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CONTROL OF *DIGITARIA ABYSSINICA* (A. RICH) STAPF. WITH GLYPHOSATE

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ABSTRACT

Investigations were conducted in Uganda on the effect of glyphosate dose rate, timing of application, and the combination of glyphosate with cultural methods for the control of *Digitaria abyssinica* (A. Rich) Stapf. Results showed a dose rate of 1.5 kg a.e.ha^{-1} to be optimum. Application with pre-plant tillage did not increase *D. abyssinica* control, but increased populations of other weeds and costs. Glyphosate efficacy was increased when preceded by slashing, burning or digging. At least one month was required between the cultural pre-treatments and spraying to allow new shoots to emerge. Glyphosate was most effective when applied to *D. abyssinica* shoots up to eight weeks after emergence. The optimum timing for spraying was between one and two months after cultural pre-treatment. Glyphosate applications considerably reduced labour requirement for preparation of *D. abyssinica* infested land.

Key Words: *Glyphosate efficacy*, **Uganda, weed control**

RÉSUMÉ

La recherche était conduite en Uganda pour étudier les effets de dose et de temps d'application et de la combinaison de glyphosate avec les méthodes culturales de contrôle de *Digitaria abyssinica* (A. Rich) Stapf. Les résultats ont montré qu' un taux d'application de 1,5 kg de matière active par hectare serait l'optimum. L'application de glyphosate combiné au pré-labour n'a pas augmenté le contrôle de *D. abyssinica*; cela a, au contraire, augmenté la population d'autres mauvaises herbes et les coûts de contrôle. L'efficacité du plyphosate avait augmenté quand il était précédé du fauchage, brûlage ou arrachage; et au moins un mois était exigé entre les traitements préculturaux et la pulvérisation afin de permettre aux nouvelles pousses de germer. Le glyphosate était efficace quant il était appliqué sur les pousses de *D. abyssinica* jusqu' à huit semaines après la germination de pousses. Le temps optimum de pulvérisation était entre un et deux mois après le traitement préculturel. Les applications de glyphosate réduisaient considérablement les exigences en main d'oeuvre pour la préparation des sols infestés par le *D. abyssinica*.

Mots Clés: **Efficacité de glyphosate, Uganda, contrôle de mauvaises herbes**

INTRODUCTION

Digitaria abyssinica (A. Rich) stapf is a perennial rhizomatous grass indigenous to East Africa (Popay and Ivens, 1982). It is a problem in arable and plantation crops from sea level to 3,000 m, and is regarded as the most troublesome of all East African weeds (Ivens, 1967). In established stands, the rhizomes form dense mats beneath the soil surface, growing to a depth of 1.0 m (Terry, 1974). Shoots form a thick cover with a leaf area similar to that of a fully grown maize crop (Prentice, 1957). Rhizomes consist of short nodes and internodes. Any part of a rhizome which includes a node, if left in the ground, can re-establish into a full plant (Otieno, 1967). *Digitaria abyssinica* is highly competitive with most crops (Popay and Ivens, 1982), though little is known about the biology and control of this weed.

On smallholder farms in Uganda, *D. abyssinica* control is almost entirely by hand. Intensive digging and sifting with a forked hoe removes many rhizomes, but total elimination of all viable fragments by this approach is almost impossible. Hand-weeding is extremely time consuming and costly. When labour for weeding is in short supply, heavy infestations of this weed can restrict the area cultivated, as well as reduce an efficacy of hand-weeding (Webb *et al.*, 1993).

Herbicides provide the most effective option for short-term control of *D. abyssinica.* Several herbicides have been shown to give good control; among these are dalapon, aminotriazole, asulam, sethoxydim and glyphosate (Parker, 1970, 1982; Terry, 1974). Of these, glyphosate appears to be the most appropriate because it is readily available in Uganda, has low mammalian toxicity, and has no residual effect in soil (Caseley, 1994). Though already recommended for use in Uganda, research has not been conducted on the use of glyphosate for *D. abyssinica* control under local conditions (Ivens, 1967). In addition, little information is available on the effect of growth stage on the susceptibility of *D. abyssinica* to glyphosphate, or to a combination of glyphosate with cultural control in order to decrease the costs and/or increase the efficacy of the treatment. This study addressed these issues.

MATERIALS AND METHODS

The studies described here were conducted between September 1994 and January1995.

Dose rate of glyphosate for *D. abyssinica* control. This experiment was conducted on two farmers' fields; in Mubende District which is located about 65 km from Kampala City. Soil type was a clay loam and sandy clay loam for Fields 1 and 2, respectively. Prior to the study, Field 1 had been under fallow for one year; *D. abyssinica* was mature and formed a dense stand with 100% ground cover. Field 2 had been under fallow for three years, but was frequently burnt during this time, and most recently burnt 28 days before spraying. In Fields 1 and 2, three and four treatment replicates were arrange respectively, in randomised complete blocks, with plots of 5 x 12 m and 4 x 9 m. A single application of glyphosate was made at rates of 0.75, 1.5 and 2.5 kg a.e. ha^{-1} and these were compared with control plots, where land was prepared by farmers according to traditional practice (i.e., digging with a hand hoe and hand picking and removal of *D. abyssinica* rhizomes). Glyphosate was applied at a volume rate of 310 l ha^{-1} in Field 1. Preparation at the same time of control plots began. In Field 2, glyphosate was applied at a volume rate of 215 l ha^{-1} on 7 September 1993, and in both cases at a time when *D. abyssinica* was vegetative and actively growing, with at least a ground cover of 50%. Control plots were dug on same day of glyphosate application. Time taken to prepare land was recorded.

Three weeks after glyphosate application, glyphosate treated plots were slashed. The whole experiment was sown with a maize-bean intercrop where one bean row was between two maize rows at a spacing of 75 cm x 50 cm leaving 2 plants per hill. In both field, counts of the weed species were taken at 20 and 40 days after crop emergence and at harvest in four 0.25 m^2 quadrants eight times per plot, at random co-ordinates. All plots were weeded by hand-hoeing after each of the first two weed counts. Maize and bean yields measurements were taken at crop harvest.

Tillage at three glyphosate dose rates. The experiment was conducted at Namulonge Agricultural and Animal Research Institute (NAARI), located about 27 km north of Kampala City. The effect of glyphosate at three dose rates was investigated with or without (zero tillage) subsequent pre-plant cultivation in two fields; referred to as Field 3 and Field 4, respectively, in this paper. Sprayed plots were compared to a control, where land was prepared according to farmer practice givinga total of seven treatments. Field 3 had a loam soil. It was at 6 months after the harvesy of cassava and was characterised by mature *D. abyssinica* which formed a cover of 80%. Field 4 had a clay loam soil and had been ploughed six months previously. It had 100% cover of *D. abyssinica* with many flowring shoots. Actual dose rates applied in Field 3 were 0.6, 1.5 and 2 kg a.e.ha^{-1} and in Field 4 were 1, 2.3 and 3.5 kg a. e. ha^{-1}. Treatments were replicated three times in a randomised block design with plots of 7 x 7 m^2. Field 3 was sprayed on 10 February, 1994, with a volume rate of 300 l ha^{-1}. Field 4 was sprayed on 27 August 1994 with a volume rate of 350 l ha^{-1}. In zero tillage plots, sowing was preceded only by slashing of the top growth. In the tillage treatment, a pre-plant cultivation by hand-hoeing (two weeks after spraying) was conducted, but without removal of rhizomes. Both fields were sown to a maize-bean intercrop, with one bean row between two maize rows at a spacing of 75 x 50 cm. Weeding was done at 20 and 40 days after crop emergence. Weed counts and shoot dry weight were assessed at 20 and 40 days after crop emergence, before each weeding and at crop harvest, in eight 0.25 m^2 random quadrants per plot. Weeds were over dried at 70° C for 48 hours. Other weed species present included *Cynodon nlemfuensis* and a range of annual broad leaved species including *Bidens pilosa, Galinsoga parviflora* and *Ageratum conyzoides.*

The effect of pre-spray treatment on glyphosate efficacy. This experiment was also conducted at NAARI in two fields referred to as Field 5 and Field 6 with similar soil types as Field 3 and Field 4. In Field 5, several years of annual crop production with frequent ploughing had resulted in high densities of *D. abyssinica.* Field 6 differed from Field 5 in having a mature population with rhizomes which had remained undisturbed for some years. Field 5 soil type was a clay loam and in Field 6 a loam. Other weed species present included *Cyperus rotundus, Oxalis latifolia, Cynodon nlemfuensis* and a range of annual broad leaved species including *Bidens pilosa, Galinsoga parviflora* and *Ageratum conyzoides.*

Glyphosate application was combined with cultural control practices. Glyphosate was applied in both fields at 2 kg a.e. ha^{-1} in a volume rate of 220 l ha^{-1} on 25 September, 1994. Four treatments were replicated five times in a randomised complete block design. In treatment 1, spraying was preceded by digging (without removal of rhizomes) while in treatment 2 by slashing of top growth, and treatment 3 by burning. In the third treatment plots, slashing was done 1 week before burning. Treatment 4 was the control where the plots received no pre-spray treatment. Following pre-spray treatment, the emergency of *D. abyssinica* was monitored by weekly counts in eight random quadrats (0.25 m^2 per plot). At intervals of one, two and three months after spraying, *D. abyssinica* regeneration was recorded by shoot counts and measurements of rhizome dry weight in eight random quadrats per plot.

Growth stage of *D. abyssinica* and the efficacy of glyphosate. Pot trials were conducted at NAARI to study the efficacy of glyphosate at different growth stages of *D. abyssinica*. Rhizome fragments were planted in pots at a depth of 2-3 cm on 28 April, 1994. Each rhizome fragment contained four nodes and originated from a position at least two nodes away from the shoot apex to avoid apical dominance. All rhizomes were collected in the same field. Seven days after planting, shoot emergence was observed and rhizomes were thinned to leave three germinating rhizomes per pot. Glyphosate was applied at 1 kg a.e. ha^{-1}, with a volume rate of 200 l ha^{-1}, on nine consecutive dates (2, 3, 4, 6, 8, 10, 12, 18 and 24 weeks after emergence) in a complete randomised design, with five repliates for each date. Pots were retained for 15 weeks after spraying to monitor re-emergence.

In all trials, glyphosate [Roundup (Monsanto)] 360 g a.e l^{-1}) was applied with a CPI5 (Cooper

Pegler) knapsack sprayer operating at 1 bar using a blue "Polijet" impact nozzle. Roundup was applied with no additional surfactant.

All results were analysed using analysis of variance and the means separated using the least significant difference.

RESULTS

Dose rate of glyphosate for *D. abyssinica* control. In Fields 1 and 2, glyphosate at rates of 1.5 and 2.5 kg a.e. ha^{-1} gave consistently better weed control than 0.75 kg ha^{-1} at all other dates (Table 1). A rate of 2.5 kg ha^{-1} did not provide significantly better control than 1.5 kg ha^{-1}. A decrease in the number of emerged *D. abyssinica* shoots in sprayed plots was accompanied by an increase in the number of other weeds, including *C. rotundus* and annual broad leaved species. In Field 2, farmer practice (FP) of hand-hoeing and picking of rhizomes resulted in control which was equivalent to the higher rates of glyphosate. In Field 1, however, where *D. abyssinica* populations were dense and mature, the FP gave variable results and are, therefore, not presented.

Tillage or zero tillage at three glyphosate dose rates. There was no significant interaction between glyphosate dose rate and tillage treatment for all of the parameters evaluated. Again in Fields 3 and 4, dose rates of equal to or greater than 1.5 kg ha^{-1} glyphosate gave consistently better weed control than lower dose rates, but increasing the dose above 1.5 kg did not significantly improve control (Table 2). At 20 days after crop emergence, there were significantly more *D. abyssinica* shoots

TABLE 1. Effect of glyphosate dose on the density of *Digitaria abyssinica* shoots (per 0.25 m^2 quadrat) at 20 and 40 days after emergence (DAE) and at harvest in Fields 1 and 2 at Mubende, Uganda

Dose rate (kg a.e. ha^{-1})	Field 1			Field 2		
	20 DAE	40 DAE	Harvest	20 DAE	40 DAE	Harvest
0.75	11.33	13.33	9.67	63.25	36.00	20.25
1.50	4.67	6.00	4.33	34.00	20.25	11.25
2.50	3.67	4.67	3.67	39.00	18.25	9.75
Control	15.67	25.67	17.67	21.00	26.75	14.00
$LSD_{0.05}$	4.41	3.24	NS	6.47	7.12	NS

TABLE 2. Effect of glyphosate dose (kg a.e. ha^{-1}) and pre-plant tillage on the density of *Digitaria abyssinica* shoots per 0.25 m^2 quadrat at 20 and 40 days after emergence (DAE) and at maize/bean crop harvest in Fields 3 and 4 at Namulonge, Uganda

Tillage	Field 3				Field 4			
	Rate	20 DAE	40 DAE	Harvest	Rate	20 DAE	40 DAE	Harvest
ZT	0.6	18.58	56.33	59.42	1.0	41.99	44.33	30.87
ZT	1.5	6.17	23.40	38.67	2.3	18.73	17.92	18.83
ZT	2.0	3.83	9.86	13.96	3.5	6.95	6.67	5.87
WT	0.6	5.50	45.26	65.70	1.0	6.22	8.46	11.20
WT	1.5	1.75	6.53	13.96	2.3	3.88	8.67	11.29
WT	2.0	0.17	1.96	3.75	3.5	3.11	4.25	10.54
FP		8.90	24.3	45.8		63.20	67.92	46.67
$LSD_{0.05}$	(d f=12)	3.40	12.50	NS		25.50	30.80	NS

ZT = Zero tillage; WT = With tillage; FP = Farmer practice in zero tillage plots (P≤0.044 Field 3; P≤0.0213 Field 4). However, while the effect of dose rate on *D. abyssinica* shoot number was still apparent at harvest (P≤0.002 Field 3), the effect of tillage treatment did not persist beyond the first weeding. Patterns of response recorded in *D. abyssinica* shoot dry weight were similar to shoot number on all occasions.

In Field 3, no significant effects were recorded on *C. rotundus* or *0. latifolia* populations, but the number of these weeds was low and highly variable. After the first weeding (40 DAE), the density of annual broad leaved species was significantly higher following the highest rate of glyphosate (1 07.6/quadrat) than at the lower rates (46.2 and 3 6.8/quadrat at 0. 6 and 1. 5 kg a. e. ha^{-1}, respectively; P≤O. 0469), but tillage treatment had no significant effect on weed density for all evaluation dates. At 40 DAE in Field 4 (where numbers of *0. latifolia* and *C. rotundus* were higher), density/quadrat was greater following tillage than following zero tillage for both *0. latifolia* (52.9 and 31.7, respectively; P≤0.0063) and *C. rotundus* (77.1 and 48.7, respectively; P≤0.0292). By harvest time, *0. latifolia* shoots had died, but *C. rotundus* density remained higher in tilled plots (P≤0.002). Numbers of annual broad leaved species at 20 DAE were also greater with than without tillage (13.4 and 5.0; P≤0.0027), but this effect did not persist beyond the first weeding. Glyphosate dose rate had no significant effect on numbers of other weed species on all evaluation dates, though the number of *C. rotundus* shoots was consistently lower in the 1 kg ha^{-1} (zero tillage) treatment, (Table 3).

The degree of *D. abyssinica* control obtained in the unsprayed plots (farmer practice) was again variable. In Field 4, weed control was poor and significantly lower than in all but the zero tillage, and the 1 kg ha^{-1} glyphosate treatment at 20 and 40 DAE (Table 2). Weed control in Field 3, following FP, was not significantly different from sprayed plots at 20 and 40 DAE. However, by harvest time, *D. abyssinica* numbers were significantly greater following FP than in the 2 kg ha^{-1} glyphosate treated plots, indicating a more lasting effect following the herbicide treatment. Records of labour requirements for land preparation and weeding (but not herbicide application) in Field 3 are indicated in Table 4.

Crop yield again did not differ among treatments, but, yield data were highly variable and unreliable under drought conditions.

The effect of pre-spray treatment on glyphosate efficacy. The regeneration of *D. abyssinica* shoots following pre-spray treatments in Field 5 is illustrated in Figure 1. Emergence of new shoots was faster following slashing and burning than after digging. At the time of glyphosate application, 4 weeks after pre-spray treatment, ground cover was 80% after slashing, 79% after burning and 45% after digging, compared to 100% cover in untreated plots.

Weed populations in Field 6 were uneven and the data were highly variable c.v. of 171 and 64% in counts of *D. abyssinica* shoots at 30 and 60 days, respectively).

No significant difference was observed in the number of emerged *D. abyssinica* shoots at 30

TABLE 3. Effect of glyphosate dose and pre-plant tillage on density of *Oxalis latifolia*, *Cyperus rotundus* and annual broad-leaf weeds (per 0.25 m^2 quadrat) at 20 and 40 days after crop emergence (DAE) in Field 4

Dose rate (kg a.e. ha^{-1})	*Oxalis latifolia*		*Cyperus rotundus*		Annual broad-leaf	
	20 DAE	40 DAE	20 DAE	40 DAE	20 DAE	40 DAE
1.0 ZT	17.67	42.38	23.1	25.29	5.50	12.33
2.3 ZT	16.97	17.50	59.67	64.63	5.38	17.04
3.3 ZT	18.43	35.13	40.17	56.08	4.22	12.13
1.0 WT	22.06	52.96	56.99	73.17	9.71	13.38
2.3 WT	18.37	43.33	68.09	70.29	14.97	8.50
3.5 WT	23.22	62.38	65.61	87.88	15.49	11.25
FP	47.44	61.33	57.32	51.58	4.56	3.25
LSD $_{0.05}$	3.45	5.55	7.22	NS	1.85	NS

ZT = zero Tillage; WT = with Tillage; FP = Farmer practice days after spraying (DAS), n(Table 5). At this time, though some necrosis was evident, it was difficult to distinguish between live and dead shoots. In Field 5, by 60 DAS, shoot numbers were significantly lower following slashing and digging than in the no pre-spray plots. Measurements of rhizome dry weight in Field 5 also showed significantly increased mortality in pre-treated plots (Table 6). By 60 DAS, dry weight was lower following digging than the control and, was significantly lower in all pretreated plots by 90 DAS. Similar trends were observed in Field 6, but variability was extremely high.

The weed population was composed mainly of *O. latifolia* and annual broad leaved species other than *D. abyssinica*. No significant difference was recorded in number of other weeds at 30 DAS, but by 60 DAS, the number was lower in pre-treated plots than in the control. It was the lowest in plots which had been burnt (Table 7). These differences did not persist up to 90 DAS.

Growth stage of *D. abyssinica* and the efficacy of glyphosate. With increasing maturity of *D. abyssinica.*, the time taken from spraying to senescence increased. When glyphosate was applied to *D. abyssinica* up to 8 weeks from the time of shoot emergence, 100% mortality of shoots and rhizomes was achieved. After 15 weeks, no re-emergence was observed, and all underground parts had decomposed. At 8 weeks after emergence (WAE), the *D. abyssinica* shoots had not exceeded a growth stage of 9 nodes. Glyphosate after this time did not provide 100% control (Table 8).

DISCUSSION

This study confirmed the efficacy of glyphosate for the control of *D. abyssinica*. A dose rate equal to or less than 1.5 kg a.e. ha^{-1} gave good control, while a rate of 1 kg ha^{-1} in effective. Increasing the rate above 1.5 kg ha^{-1} did not significantly increase the level of control. These results support the findings of Terry (1974), who tested rates of 1, 2, and 4 kg ha^{-1} in field trials in Tanzania. When good control was achieved, the effect of the treatments was still evident at harvest, indicating that the benefits of applying glyphosate during land preparation in *D. abyssinica* infested fields may continue into the following cropping season.

Digitaria abyssinica is known to be a highly competitive species (Popay and Ivens, 1982). When competition due to this weed was reduced in the sprayed plots, the other species tended to increase in number. These included annual broad leaved species as well as the troublesome perennials *C. rotundus* and *0. latifolia*. These other perennial weeds showed no significant response to glyphosate treatments, despite their known controll at rates of 1.5 kg ha^{-1} (Terry, 1984). Owing to *D. abyssinica's* lower stature, it is likely that they received inadequate spray coverage when glyphosate was applied onto dense stands.

The advantage of using glyphosate for weed control during land preparation is that it can allow the adoption of zero or reduced tillage systems. This study investigated the effect of glyphosate on *D. abyssinica* with or without pre-plant tillage. It was observed that tillage reduced the number of *D. abyssinica* shoots up to the first weeding, but did not affect the density of shoots emerging after weeding. This suggests that tillage did not influence the mortality of rhizomes in the sprayed population. Tillage did, however, affect populations of other weeds. By encouraging a flush of seed germination, pre-plant tillage increased the density of annual broad leaved species present between crop sowing and the first weeding. Tillage also increased populations of *C. rotundus* and *0. latifolia*, an effect which persisted beyond the first weeding. By fragmenting rhizomes and dispersing tubers and bulbs, single cultivations in the absence of other control mechanisms tend to cause an increase in populations of these species (Terry, 1984).

Information on the effect of glyphosate rate and tillage treatment on crop yield was not obtained in this study, because crops were seriously affected by late season drought. Future work should consider yield comparisons in the investigation of the benefits of tillage or zero tillage systems in terms of crop yield, and to examine the effect on crop yield of suppressing *D. abyssinica* populations.

The efficacy of glyphosate on perennial weeds is increased when the herbicide is applied onto

TABLE 4. Labour requirements for land preparation and weeding in Field 3 (converted to workdays ha^{-1})

Dose rate (kg a.e. ha^{-1})	Land preparation		First weeding		Second weeding	
	Zero tillage	With tillage	Zero tillage	With tillage	Zero tillage	With tillage
1.6	4.6	29.6	15.7	16.0	14.2	12.3
1.5	4.6	37.1	15.1	13.6	11.7	11.5
2.0	4.6	28.0	16.0	13.3	11.5	11.4
FP	61.4		16.0		32	

1 work day = 7 working hours; FP = Farmer practice

TABLE 5. Density of *Digitaria abyssinica* (shoots/0.25 m^2 quadrat) according to pre-spray treatment at 30, 60 and 90 days after spraying (DAS) in Field 5

Practice	30 DAS	60 DAS	90 DAS
Slashing	17.15	5.55	8.50
Burning	18.55	7.60	11.05
Digging	14.00	2.90	7.15
No treatment	15.30	13.05	11.93
$LSD_{0.05}$	NS	1.4	NS

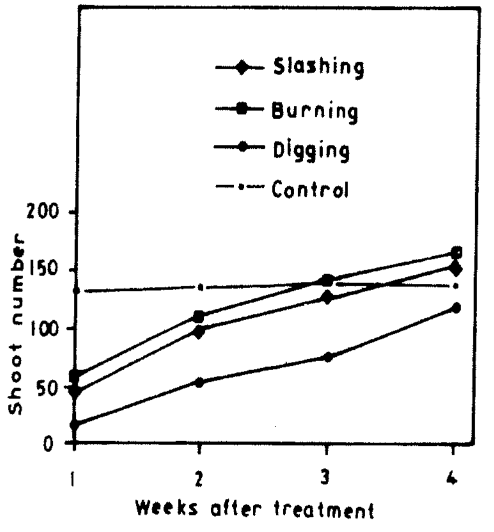

Figure 1. Number of *Digitaria abyssinica* shoots following pre- spray treatment in Field 5 (mean number m^{-2})

plants in an active phase of growth (Caseley, 1994). In order to encourage a flush of vigorous growth in *D. abyssinica* stands, plots were slashed, dug or burnt one month prior to glyphosate application. All three methods of pre-spray treatment increased the level of weed control achieved compared to glyphosate applications onto mature and undisturbed stands. Three months after spraying, rhizome dry weight remained significantly lower in pre-treated plots. The pre-spray treatments also reduced numbers of other weeds including *0. latifolia* and annual broad leaved species. Burning was particularly effective for the latter, probably by destroying seeds on the soil surface.

Since glyphosate has no residual effect in the soil, in order to maximise kill of underground parts, it is important that as many rhizomes as

TABLE 6. Dry weight of *Digitaria abyssinica* rhizomes (g m^{-2}) according to pre-spray treatment at 30, 60 and 90 days after spraying (DAS) in Fields 5 and 6 at Namulonge, Uganda

Treatment	Field 5			Field 6		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Slashing	184.44	161.51	71.68	432.67	241.89	127.48
Burning	171.72	149.93	65.16	313.43	150.28	140.98
Digging	151.34	96.84	46.40	208.70	138.23	113.68
No treatment	177.24	189.05	113.28	433.29	291.57	173.68
$LSD_{0.05}$	NS	11.71	NS	NS	NS	NS

possible have aerial shoots in active growth at the time of spraying. Terry (1984) noted that fragmentation of rhizomes by cultivation before spraying can reduce control, as many viable but dormant fragments can remain untouched by the herbicide. This was not the case in the present study. However, shoot number and rhizome dry weight were consistently the lowest in plots which had been dug prior to spraying. There was no advantage of burning compared to slashing in terms of the degree of *D. abyssinica* control obtained. By increasing nutrient loss and by creating the risk of fire damage, burning is the least acceptable of the three options assessed, though in practice, it is often used by Ugandan farmers in vegetation management.

One of the objectives of this study was to establish the optimum timing of glyphosate applications for *D. abyssinica* control. Terry (1984) recommended that a long interval should be left between cultivation and spraying of perennial grasses in order to allow maximum germination of viable rhizomes. Monitoring during the four weeks following application of the pre-spray cultural treatments showed that new shoots continued to emerge throughout this period. The results of a preliminary pot trial to investigate the efficacy of glyphosate according to *D. abyssinica* growth stage indicated that complete control was achieved when glyphosate was applied up to 8 weeks after emergence (when the *D. abyssinica* had reached a growth stage of 9th node), but that control decreased after this time. This suggests that optimisation of control requires 1-2 months interval between pre-spray cultural treatment and spraying. To confirm this inference, further studies of glyphosate efficacy according to *D. abyssinica* growth stage are needed.

TABLE 7. Density of annual broad leaved weeds and *Oxalis latifolia* per 0.25 m^{-2} quadrat according to pre-spray treatment at 60 days after spraying in Fields 5 and 6 at Namulonge, Uganda

	Broad leaved species		*Oxalis latifolia*	
	Field 5	Field 6	Field 5	Field 6
Slashing	2.05	19.65	4.80	3.35
Burning	1.05	10.10	3.25	3.20
Digging	3.20	16.90	5.60	2.20
No treatment	10.60	23.55	14.80	5.85
$LSD_{0.05}$	2.41	1.11	NS	NS

TABLE 8. Number of regenerating *Digitaria abyssinica* shoots per pot according to growth stage at the time of glyphosate application

Glyphosate application (WAE)	Growth stage at spraying	Days to senescence (after spraying)	shoots pot^{-1} 15 WAS
2	2nd node	30-32	0
3	4th node	29-31	0
4	5th node	34-35	0
6	7th node	38-39	0
8	9th node	40-41	0
10	12th node	40-41	1.6
12	10% SF	42-44	2.6
18	80% SF	47-48	2.6
24	Seed shed	60-63	2.4

SF = Shoots flowering; WAS = Weeks after spraying; WAE = Weeks after emergence

One of the problems currently faced by smallholder farmers in Uganda is shortage of labour during critical periods in the cropping cycle. Labour bottlenecks during land preparation are particularly important, and can result in a reduction in the area cultivated or in sub-optimal agronomic practices (e.g. late sowing, inefficient weeding). Seasonal labour shortage is exacerbated when fields are heavily infested by *D. abyssinica* (Webb *et al.*, 1993). The traditional practice of digging with a hoe and hand picking rhizomes is extremely time consuming. Land preparation by farmers in the plots indicated the equivalent of 334 workdays per hectare, which is less than the estimate given by Prentice (1957) of 300 workdays to clean 17 m^2 by digging to a depth of 60 cm. By eliminating the need to hand pick rhizomes, the application of glyphosate can considerably reduces labour requirements for land preparation.

In the research station trials, a comparison of labour requirements under the traditional system was made with those under improved systems of glyphosate application, with or without pre-plant tillage. Hand picking of rhizomes in control plots was less intensive here than in the on-farm trials. But treatment comparisons still showed labour requirements for land preparation to be considerably reduced where glyphosate was applied, and to be lowest in the sytem with no pre-plant tillage. There was no difference between systems in terms of labour requirements for subsquent weeding of the crop, perhaps because of the tendency of other weeds to increase in number once *D. abyssinica* is controlled.

Records of labour inputs from small plots cannot be extrapolated with confidence; and a full economic analysis of the different systems was, therefore, not attempted. Nevertheless, the data illustrate the potential of this technology to alleviate seasonal labour shortages.

This study confirmed the usefulness of glyphosate for *D. abyssinica* control by increasing efficacy and decreasing labour requirements for weed control compared to traditional practice. Glyphosate is already used by some smallholder farmers for this purpose, and the dissemination of information and improved recommendations could increase its use. However, there are other farmers for whom the use of herbicides is not at present an option for reasons such as lack of access to herbicides, sprayers or information, or lack of capital for the single, relatively large cash outlay required (Webb *et al.*, 1993). For these farmers, research to develop other less costly methods of D. abyssinica control is needed.

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