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9. ABSTRACT
Describes the results of three years' research at CIAT and highlights the importance of timely weed control and the adoption of an adequate control program. All crops are subject to weed competition for light, water and nutrients. The critical period of competition for cassava continues until the canopy has formed and can last up to 120 days. Weeding after 120 days did not increase production. Two well-spaced weedings produced 75% of the maximum yield. Crop density is also important. Under weed free conditions a crop maximizes its use of essential nutrients, water and light, and a low cassava population can yield as much as higher ones. Higher crop density will compensate for the effects of weed competition. Four trials were conducted to screen herbicides. Eighteen products were found to cause no injury to cassava even at three or four times the recommended rate. The report also discusses incorporated herbicides and the planting schemes, postemergence herbicides, and integrated control. There is a table showing the chemical weed control recommendations for cassava. To arrive at these recommendations, the effectiveness, selectivity, availability, and cost of each product was taken into account. Rarely will a single application of herbicide give sufficient weed control until the canopy closes so each field must be observed closely to determine when complementary hand or mechanical weedings should be performed.

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METHODS OF WEED CONTROL IN CASSAVA

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CIAT is a nonprofit organization devoted to the agricultural and economic development of the lowland tropics. The Government of Colombia provides support as host country for CIAT and furnishes a 522-hectare farm near Cali for CIAT's headquarters. Collaborative work with the Instituto Colombiano Agropecuario (ICA) is carried out mainly at its Experimental Centers at Turipaná and Carimagua. CIAT is financed by a number of donors represented in the Consultative Group for International Agricultural Research. During the current year these donors are the United States Agency for International Development (USAID), the Rockefeller Foundation, the Ford Foundation, the W.K. Kellogg Foundation, the Canadian International Development Agency (CIDA), the International Bank for Reconstruction and Development (IBRD) through the International Development Association (IDA), the Interamerican Development Bank (IBD), the United Nations Environment Programme, the Ministry of Overseas Development of the United Kingdom and the governments of Australia, Belgium, the Federal Republic of Germany, the Netherlands and Switzerland. In addition, special project funds are supplied by various of the aforementioned entities plus the International Development Research Centre (IDRC) of Canada. Information and conclusions reported herein do not necessarily reflect the position of any of the aforementioned agencies, foundations or governments.

METHODS OF WEED CONTROL IN CASSAVA

(*Manihot esculenta* Crantz)

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It has been recognized that cassava yields can be greatly increased by eliminating weed competition during the initial growth periods; nevertheless, many consider that it is able to survive, compete and produce with only minimal weed control efforts. Even under ideal growing conditions, it takes two months or longer for the cassava canopy to close; under less favorable conditions, it may take up to four months. Until a complete canopy is formed, attention usually needs to be given to controlling weeds.

Cassava yields, four times greater than the national production averages of many countries, are being obtained experimentally as a result of the integration of many technological advances (i.e., improved varieties, proper pest and weed control measures, adequate fertilization and other cultural practices). A very essential part of this cassava production package is weed control. This bulletin presents the results of three years' research efforts at CIAT and highlights the importance of timely weed control and the adoption of an adequate control program.

Effects of weed competition

As with any crop, cassava is subject to weed competition for light, water and nutrients. For most short-season annual crops, the critical period of weed competition occurs during the first few weeks after planting (Kasasian and Seeyave, 1969). If crops are

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kept weed free during this period, optimal yields are obtained. An experiment was conducted to determine the critical period of competition in cassava, based on hand weedings performed at various frequencies and intervals. The variety CMC-39 was planted in ridges at a population of 10,000 plants per hectare in a field where the principal weeds were Cyperus rotundus (purple nutsedge), Rottboellia exaltata (Raoul grass), Sorghum halepense (Johnson grass) and Ipomoea spp. (morning-glory).

Results indicate that the weeding operation must begin 15 to 30 days after planting and continue until a canopy has formed; in this trial, it was 120 days due to the high density of aggressive weeds (Table 1). Weeding after 120 days did not increase production. One weeding was not sufficient, whereas two well-spaced weedings produced 75 percent of the maximum yield. When weeds competed during the first 60 days, yields were reduced by nearly 50 percent. The highest yield was obtained by chemically weeding the cassava, never allowing weeds to compete with the crop. Under the foregoing conditions, the critical period of competition began at planting and continued for 120 days.

Plant populations and weed control systems

The weed complex, soil fertility level and characteristics of the cassava variety are not the only important factors that affect the degree of weed competition; crop density is also very important. Under weed-free conditions, a crop maximizes its use of essential nutrients, water and light; and a low cassava population yields as much as higher ones (CIAT, 1973). On the other hand, when weeds are present, it is expected that higher crop populations will compete better with the weeds than lower densities. This expected interaction was studied. The varieties CMC-9 (a tall, branching type) and Mexico 11 (a shorter, nonbranching type) were planted in populations ranging from 2,940 to 25,000 plants per hectare. The results are presented in Figure 1.

Cassava kept weed free during the ten-month period with herbicides (alachlor plus diuron in preemergence and directed, shielded applications of paraquat in postemergence) gave the highest yields for each variety; optimal production was reached around 15,000 plants/ha. When the traditional methods of one or two hand weedings were employed, the highest yields were obtained at 15,000 to 20,000 plants/ha for Mexico 11 and between 20,000 and 25,000 for CMC-9 (Fig. 1). Two hand weedings were nearly as effective as the use of herbicides.

Table 1. Effect of hand weedings at different times and frequencies on the fresh root yield of cassava (CMC-39) at 280 days after planting.

No. of hand weedings	Frequency of hand weedings (days)	Fresh root yield (tons/ha)	Fresh root yield % of maximum yield*
4 + **	15, 30, 60, 120, UH***	18.0	86
3 +	30, 60, 120, UH	16.0	76
2 +	60, 120, UH	11.0	52
1 +	120, UH	7.0	33
4	15, 30, 60, 120	19.5	92
3	15, 30, 60	12.9	61
2	15, 30	13.3	63
1	15	5.8	28
2	30, 60	16.3	77
2	15, 45	15.4	73
0	Weedy check	1.4	7
0	Chemical control****	21.1	100

* Percentage of the yield of cassava weeded with herbicides
** The "+" indicates additional weedings
*** UH = until harvest, as needed
**** Alachlor + fluometuron were applied in preemergence, and directed applications with a shielded nozzle were made of paraquat as needed in postemergence.

Higher crop density will compensate for the effects of weed competition when the weed control system is not sufficiently intensive to keep the cassava relatively weed free. The data also illustrate that by keeping the crop totally weed free, especially during the early growth stages, fewer plants per hectare are needed to achieve maximum production. When no weeds were removed, cassava yields were extremely low; nevertheless, yields increased as plant density increased.

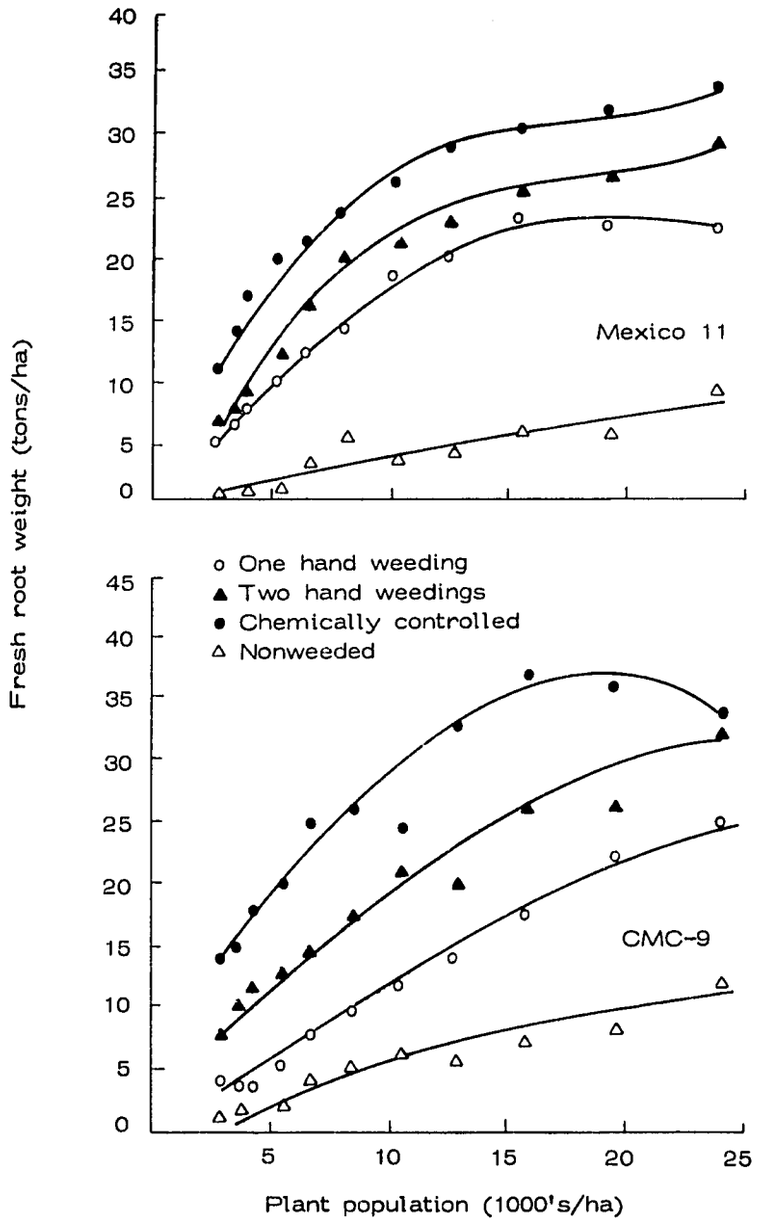

Figure 1. Effect of cassava population and weed control system on fresh root weight 10 months after planting for Mexico 11 and CMC-9.

Herbicide selectivity

Preemergence and preplant-incorporated herbicides

In Latin America up to the present, relatively few large-scale, preemergence herbicide applications have been made in cassava in comparison to other food crops. In part this is due to incomplete knowledge of safe and effective herbicides; therefore, four trials were conducted to screen commercial and promising experimental herbicides. To determine the margin of selectivity of each product, the recommended rate and two, three or four times this amount were applied. Those herbicides causing serious injury to cassava at the recommended rate were classified as nonselective; those causing injury only at double the recommended rate, moderately selective; and those causing no injury even at 3 or 4 times the recommended rate, highly selective (Table 2).

Eighteen products were found to be highly selective in cassava, and among these the right herbicide or combination of these could be found for almost any weed complex. Those products classified as moderately selective could also be recommended as there is no danger of crop damage if the exact rate for a given soil type is applied; only if an overdose is applied would there be a problem of crop injury. Herbicides in the third group may be harmful even at the normal rate and obviously should not be recommended.

Incorporated herbicides and the planting scheme

One of the hardest weeds to control in the tropics is purple nutsedge (*Cyperus rotundus*). Butylate is the only selective herbicide (Table 2) that controls it, and it must be soil incorporated immediately after application to prevent losses due to its high volatility. This can present a problem when cassava is to be planted in ridges, as is frequently done in relatively flat areas and in heavy-textured soils. As the ridges are formed after the herbicide has been incorporated, the herbicide accumulates in the ridge, reducing crop tolerance as well as leaving the area between ridges with less product and therefore poorer weed control.

A trial was conducted to study this aspect of three preplant-incorporated herbicides: butylate, EPTC and trifluralin. Each was applied at the recommended and double the recommended rate and immediately incorporated. Half of each plot was then ridged while the other half was left nonridged.

Table 2. Selectivity of preemergence and preplant-incorporated herbicides in cassava.*

Highly selective	Moderately selective	Nonselective
Alachlor	Ametryn	Atrazine
Benthiocarb	Butylate	Bromacil
Bifenox	Chlorbromuron	DPX-3674
Butachlor	Diuron	EPTC
Chloramben	DPX-6774	Karbutilate
Cyanazine	Fluometuron	Tebuthiuron
Dinitramine	Linuron	Vernolate
DNBP	Methabenzithiazuron	
Fluorodifen	Metribuzin	
H-22234	Oxadiazon	
Methazole	Prometryn	
Napropamide	Terbutryn	
Nitrofen		
Norea		
Perfluidone		
Pronamide		
S-2846		
Trifluralin		

* Based on the results of four trials

More crop damage was observed with EPTC in the ridged than in the nonridged system (Table 3). Butylate gave similar results but was much more selective, verifying the selectivity classification of Table 2. Trifluralin caused no crop injury at either rate in either system. Grass weed control was reduced by the ridging operation, especially between ridges, confirming that less product remains in this zone after ridging. In each system a combination of diuron + alachlor was applied in preemergence after planting cassava and gave excellent weed control in both (Table 3). In conclusion butylate is recommended to control purple nutsedge, and better control is obtained in nonridged systems. Hand or mechanical weedings should be performed as often as needed until the cassava has shaded over since the residual effect of butylate is normally 30 to 40 days only. Trifluralin can also be used in this way (incorporated), especially when the principal weeds are grasses.

Postemergence herbicides

Farmers who do not apply preemergence herbicides often have serious weed infestations and seek solutions with postemergence

Table 3. Effect of three preplant-incorporated herbicides on percentage of germination, injury rating, grass control and cassava production when cassava is planted in ridged and nonridged soil.

Treatments	Rate (kg a.i./ha)	% germination[1]	Injury rating[2]	Grass control[1] (%)	Fresh root yield[3] (tons/ha)
Cassava planted in ridges					
EPTC (PPI)[4]	4	75	5.2	73	22.0
EPTC (PPI)	8	45	7.7	86	8.4
Butylate (PPI)	4	77	0.7	36	33.0
Butylate (PPI)	8	83	3.5	80	30.8
Trifluralin (PPI)	1.5	94	1.5	62	35.8
Trifluralin (PPI)	3.0	100	0	76	35.6
Diuron + alachlor (PRE)[5]	0.8 + 1.5	96	0.5	100	27.9
Weedy check	-	94	0	0	18.3
Average		83	2.3	64	26.5
Cassava planted on the flat					
EPTC (PPI)	4	92	1.5	98	41.7
EPTC (PPI)	8	64	1.2	100	33.1
Butylate (PPI)	4	98	0	92	34.2
Butylate (PPI)	8	79	1.0	96	39.0
Trifluralin (PPI)	1.5	96	0	88	42.5
Trifluralin (PPI)	3.0	94	0.5	93	42.6
Diuron + alachlor (PRE)	0.8 + 1.5	98	0	100	36.9
Weedy check	-	100	0	0	21.4
Average		90	0.5	83	36.4

1 60 days after planting
2 60 days after planting; 0 = no injury, 10 = completely killed
3 10 months after planting
4 PPI = preplant incorporated
5 PRE = preemergence

products. For this reason, several postemergence herbicides commonly applied in other crops were tested in cassava.

Diuron proved to be the most selective product in over-the-top, broadcast applications; but even then yields were reduced 16 percent as compared with hand-weeded cassava yields. Amitrol, bentazon, paraquat, dalapon, MSMA, DNBP and glyphosate were totally nonselective; nevertheless, directed applications greatly increased their selectivity. For example, diuron, MSMA and dalapon, applied to the lower half of the plant, did not decrease yields. Paraquat and glyphosate were still injurious to cassava with this system, especially in young plants 40 to 65 days old. These postemergence products should, therefore, be applied only with a shielded nozzle to prevent plant contact.

Recommendations

Based on the foregoing and other research, chemical control recommendations are presented in Table 4. To arrive at these recommendations, the effectiveness, selectivity, availability and cost of each product have been taken into account. As was previously mentioned, rarely will the single application of an herbicide give sufficient weed control until the crop canopy closes; therefore, each field must be observed closely to determine when complementary hand or mechanical weedings should be performed.

Integrated control

In order to develop the best weed control program for each farm, it is not enough to know which herbicides are selective, nor should cassava be considered as a short-season crop such as corn or soybeans. Its slow initial growth gives weeds an opportunity to grow vigorously; and even when herbicides are used, the best products control weeds for approximately 60 days and the cassava canopy has not yet closed. Therefore, an experiment was conducted to evaluate how to integrate the various methods of control best. The systems studied were preemergence herbicides followed by postemergence ones, preemergence herbicide applications complemented with a hand weeding, and postemergence applications followed by a hand weeding. These methods were compared to the traditional system of three hand weedings.

The highest yield was obtained with three timely hand weedings (31 tons/ha at ten months); the use of diuron in preemergence, complemented with one hand weeding, was the next best system (27 tons/

Table 4. Chemical weed control recommendations for cassava.

Herbicide[1]	Rate (com. prod./ha)[2]	Time of application	Notes
Fluometuron (Cotoran)	4-5 kg	Pre[3]	Most annual weeds
Diuron (Karmex)	2-3 kg	Pre	Most annual weeds
Alachlor (Lazo)	4-6 liters	Pre	Excellent on grasses
Linuron (Afalon or Lorox)	2-3 kg	Pre	Most annual weeds
Fluometuron + alachlor	2 kg + 2.5 liters	Pre	Tank mix
Diuron + alachlor	1 kg + 2.5 liters	Pre	Tank mix
Trifluralin (Treflan)	2.5-3.5 liters	PPI[4]	Excellent on grasses
Butylate (Sutan)	5-6 liters	PPI	Controls grasses and sedges
Dalapon (Dowpon or Basfapon)	8 kg	Post[5]	Directed application
Paraquat (Gramoxone) + diuron	2 liters + 2 kg	Post Post	Tank mix; directed application with a shield

1 Name of commercial product given in parentheses

2 The lower rate is for lighter soils and the higher one for heavy-textured soils.

3 Pre = preemergence, before crops and weeds emerge

4 PPI = preplant incorporated; ridging after incorporation may reduce weed control.

5 Post = postemergence; a surfactant should be added.

ha). The lowest yields were from the preemergence treatments alone, emphasizing the need to integrate the use of chemical control with complementary measures.

In general, the hand weeding that follows the preemergence application should be done two to three weeks prior to the canopy's closing (normally 60 to 75 days after planting under conditions at Palmira); but if there is a serious weed problem prior to this time, weedings should be practiced as often as needed to avoid competition with cassava.

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