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9. ABSTRACT
Data from ICRISAT village level studies is used to document the extent and timeliness of weed control activities by farmers in three distinct agro-climatic zones of India. The farmers' understanding of the weed problem and its constraints is examined. Budgets are presented for alternative weed control plans with and without herbicides to assess the potential for use of herbicides in these areas at the present and with existing resource position. The implications for weed research are also explored The studies began in 1975 in six villages in the Akola, Mahbubnagar, and Sholapur districts. The three districts are quite different in climate. Weed control activity is guided by rational consideration. More effort is allocated to crops on better land and to crops with high value per unit area. Dry crops herbicides cannot at present be advocated on the basis of cost considerations in the semi-arid areas of India. Justification for the use of herbicides must come from the possible yield effect of more timely weed control. This is achieved by using herbicides or by keeping the fields free of weeds during the first two or three weeks of plant growth when farmers cannot yet go in with handweeding or interculture. It still must be experimentally confirmed that farmers' weed control activity is low because of low payoff to weed control under existing varieties and fertilizer use levels, rather than resource constraints such as bullock power, or a desire to use weeds as fodder. If the problem is low capital, herbicides may not provide a solution.

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Economic Aspects of Weed Control in Semi-Arid Tropical Areas of India*

Hans P. Binswanger & S.V.R. Shetty †

The economical control of weeds is one of the oldest and most frustrating problems of agricultural production. In developed countries it has been made easier by enormous amounts of power available to farmers and by the invention of chemicals for weed control which, at the high wage rates of the developed countries, have almost totally replaced handweeding.

In the developing countries of Asia, capital is much more scarce than in developed countries and wage rates are lower. Farmers frequently do not even have sufficient funds to make effective use of improved seeds and fertilizers. Frequently one observes poor crops on weed-infested fields. As a consequence it is often assumed that farmers in areas like SAT India have either a poor understanding of the damage caused by weeds, or understand the damage but do not possess the draught power and labor resources to effectively take care of weeds by hand-weeding and interculture.

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In this paper, we firstly use data from ICRISAT's Village Level Studies to document the extent and timeliness of weed-control activities by farmers in three distinct agro-climatic zones of SAT India. We want to see to what extent the assumption about farmers' understanding of the weed problem or of their constraints are correct. Secondly, we present budgets for alternative weed-control plans with and without herbicides to assess the potential for use of herbicides in these areas at the present time and with the existing resource position. We finally explore the implications for weed research.

The analysis in this paper raises a number of questions which require further analysis. It is planned to attempt to answer these using 1976-1977 data as soon as they become available. Also, certain questions will require some further field observations.

CURRENT WEED-CONTROL PRACTICES

The results of this paper are based on data from ICRISAT's Village-Level Studies which started in May 1975 in six villages in the Akola, Mahbubnagar, and Sholapur districts. A stratified random sample of 40 households, of which 30 are cultivators operating more than one half acre of land was studied in each village. The data refer mainly to the cropping year 1975/76, except for the frequency distribution of weeding and interculture in the Mahbubnagar villages, which are based on

1976/77 data observations. Also in the Sholapur villeges the data are available for both 1975/76 and 1976/77. The households in the surveys were interviewed every 3 weeks and the cultivation data gathered plotwise. Each field operation was recorded with its date. This allows the investigation of interval lengths between operations.

Agro-climatologically the three districts are vastly different (Table 1). Akola district in Maharashtra is an assured-rainfall area with medium-deep black soils and kharif cropping. The chosen villages Kanzara and Kinkheda have very little (3%) irrigated land. The main cash crop is cotton (sometimes mixed with sorghum and pigeonpea) and sorghum is the main food crop. Groundnuts are also grown. Some of the farmers have taken to hybrid cotton and hybrid sorghum, and are using fertilizers and insecticides. Herbicides are not used in this area, nor in the other two areas of the investigation.

In general, cotton fields in Akola are quite weed-free when cotton is grown as a sole crop. On the better soils, cotton is grown by square planting and this facilitates two-way intercultivation using animals. The farmers consider five to six intercultivations along with hand picking of weeds and stubbles as adequate. In the case of groundnuts, four intercultivations and one handweeding is the practice regarded as desirable by many farmers (depending upon the bullock and labor resources available). In general, cotton is sown earlier than other crops

Table 1 : Characteristics of the sample households and Study areas.

District:-	Akola	Mahbubnagar		Sholapur
Village:-	Kanzara/ Kinkheda	Aurepalle	Dokur	Kalman/Shirapur
Average Farm size (Net cultivated area in ha)	6.0	4.4	2.6	6.25
Soil type	Medium black kharif crop area	Medium/ shallow red		Deep to medium black rabi crop areas
Average rainfall(mm)	818	636	659	654
Total cropped area irrigable (%)	3	13	38	11
Bullocks per(no) 100 ha/of net cultivated area (sample farms)	26.5	42.2	47.9	17.4
Family workers(no) per 100 ha (sample farms)	70.6	109.4	152.8	71.2
Landless households (%) in population of village	36.2	27.5	13.10	23.9

Source: Village-Level Studies, ICRISAT.

and first preference is given to cotton during weeding operations. Wherever hybrid H4 cotton is sown, weed management is excellent. However, this is not always so with hybrid sorghums.

The intercultivating equipment is the " blade harrow " or "Guntaka" which seems to be more efficient and does a better job than the "Guntaka" observed in Mahbubnagar district; the blade being sharper and stronger. Handweeding is done squatting on the ground and using a small hoe. Hoes with long handles are not seen in the three areas.

In the farms where timely weed-control was not practiced, the major weed species found were *Cynodon, Cyperus, Digitaria, Echinochloa, Eragrostis, Amaranthus, Celosia, Desmodium, Corchorus, Crotalaria and Ipomoea*. *Cynodon* and *Cyperus* are the two most serious weeds of this medium black soil region. Even in some cultivated fields, large patches were left uncultivated in the middle due to the *Cynodon* problem. In many of the hybrid sorghum plots, weed infestation was heavier than in cotton and the weedy situations were quite visible due to the short stature of hybrids.

Farmers are aware of the importance of post-harvest operations in managing weeds. However, due to many constraints and nonavailability of resources, only few farmers undertake post-harvest operations within the first month after harvest. This may allow weed to mature seeds.

The Mahbubnagar area receives about 650 mm of rainfall on shallow to medium red soils and soil moisture is much less assured. The two villages Aurepalle and Dokur are about 60 km apart and have quite different cropping patterns. Aurepalle has 12 percent of its cropped area irrigated while Dokur has a much larger area of 32 percent. In both villages irrigation is mostly used for paddy. The major rainfed cereal is sorghum and it is generally mixed pearl millet, pigeonpea, and upto four other crops like mungbean, mesta, and cucumber. Sorghum as sole crop is grown mostly with supplementary irrigation. In Aurepalle, the major cash crop is castor. In Dokur groundnuts are grown both in the kharif and rabi season, with irrigation from wells used during the rabi.

A notable feature of intercultivation in the Mahbubnagar area is the different types of equipment farmers use for the purpose. Whereas the farmers of Aurepalle village use a single-bladed "guntaka", in Dokur the common equipment is a primitive type of "danthe," wherein two to three unsharpened iron blades are attached to two to three big wooden hoes branched at the end. Two or three persons are required for the operation to guide the hoes as well as the bullocks. However, two to three rows of crops can be intercultivated simultaneously. This type of equipment does not always perform satisfactorily and patches of weeds may still be left even after passing this equipment a number of times, since the blades are not sharp enough to lift the

layer of the soil. With either "guntaka" or "danthe;" farmers were not able to remove *Cyperus* and *Cynodon*, the serious weeds of the region.

Handweeding of unirrigated crops is not done in Aurepalle, but is considered desirable in Dokur. In Dokur, farmers have a definite sequence of weeding crops. Groundnuts come first, followed by irrigated sorghum (the food crop mixture) and finally other minor crops sown on very poor lands. Handweeding of unirrigated kharif crops does not conflict with the main thrust of paddy cultivation since the tank-irrigated paddy is only transplanted in September or later when the tank is full. Farmers who also have kharif paddy under wells will however give first preference to weeding these paddy plots. This is quite a rational sequence, given the payoffs from handweeding of these crops.

In Aurepalle, where unirrigated crops are not handweeded, preference for interculture is given to castor before the food-crop mixture. Usually intercultivated castor fields look clean without many weeds, whereas in other crops, as well as mixed-cropping systems, weeds within the rows still remain even after intercultivation. To remove as many weeds within the rows as possible, farmers will first "shave" the castor plants from the left and then from the right side, displacing them sideways each time, so that no weeds remain within

the row. The deep roots of castor permit this and farmers claim that the plants do not suffer. Generally less weed infestation is observed in those fields planted to castor in the previous year. This may be caused by the frequent intercultivation (6 to 7 times in a season) of the castor crop resulting in reduced weed-seed production and disperseal at the end of the crop season.

In Dokur village of Mahbubnagar district the paddy crop is only handweeded and not intercultured. Handweeding is done without the use of implements by women in a bending position in standing water.

Sholapur District is a rabi-crop area with deep to medium-deep black soils. Rainfall is lower than in Akola, and rains in the first half of the monsoon are uncertain. 1975/76 was a very wet year and the planting of rabi crops was delayed until mid-November. Rabi sorghum suffered from the cool weather and developed sugary leaf disease. The yields were so poor that the area was declared a "scarcity-affected" zone and recovery of loans and land revenue was postponed.

On the other hand 1976/77 was a very low rainfall year, but the rains were sufficiently well distributed to result in fairly good crop yields except for kharif groundnuts and rabi safflower which

failed. Due to drought condition at sowing time of the rabi crops most farmers decided not to grow safflower.

Weeds are a severe problem in the kharif crops of Sholapur. Kharif crops consists mainly of groundnuts and bajra mixtures in the lighter soils.[1/] In the rabi season, the weed problem is less severe because most plots are harrowed several times during the kharif season and crop growth as well as weed growth is slower due to lower temparatures. Thus most rabi plots look quite weed free.

Data on the handweedings and interculture operations in the sample villages is presented in Table 2. Panel A gives the percentage of plots handweeded never, once, twice, etc.[2/] Panel B groups those plots handweeded at least once into those with delays between sowing and handweeding of less than 15 days, 16 to 25 days, etc., and gives the proportion falling in each class. Panel C shows the proportions of plots intercultured a given number of times, and Panel D analyzes the delays between the sowing and the first interculture.

1/ The difficulty of weed control in the kharif season on the deep black soils may be one reason for widespread practice of kharif fallow in these areas.

2/ The analysis is presented here in terms of proportion of plots rather than proportion of total area planted to a given crop or mixture of crops. In Akola the analysis was also done in terms of area, with practically identical results. This implies that there is no strong association between farm size and weed control behaviour, which a perusal of the raw data continued.

Table 2 : Probability distribution of weeding and weeding delays and of interculture and interculture delays.

Crops a/	No. of plots observed	A. Percentage of plots handweeded				B. Percentage of delays to first handweeding b/				C. Percentage of plots intercultured						D. Percentage of delays to first c/ interculture				
		Never	Once	Twice	Three or more	≤15	16-25	26-35	≥36 days	Never	Once	Twice	Thrice	Four	Five	≤ 15	16-25	26-35	36-45	≥46 days
AKOLA VILLAGES 1975/76																				
Sorghum Mixture(K)	65	31	49	17	4	20	16	22	42	8	2	18	20	29	23	58	37	5		
Sorghum (Sole)(K)	29	17	48	28	7	8	33	17	42	3	7	45	28	14	3	36	46	14	4	
Cotton(sole & mixed)(K)	110	15	40	24	21	8	19	22	51	14	3	8	16	23	36	45	47	8		
Groundnut(K)	16	19	44	12	25	23	8	23	46	19	13	19	25	13	13	61	31	8		
MAHBUBNAGAR(AUREPALLE)1976/77																				
Sorghum Mixture(K)	34	94	3	3						6	17	35	24	9	9		13	62	9	16
Castor(K)	41	98	2							27	7	10	12	22	22		7	60	20	13
MAHBUBNAGAR(DOKUR) 1976/77																				
Sorghum(sole & mixed)(R)	9	33	67				17		83	33	22	45				33		50		17
Groundnut(sole & mixed)(K)	11	18	73	9			11		89	9	55	36				10		70	10	10
Paddy (K)	45	4	91	5		23	5	40	32	98	2									100

a/ K refers to kharif (monsoon) crop and R to rabi crop (Postmonsoon)
b/ As percent of the number of plots handweeded at least once.
c/ As percent of the number of plots intercultered at least once.

Source : Village-Level Studies data from ICRISAT.

Table 2(a) : Probability distribution of weeding and weeding delays and of interculture and interculture delays.

Crops a/	No. of plots observed	A. Percentage of plots handweeded				B. Percentage of delays to first handweeding b/				C. Percentage of plots intercultured						D. Percentage of delays to first interculture c/				
		Never	Once	Twice	Three or more	≤15	16-25	26-35	≥36 days	Never	Once	Twice	Thrice	Four	Five	≤15	16-25	26-35	36-45	≥ 46 days
SHOLAPUR VILLAGES 1975/76 & 1976/77																				
Sorghum mixtures(R)																				
1975/76	39	87	13					60	40	23	41	23	13				3	3	17	77
1976/77	46	100								4	74	22					9	14	11	66
Sorghum(Sole)(R)																				
1975/76	160	81	16	3			3	29	68	49	34	14	3			4	6	12	18	60
1976/77	119	94	6				43	29	28	18	64	17	1				11	14	11	64
Chickpea (R)																				
1975/76	51	96	4							63	35	2						16	16	68
1976/77	12	92	8			100				42	58					14				86
Pearl Millet(K) mixture																				
1975/76	18	83	17							50	44	6						56	11	33
1976/77	35	80	14	3	3		29		71	6	37	28	26	3			6	27	49	18
Pigeonpea mixtures (K)																				
1975/76	78	82	18					7	93	49	37	14					15	40	28	17
1976/77	60	81	17	2		18		27	55	15	59	18	5	3				16	39	45
Groundnut(K)																				
1975/76	12	33	50	8	8			37	63	100										
1976/77	23	18	65	13	4	5	21	16	58	79	17	4					20	20		60
Chillies(K)																				
1975/76	12	17		17	67		30	50	20	100										
1976/77	5	20	40		40			25	75	40	60								33	67

a/ K refers to Kharif(monsoon) crop and R to rabi crop (Postmonsoon)
b/ As percent of the number of plots handweeded at least once.
c/ As percent of the number of plots intercultured at least once.

Source: Village-Level Studies data from ICRISAT.

In the Akola villages, between 15 and 30 percent of the fields in all major crops are never handweeded. A little less than half the fields are handweeded once. In cotton, 45 percent of the plots are handweeded two or more times. The delays in handweeding can be substantial. More than 40 percent of the crops are handweeded for the first time later than 36 days after sowing.

Less than 20 percent of the plots in the Akola village are never intercultured and for mixed sorghum and sole sorghum the corresponding percentages are only 8 and 3, respectively. For both these crops, as well as for cotton (sole and mixed), more than 80 percent of the plots receive two or more interculture operations. In cotton almost 60 percent of the plots are intercultured more than four times. More remarkable is that in the food-crop mixtures and in cotton and groundnuts, more than 90 percent of the crops are intercultured for the first time within the first 25 days after sowing. This is a remarkably good degree of weed-control and implies that the delays in handweeding are of less consequence, especially in many of the cotton fields which are intercultured in a crosswise manner. The overall picture is one of thorough and timely weed control, there were a few exceptions.

In the Mahbubnagar village of Aurepalle unirrigated crops are practically never handweeded. Six percent of the food-crop mixtures are never intercultured, whereas 27 percent of the castor fields go without interculture. On the other hand, almost 60 percent of the castor fields receive three or more intercultures, which are very thorough.[1/] In both crops delays are longer with most plots receiving their first interculture between 26 to 35 days after sowing. The question arises whether the less intensive weed control in Aurepalle compared to Akola is sufficient for effective weed control. Table 1 shows that it cannot be due to lack of bullock power or family labor, as Aurepalle has substantially higher numbers per 100 ha than the Akola villages. The proportion of landless households is lower in Aurepalle but not by very much. While total availability of labor is not less than in Akola, the laborers may have better opportunities during the weeding season in neighbouring villages which have much more paddy cultivation than Aurepalle itself.[2/]

1/ See the large amount of bullock-pair hours used per interculture in castor (Appendix Table 1)

2/ We must be able to show that the female laborers are indeed employed elsewhere and not simply unemployed to show that there is a real labor constraint. Analysis is under way to test this hypothesis.

On the other hand, payoffs to handweeding are probably lower in Aurepalle than in Akola, partly because of the special feature of castor interculture and partly because growth of weeds as well as of crops is less vigorous on the light sandy soils of Aurepalle than on the medium-deep black soils of Akola. Growth of weeds is clearly slower in Aurepalle which partly explains the longer delays. Furthermore, visual inspection of the intercultured castor fields showed that weed control by interculture along achieved fairly clean fields. It is thus possible that the main reason for the lesser degree of weed control activity in Aurepalle is the smaller payoff from it, rather than unawareness of losses due to weeds.

In Dokur, farmers also rely more heavily on interculture than on handweeding for the unirrigated crops. Of the sorghum and groundnut plots, 33 and 9%, respectively do not get any interculture. Of those which are intercultured, most are initiated before the 35th day after sowing. Handweeding is done in more than 6 percent of the plots, but is mostly delayed till after the 35th day. In paddy practically all plots are handweeded once and only 5 percent are handweeded twice. Around 70 percent of the plots are handweeded before 35 days have elapsed, which is a reasonable degree of timeliness. This confirms that weed-control activity is heavily concentrated in paddy--the highest value crop--while unirrigated crops receive only second priority.

In Sholapur, the agricultural resource base is much poorer than in Akola. Furthermore, the 3 years preceding 1975/76 were extreme drought years and the villagers had lost up to two-thirds of their cattle. During the first year of investigation, the capital stock of the farmers was depleted so that many of them could not even buy groundnut seed to grow this otherwise prevalent cash crop.

Table 2 gives details on handweeding and interculture for three rabi and four kharif crops in Sholapur for 1975/76 and 1976/77. In both years rabi crops were practically never handweeded. In the first year 23 percent of sole jowar plots and 49 percent of the mixed jowar plots were never intercultured as well, whereas in the second year the frequency of zero interculture dropped to 4 and 18 percent respectively. The neglect of interculture in the first year in the jowar fields is probably because of the near crop failure during that year; by the time of interculture sorghum was already severely attacked by sugary leaf disease and stunted in growth which led many farmers to stop investing further in the crop.

Note further that in both years rabi sorghum fields were usually intercultured with a very large delay. Between 60 to 77 percent of the plots intercultured were intercultured with a delay of more than 46 days from sowing. We will discuss the reasons for this below.

In rabi chickpea the situation is similar to sorghum except that an even higher proportion of the fields were never intercultured at all in both years.

On a visit in January 1977 we questioned farmers about the reasons for the delays in interculture of the rabi crops. They generally explained that there are few weed problems in the rabi season because of dry conditions and frequent harrowing of the kharif fallowed fields. Also low temperatures generally delay plant growth. Visual inspection of the fields confirmed the almost total lack of weeds, in the rabi season. Interculture is usually delayed up to the flowering stage and then performed by a small hoe which is pulled by one man and guided by another one. The main purpose of this operation is not weed-control but closing of the gaps in the deep black soils to prevent moisture losses, and the pushing of the soils towards the plants to give them better support.

In the kharif crops we have data pearl millet based mixtures, which can also include pigeonpeas as a component. We also have data for pigeonpea as a sole crop or in mixtures which do not include pearl millet. Both of these crop mixtures are grown on the light soils. There is little handweeding in the kharif crops and in 1975/76 half the pearl millet plots did not receive interculture, whereas in 1976/77 the interculture of these crops was much more frequent. Also the delays of interculture were short-

er than for the rabi crops. The increase in frequency of interculture may have several reasons. 1975/76 was wet and up to the weeding stage rainfall was very frequent, which might have made timely interculture difficult. Furthermore in 1976/77 the kharif crops looked remarkably good up the flowering stage thus prompting farmers to invest more in weed-control. However, the crops were subject to severe drought in the later part of the season and groundnuts failed completely. Finally in groundnuts and chillies weed-control is mainly done by handweeding and there seem to be substantial delays in more than half the cases. Overall, farmers in Sholapur seem to allocate their resources to weed-control in a fairly rational manner. They put in more effort in the kharif season crops than rabi crops because weed problems are more; and where crops stands are good, more effort is spent than when crops appear to be failing. Nevertheless visual inspection confirmed that weed-control in the kharif season crops is not sufficient and with exception of the high valued groundnut and chillies crops, handweeding is practically absent. Family labor availability is the same in Sholapur than in Akola.(Table 1). The lack of handweeding is thus not explained by low labor availability. On the other hand, Sholapur had almost 40 percent fewer bullocks than Akola per 100 ha. The insufficient and delayed interculture in the kharif season is therefore possibly explained by bullock power constraints.

Overall, weed-control activity seems to be closely related to (1) the basic fertility of the area, (2) to the value of the crop grown on a field and (3) the crop condition at the weeding and interculture stages. In the assured rainfall area of Akola, weed-control activity can only be described as good, while in the poorer Mahbubnagar and Sholapur areas, much less activity takes place and certain crops may be neglected.

Data on the sex allocation of handweeding and interculture is presented in Table 3. Handweeding is almost exclusively done by females while interculture is done primarily by males (family and permanent labor force). Not presented is the percentage of hours performed by children (of less than 14 years) which was frequently zero or very low and reached a maximum of 5 percent of total hours only in the case of the food mixture in Dokur. Thus, contrary to expectations, primary school age children do not participate substantially in handweeding. They may, however, be called on more heavily during the harvesting season.

Quite impressive is the fact that generally more than two thirds of all handweeding hours are performed by <u>hired</u> females and that in Akola it was more than 80 percent except for chillies where only about 100 hours were involved. The percentage of hired women hours was

Table 3 : Distribution of weeding and interculture hours by sex

Crops a/	Total Hand weeding hours	% hours by females	% hours by hired females (of total)	Interculture Total Hours	Interculture % of hours by males
AKOLA (1975/76)					
Food Crop Mixture(K)	5886	98	93	4137	100
Sorghum (K)	5734	96	77	663	95
Cotton (K)	18774	98	91	7710	98
Groundnut(K)	1271	95	83	429	94
Chillies (K)	98	65	35	50	100
MAHBUBNAGAR(Aurepalle)(1976/77)					
Food Crop Mixture(K)	0	--	--	336	100
Castor (K)	72	89	44	1066	100
MAHBUBNAGAR(Dokur)(1976/77)					
Food Crop Mixture(K)	692	95	79	88	100
Jowar (K)	984	100	62	136	100
Groundnut (K)	1078	100	77	133	100
Paddy (K)	2574	99	94	0	--
SHOLAPUR (1975/76)					
Food Crop Mixture(R)	0	--	--	509	100
Sorghum (R)	2698	100	70	1826	94
Groundnut (K)	1128	95	63	0	--
Chillies (K)	1149	100	48	0	--

a/ R : Rabi
K : Kharif

lower in Sholapur than in the other villages. In table 1, we can also see that the percentage of landless households is lower in Sholapur than in Akola, thus forcing households to use more of their own labor. A look at the raw data by farm size also indicated that even small and medium holdings frequently hired female labor for handweeding. It is therefore clear that any reductions in handweeding hours made possible by herbicides would primarily reduce work and income opportunities of the most disadvantaged labor group in the Indian economy, namely female agricultural laborers. We examine this issue more thoroughly in the ensuing section.

COST ANALYSIS OF ALTERNATIVE WEED-CONTROL METHODS

In Table 4 we drawn up three plans for weed-control for eight crops or crop combinations. Plan 1 is based entirely on herbicides; plan 2 combines herbicides, interculture, and handweeding in a more realistic manner and plan 3 uses no herbicides. We have tried to draw up the plans in such a way that they give an equivalent quality of weed-control within each crop. Any possible yield effect of herbicides is neglected for the moment. We do not endorse the use of the chemicals in the plans, but consider them as indicative. When a choice between equivalent herbicides was possible, we choose

Table 4 : Alternative weed control methods.

Methods	Cotton	Groundnuts	Castor	Sorghum	Pearl Millet	Chickpea	Mixture Sorghum P.Millet Pigeonpea	Paddy
1. High Herbicide [a]								
Chemical, Pre	Diuron 1 kg/ha	Alachlor 2.5 kg/ha	—	Atrazine 1 kg/ha	Atrazine 0.5 kg/ha	Nitrofen 2 kg/ a	Prometryn 1 kg/ha	2,4-D Ester 1 kg/ha
Chemical, post	MSMA 2 kg/ha	Not available	Paraquat apply twice 1 kg/ha each time (Directed)	2,4-D Salt 1 kg/ha	2,4-D Salt 0.5 kg/ha	—	Paraquat 0.5 kg/ha (directed)	Propanil 3 kg/ha
2. Selective Herbicide [a]								
Chemical, pre	Diuron 0.5 kg/ha	Alachlor 1 kg/ha	—	Atrazine 0.5 kg/ha	Atrazine 0.4 kg/ha	Nitrofen 1 kg/ha	Prometryn 0.75 kg/ha	2,4-D Ester 0.5 kg/ha
Chemical, post	MSMA 1 kg/ha	—	Paraquat 0.5 kg/ha (Directed)	—	—	—	—	—
Intercultivation [b]	2	1	2	1	—	—	1	—
Handweedings [b]	1	1	—	1	1	1	1	1
3. No Herbicide								
Intercultivations	6	3	4	2	1	—	2	—
Handweedings [b]	4	2	—	2	2	2	2	2

a Herbicide rates are in kg of active ingradients/ha. These chemicals are selected only for our economic analysis and the authors do not necessarily endorse the use of these listed herbicides. Many other herbicides are also used on these crops.

b Rainfall and soil conditions permitting.

the cheaper ones. The prices used in the cost analyses are approximate market prices prevailing in January, 1977.

Human and bullock hours required for handweeding and interculture are based on the hours actually used in the study villages for these operations. The Akola data were used for cotton, groundnuts, and cereals, and it was assumed that chickpea weeding required the same amount of labor as cereals. Aurepalle data were used for castor and Dokur data for paddy. Labor bullock coefficients are given in Appendix Table 1. 1/

For each plan four alternative costs have been worked out, each with a different valuation of labor costs. Financial costs are costs faced by farmers who hire labor and have to commit the full wage rate as costs. The opportunity cost is faced by farmers using only family labor for interculture and weeding operations and who value

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1/ In Akola cereal crops, the per-hectare female handweeding labor requirement is 7.25 8-hour days. On ICRISAT watersheds in 1976, we used 8.6 female days per ha for the first handweeding on ridges and furrows in maize, which is not much different. In cereal crops in Akola 6.84 bullock-pair hours were required for interculture per ha while in ICRISAT we required 7.12 bullock pair hours for the first interculture.

their own effort at only about 70 percent of the current wage rate.[1/]

Finally, to study the sensitivity of rankings of the plans, wage rates and opportunity costs were increased by 50 percent and costs calculated again. This is a large rise in real wage rates relative to recent historical experience. Most evidence suggests that in SAT states of India (and in most of tropical Asia) real rural wage rates have failed to rise rapidly and may have fallen in some instances during the past 10 to 20 years.[2/] The failure of real rural wage rates to rise is one of the most striking features of India's development experience. For example in West Bengal and Bihar, real rural wages have not risen in the past 100 years.[3/] Given the current demo-

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1/ This is based on the analysis of Subrahmanyam and Ryan[4]. The value of labor on ones own farm is the value of earnings foregone by not working in the hired labor market. The expected wage rate in the hired labor market is the actual wage rate times the probability of finding a job on any given day. In Kanzara this probability was around 70 percent for both males and females during the weeding season of 1975/76. It may be different in the other two areas; therefore the sensitivity analysis on wage rates is quite important.

2/ If we take 1956/57 as a base year (=100), then the index of real wage rates for male agricultural field laborers in 1971/72 for states with substantial semi-arid tropical areas were as follows: Andhra Pradesh, 119; Gujarat, 125; Karnataka, 92; Madhya Pradesh, 102; Maharashtra, 99; Tamilnadu, 113. Source: Jose [3].

3/ See Bhattacharya and Malakar[1]. Daily male wage rates per day have fluctuated in the range of 2 to 4 kg of rice and have been less than 3 kg since the early 1950s.

graphic projections, rises in real rural wage rates of more than 50 percent are unlikely within the next 10 to 15 years.[1/]

The cost data are presented in Table 5. It is immediately clear that in none of the crops considered is it economical to use only herbicides. These plans are at least two and one-half times more expensive than plans without herbicides (Financial Cost) and in the case of chillies the cost ratio rises to 8. Even if wage rates were to rise by 50 percent the pure herbicide plans are still about twice as expensive as the no herbicide plans in the case of pearl millet and cotton. From this we can conclude that, on the basis of cost considerations alone, pure herbicide plans are out of the question for a long time to come.

The mixed plans, involving selective use of herbicides, are also not attractive (at present wage rates) for the rainfed crops under the present system of cultivation. In the case of paddy, the mixed plan, which substitutes for one handweeding a pre-emergence herbicide is Rs.25 cheaper (Financial cost) than the pure handweeding plan. Even a farmer using his own family labor might find the use

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1/ The most conservative population projections, according to Cassen & Dyson[2], put the all India population in year 2000 at slightly less than 1000 million. Most other projections assume values higher than 1000 million people. Furthermore, Census data over the past 50 years show that the proportion of female agricultural alaborers as percent of female population is rising.

Table 5 : Costs of alternative weeding Plans

	Cotton		Groundnut		Castor		Sorghum		Pearl Millet		Chickpea		Sorghum, Pearl Millet, Pigeonpea		Paddy	
	Financial Cost	Opportunity Cost	Fin. Cost	Opp. Cost	Fin. Cost	Opp. Cost	Fin. Cost	Opp. Cost	Fin. Cost	Opp. Cost	Fin. Cost	Opp. Cost	Fin. Cost	Opp. Cost	Fin. Cost	Opp. Cost
Pre Herbicide[a]																
1. Chemical, pre	118		200				128		64		240		120		90	
2. Chemical, post	200		na		630		40		20		-		158		330	
3. Application Charge[b]	20		10		20		20		20		10		20		20	
Total :	338	338	210	210	650	650	188	188	104	104	250	250	298	298	440	440
Selective Herbicide																
1. Chemical, pre	59		80		—		64		51		120		40		45	
2. Chemical, post	100		—		158		—		—		—		—		—	
3. Application Charge	20		10		10		10		10		10		10		10	
4. Interculture[c]	28		12		86		16		—		—		16		—	
5. Hand weeding[c]	6		5		—		7		7		7		7		41	
Total :	213	205	107	103	254	234	97	91	68	66	137	135	123	117	96	86
Wages at 150%	226	216	114	109	269	246	106	49	74	71	143	140	132	125	119	104
No Herbicide																
1. Interculture[c]	82		35		173		31		16		—		31		—	
2. Weeding[c]	50		20		—		27		27		31		27		121	
Total :	132	102	55	42	173	134	58	45	43	33	31	21	58	45	121	94
Wages at 150%	174	134	73	56	197	152	79	61	60	46	40	31	79	61	184	142

a : Prices of herbicides are: 2,4-D Ester, Rs.40/kg; 2,4-D Salt, Rs.40/kg, MCMA, Rs.100/kg; Propanil, Rs.110/kg; Diuron, Rs.118/kg; Alachlor, Rs.80/kg; Paraquat, Rs.315/kg; Atrazine, Rs.128/kg; Prometryn, Rs.120/kg; and Nitrofen, Rs.120/kg.

b : Application by knapsack sprayer, hand-operated. A charge of Rs.10 per application is assumed — Rs.5 for labor and Rs.5 for sprayer. For the 50% higher wage rate, the charge thus comes to Rs.12.50.

c : For detailed cost calculations see Appendix Table 1.

of one herbicide application to be about Rs.10 cheaper (opportunity cost) than the use of two handweedings. In rainfed crops, however, even a rise of the wage rates by 50 percent would not make a single mixed plan attractive. In pearl millet the selective herbicide plan is still 25 percent more expensive than the no herbicide plan, and in all other plans the cost difference is much larger. With pearl millet where the cost structure is most favourable for herbicides--doubling of wage rates from the initial level would raise the cost of the selective herbicide plans to about Rs.80 while the cost of the no-herbicide plan rises to Rs.76. Therefore even a doubling of the real rural wage rates is not sufficient to make a single selective herbicide plan for rainfed crops financially attractive on the basis of cost considerations. For the small family farmer, whose opportunity wage rate is less than market costs, the situation is even less in favor of selective herbicide plans in rainfed crops.

If we consider mixed cropping rather than single cropping of pearl millet and sorghum (where herbicides might become attractive most rapidly), the costs of both herbicide plans rises since we are forced to use more costly and more selective herbicides. Mixed cropping will thus further reduce the comparative advantage of herbicides.

CONCLUSIONS

We have shown that weed-control activity is clearly related to the quality of the resource base. The better the growth environment for the plants and weeds, the more and better weed control is undertaken by farmers. While, in Sholapur and Mahbubnagar, present weed-control practices may be deficient in some crops, they are clearly adequate in the case of Akola. Even in Akola some fields go without weed-control, but they are mostly the fields with poor quality land.

Farmers weed-control activity seem to be guided by quite rational consideration. They will allocate more effort to crops on better lands and to crops with high values per unit area. They will also reduce the weed-control effort considerably if, at the weed-control stage, crops appear to be failing. We can thus be optimistic that farmers will respond with increased weed-control effort to improvements in their farming system via better varieties and/or improved soil management techniques.

We have also shown that for dry crops herbicide use cannot at present be advocated on the basis of cost considerations in the semi-arid areas of India. Justification for use of herbicides must come from the possible yield effect of better timeliness in weed-control achievable by herbicides or from the effect of keeping the

fields free of weeds during the first 2 or 3 weeks of plant growth when one cannot yet go in with handweeding or interculture. Only experiments which compare totally weed-free plots with plots which are kept weed free only from the 15th or 20th day after sowing can tell us whether such yields effects of early weed control exist. Such experiments are now under way at ICRISAT.

Finally it is clear that interculture is done primarily by males while handweeding is primarily be done by hired female labor. Labor saving due to herbicides would therefore decrease income opportunities for the most disadvantaged labor groups in India, landless female laborers.

Which then are the agronomic weed-research activities most likely to result in production practices which will increase agricultural productivity in SAT India? We still do not have sufficient knowledge about the real payoff of additional weed-control by farmers under existing farming practices for areas like Mahbubnagar or Sholapur, we still must confirm experimentally that farmers weed-control activity is low because of low payoff to weed-control under existing varieties and fertilizer use levels rather than because of resource constraints such as bullock power, or a desire to use weeds as fodder. If the problem is capital scarcity, herbicides may not provide a solution. We cannot expect farmers to buy herbicides in a situation

where their capital resources are so severely constrained that they cannot even invest in better seeds or fertilizers. To answer this question will require a limited amount of operational research in farmers' fields and some surveys of attitudes towards the weeding problem.

Within the existing farming system, it will also make sense to explore more thoroughly the use of herbicides for treating patches of weeds which are difficult to control mechanically--such as perennial grasses and sedges.

On the whole, however, agronomic weed control research will be most productive if it is focussed on and associated with research efforts aimed at achieving substantial changes in farming systems via new varieties or improvements in soil and water management. As an example, growing crops on deep black soils during the kharif season may be one way to substantially increase the agricultural productivity of the rabi-growing tracts. There may be areas where a high probability of prolonged wet spells after sowing time may make it impossible to control weeds by handweeding or interculture on medium to deep black soils during the kharif season. In such areas herbicide use may be required for kharif cropping. Further agroclimatic analysis of the probability of wet spells could help in

delineating those agro-climatic zones where the probability of wet spells after sowing time is sufficiently high to warrant the use of herbicides. Another example is the problem of weed and stubble control when short-duration and/or short-statured varieties allow double cropping in medium to deep soil areas where single cropping prevailed before. Weed-management problems may become more severe and the time between harvesting of the first crop and sowing of the second crop may be so short as to require the use of minimum tillage methods and herbicides. Finding and solving such specific problems will require close association of the weed agronomist with plant breeding, cropping-systems research and economics.

Finally we would like to stress the location specificity of these findings. They are not valid for environments where, as in many parts of Africa, substantial scope exists for expanding land area cultivated per worker and where wage rates are much higher. The economics of weed control in such areas may be more favourable for herbicides and the findings of this paper are specific to the economic environments studied.

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Appendix Table 1 : Cost of hand weeding and interculture per hectare per operation

	Hand weeding						Interculture				
	day/ ha.	Full Cost[a]	Opp. Cost	Bullock pair hours per ha	Full Bullock Cost[b]	Opp. cost of bullocks[b]	Labor days per ha for inter-culture	Labor[c] Cost	Opp. cost of labor[c]	Total cost of inter-culture	Total opp. cost of inter-culture
Cotton[d]	6.75	12.56 (18.84)[g]	9.65 (14.48)	6.75	8.27	6.37	1.43	5.38 (8.07)	4.15 (6.23)	13.65 (16.34)	10.52 (12.60)
Groundnut[d]	5.4	10.04 (15.06)	7.72 (11.58)	5.4	6.53	5.03	1.35	5.08 (7.62)	3.92 (5.88)	11.61 (14.15)	8.95 (10.91)
Castor[e]				25.5	31.28	24.16	3.19	11.99 (17.99)	9.25 (13.88)	43.24 (49.27)	33.41 (38.04)
Cereal Crops[f]	7.25	13.49 (20.24)	10.37 (15.56)	7.25	8.87	6.84	1.81	6.81 (10.22)	5.25 (7.88)	15.68 (19.09)	12.09 (14.72)
Paddy	33	61.38 (92.07)	47.19 (70.79)								

a Female wage rate of 1.86 and opp. cost of 1.43 per 8 hour day for Kanzara, August to September 1975, Source: Subrahmanyam and Ryan [4]

b 1975/76 average bullock hire rate of 8.70 per day per pair per day of 7.1 hour without driver. Opp. cost assumes same probability of employment than for men.

c Male wage rate of Rs.3.76 per 8-hour day, opp. cost of Rs.2.90 for Kanzara village. Source:Subrahmanyam & Ryan [4]

d Based on 1975-76 data for Kanzara and Kinkheda, Akola district.

e Based on 1974-75 data for Aurepalle, Mahbubnagar district

f Based on 1974-75 data for Dokur, Mahbubnagar district.

g Values in brackets are computed assuming a 50% rise in all wage rates.