison, Wisconsin: American Society of Agronomy and Crop Science Society of America, pp. 327–339

Eplee, R.E. and Klingman, G.C. (1968) Effect of corn population and simazine on weed growth, *Agron. J.* **60** 87–89

Hay, R.K.M. (1981) Timely planting of maize—a case-history from the Lilongwe Plain, *Trop. Agric. (Trinidad)* **58** 147–155

Klingman, G.C. (1961) *Weed control as a science*, New York: John Wiley & Sons

Lungu, N.F. (1971) *An investigation into the causes of decreased yields in late-planted maize,* PhD Thesis, University of Malawi

Malawi Government (1977) *Annual report of the Department of Agricultural Research for the year 1973-74,* Government Printer, Zomba, Malawi

Parker, C. (1972) The role of weed science in developing countries, *Weed Sci.* **20** 408–413

SAS Institute (1979) *SAS user's guide,* Statistical Analysis Systems Institute, Inc., Raleigh, NC, USA

Steel, R.G.D. and Torrie, J.H. (1960) *Principles and procedures of statistics*, New York: McGraw-Hill

Vega, M.R., and Obien, S.R. (1965) Weed control in corn: studies in competition, in: *2nd Inter-Asian Corn Improvement Workshop,* Univ. of Phillipines

Young, D., Miller, S., Fisher, H. and Shenk, M. (1978) Selecting appropriate weed control systems for developing countries, *Weed Sci.* **26** 209–212