Pesticide use in Tanzania

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INTRODUCTION

Pesticides are agro-chemicals which are widely used to recoup agricultural crop yields that would otherwise have been lost through the ravages of disease and insect pests. They are comparatively well defined agricultural innovations (farmers know whether they use them or not), their use can be graduated and quantified (farmers know the number of applications they have made), and their effect on yield can be substantial, but their cost can also be high, particularly when there is an acute foreign exchange constraint. It is important, therefore, to know whether farmers are using this sophisticated chemical technology in a rational way and to greatest effect.

Some control over the way in which farmers use pesticides to amend various agro-ecosystems is often attempted through formal recommendations by the manufacturer or distributor, crop authorities and local departments of agriculture. To some extent, user recommendations may be enforced by rigid control over pesticide marketing arrangements. The development and implementation of appropriate user recommendations and marketing arrangements provide a potentially useful tool with which to modify farmer behaviour towards an acceptable norm chosen by some 'higher authority'. The reaction of farmers to such recommendations, the extent to which existing recommendations are adopted and the way in which they are adapted in actual farm practice, should be considered carefully if more effective recommendations are to be designed.

The work described here was carried out at the Economic Research Bureau of the University of Dar es Salaam, between October 1980 and July 1982, under the ODA/ODI Overseas Research Fellowship Scheme. A summary has been published previously as an ODI Discussion Paper (Cox, 1982).

A series of farmer surveys was initiated to examine the ways in which pesticides are used. Three crop/pest/pesticide triangles were considered: i. the use of insecticides on cotton; ii. the use of copper fungicides on coffee; and iii. the use of DDT against stalkborers in maize. Thus, the surveys covered both insecticides and fungicides (the two main groups of pesticides used in Tanzania) and both cash crops (cotton, coffee, maize) and a subsistence food crop (maize).

The financial support of the Overseas Development Administration, through its Overseas Research Fellowship Scheme, is gratefully acknowledged.

The field surveys would not have been possible without the able assistance of Mr C. Msonganzila.

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PATTERNS OF PESTICIDE USE

Cotton

Cotton is one of the most important cash crops in Tanzania in terms of area under cultivation (about 500,000ha), the proportion of farmers growing it (about 2.5 million or 14.7% of the population) and its contribution to foreign exchange earnings (Marketing Development Bureau, 1980). It is typically a smallholder crop mainly grown in Shinyanga and Mwanza Regions but also in Mara, Kagera, Tabora, Kigoma and Singida Regions in the lake zone. These regions (collectively known as the Western Cotton Growing Area or WCGA) produce more than 90% of Tanzania's cotton. The remainder of the crop comes from the Eastern Cotton Growing Area (ECGA), particularly from Morogoro Region but also from Mbeya, Coast, Kilimanjaro and Tanga Regions.

Cotton in Tanzania is almost entirely rainfed, grown on small plots of land using few inputs. Concern is often expressed that although insecticides and fertilisers have been subsidised by the parastatal responsible for cotton production, the Tanzania Cotton Authority (TCA), it is estimated that less than 10% of the crop is effectively sprayed and even less receives inorganic fertiliser (Jones, 1980). Different user recommendations have been developed for the ECGA, where insect pests are often serious, and for the WCGA where pest attack is usually less severe, but the major pest in all areas is thought to be the American bollworm (*Heliothis armiger* Hb). Other pests can also cause serious damage in some seasons, for example stainers (*Dysdercus* spp), spiny bollworm (*Earias* spp) and jassids (*Empoasca* spp) (Bohlen, 1978). Crop diseases are also sometimes a problem (Hillocks, 1981).

The survey of pesticide use on cotton was conducted in Morogoro District within the ECGA for three reasons. First, insect pests were thought to be a serious problem there, suggesting that the yield response to pesticide use would be substantial (and hence more easily detected). Secondly, Morogoro is on the edge of the ECGA at the extreme of the cotton growing area (so differences in the yield response across the District might be more pronounced than elsewhere). Thirdly, it was more cost-effective, as Morogoro is only 120 miles from Dar es Salaam. The same farmers were interviewed both towards the end of the spraying period and after completion of the harvest, to get final yield data. The surveys were carried out with the approval and help of the Tanzania Cotton Authority.

The recommended method of growing cotton in Morogoro Region is to sow in February, putting 5-8 seeds in holes 0.3m apart on ridges 0.9m apart (Tanzania Cotton Authority, 1979). The plants should be thinned to one per stand and weeded early. No fertiliser should be applied. Using a conventional hand-pumped knapsack sprayer, eight sprays of a mixture of DDT (1kg ai/ha in 120 litres of water) and Dimethoate (0.042kg ai/ha) should be applied at weekly intervals, starting at flowering time about eight weeks after germination. A closed season should be observed

Table 1: Mean estimated cotton yield, sowing date, number of sprays applied and sorghum/maize ratio at four sites in Morogoro District, July 1981

Site	Direction from Morogoro	Village	No.of farmers interviewed	Cotton yield (bags/acre)[a] mean	sd	No.of sprays mean	sd	Sowing date[b] mean	sd	Sorghum/Maize[c] Index
1	10 km East	Kitungwa	20	5.9	3.6	4.5	2.9	2.5	1.4	0.94
2	60 km North	Mgudeni	20	6.6	4.4	6.1	1.8	3.9	1.1	0.32
3	100 km South	(a)Mbwade (10) (b)Mvuha (10)	20	5.8	4.4	7.6	1.2	4.7	1.2	0.8
4	40 km West	Mangae	19	2.2	1.6	3.9	2.8	4.7	1.1	1.9
	TOTAL		79	5.1	4.0	5.5	2.7	3.9	1.5	0.99

a. Calculated from farmers' estimates (before harvest) of their total cotton yield and the area of each plot (1 bag weighs approximately 50 kg)

b. Early January = 1, late January = 2, early February = 3, etc.

c. Ratio of number of cotton farmers who also grow sorghum to number who grow maize at each site; some farmers grow both by uprooting the plants before late October. The TCA sells insecticides to farmers in packs sufficient to spray an acre (0.4ha) of cotton eight times at the recommended dose rate.

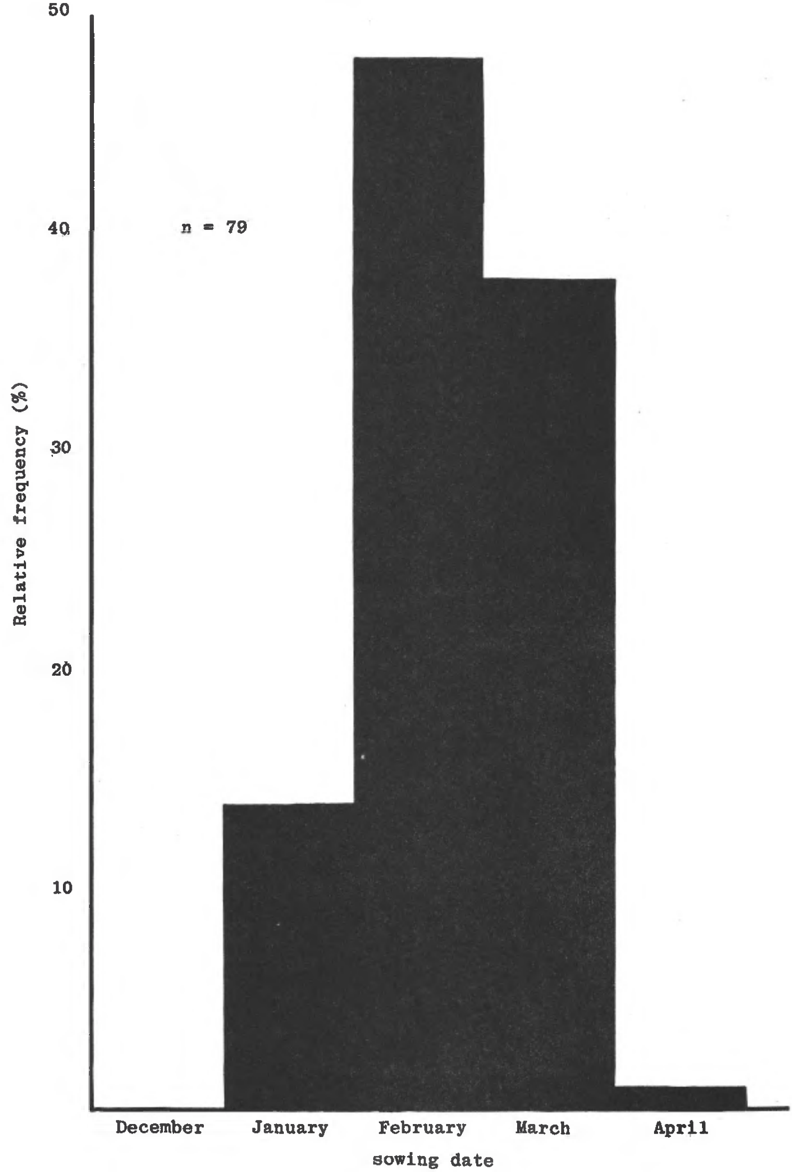
Survey - During July 1981, when spraying was almost completed and harvest had just begun, about 20 cotton farmers at each of four sites in Morogoro District were interviewed concerning their cultivation practices, the number of sprays they had applied and the yield they expected to get (see Table 1). The villages were selected in consultation with the TCA, to illustrate the variety of farming conditions in the area. Farmers were chosen haphazardly (no sampling frame was available): those encountered during a walk around the village. Each farmer was interviewed alone, away from other farmers and village officials, and in each case the interview, which lasted about 30 minutes, was conducted in the farmer's own field.

During December 1981, after the harvest, 56 of the 80 farmers (71%) were re-interviewed about the yield of cotton actually obtained.

Statistical analysis of the data included simple linear regression and multiple linear regression using procedures described by Gomez and Gomez (1976).

Results and discussion - Except for the choice of sowing date and the number of insecticide applications made, the growing method was remarkably uniform. The mean size of plot was 0.49ha (standard deviation 0.25ha), based on the farmers' estimates. The ground was prepared predominantly by hand hoe, although 13% of farmers had used a tractor (mainly at site 2). The same variety of cotton was used: Ilonga 74, supplied by the TCA. No

<u>Figure 1</u> Relative frequency (%) with which different sowing dates for cotton were chosen by farmers in Morogoro District (July 1981)



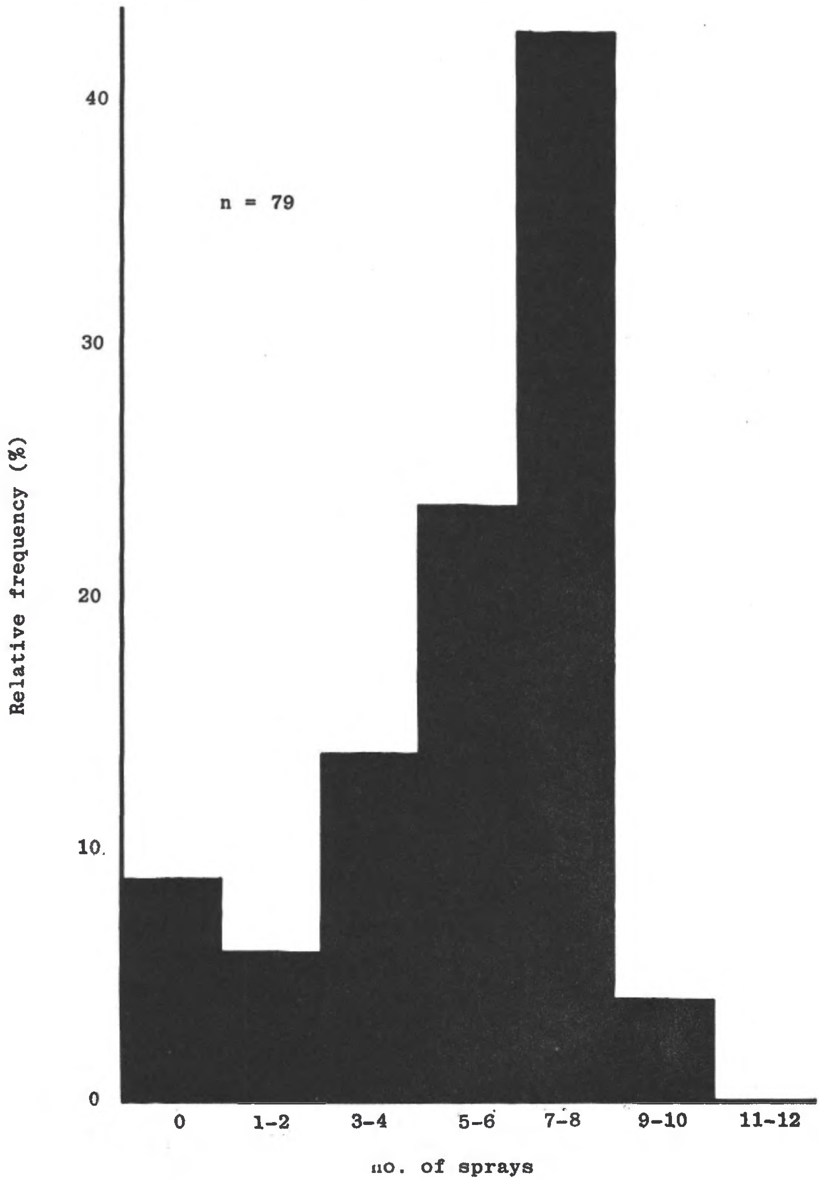
fertiliser was applied except for one farmer using poultry manure. Most of the cotton was sown before the end of February (mean 3.9, standard deviation 1.5; see legend to Table 1 for explanation of sowing date scale), but 30 farmers (38%) sowed later, and 11 farmers (14%) sowed earlier than the recommended month (Figure 1).

DDT 75% WP and Dimethoate (as Rogor 40% EC) were applied together using a hand-pumped knapsack sprayer, except in one case where ULV Thiodan was applied by TCA extension staff at the request of the farmer. The mean number of spray applications was 5.5 (standard deviation 2.7). The relative frequency with which farmers used different numbers of sprays is shown in Figure 2. Seven farmers (9%) did not spray at all; three (4%) sprayed more than the recommended number of times. Cotton stainers were seen at all sites, but were particularly severe on unsprayed cotton at site 1.

Most farmers (77%) also grew maize (mean area under maize/holding, 0.69ha, standard deviation 0.77ha). Other crops grown included sorghum (by 67% of farmers), sunflower (18%), rice (18%), cassava (8%) and sesame (5%). Site 4 was clearly affected by drought; all the farmers interviewed there also grew sorghum, which is more resistant to drought than maize (Acland, 1971) .

The mean yield of the cotton crop at each site (calculated from the farmers' estimates of their total yield and the area of their plots) is given in Table 1, together with data on the mean number of spray applications, the mean sowing date, and the ratio of the number of cotton farmers also growing sorghum to the number growing maize at each site. The mean estimated cotton yield is inversely proportional to the sorghum/maize ratio ($y = 8.0 - 2.9x$, $r = -0.97$, $p<0.05$). At all sites, the

Figure 2 Relative frequency (%) with which different numbers of DDT plus Dimethoate applications were used by cotton farmers in Morogoro District (July 1981)



NB: the current recommendation is to spray eight times estimated cotton yield increased as the sowing date was postponed and more insecticide sprays were applied ($0.17 < R^2 < 0.48$). (See Table 2.)

The mean number of spray applications by farmers as a group at each site was proportional to the marginal physical product expected to result from pesticide use, as estimated by the partial regression coefficient ($y = 3.7 + 1.5x$, $r = 0.97$, $p<0.05$).

The gross revenue (per unit area) was directly proportional to the farmers' estimated yield before harvest ($r = 0.59$, $p<0.01$). (See Figure 3.)

The high negative correlation between the mean estimated cotton yield and the sorghum/maize ratio at each site suggests this as a useful measure of site specific variation. The extensive adoption of sorghum in preference to maize is an adaptive response by farmers in areas of unreliable rainfall. Although no data are available to indicate the relation between this index and a more fundamental drought index (such as expected March precipitation), its relation with the cotton yield is consistent with this interpretation.

The consistent increase in estimated cotton yield as the sowing date was postponed was probably associated with the unusually dry weather in March 1981. Delay in sowing beyond February appeared to have been an adaptive response to the possibility of drought (farmers do not usually wait for the rains to begin before sowing their cotton). Drought reduces the mean yield but delayed sowing reduces the possibility of an excessively low yield.

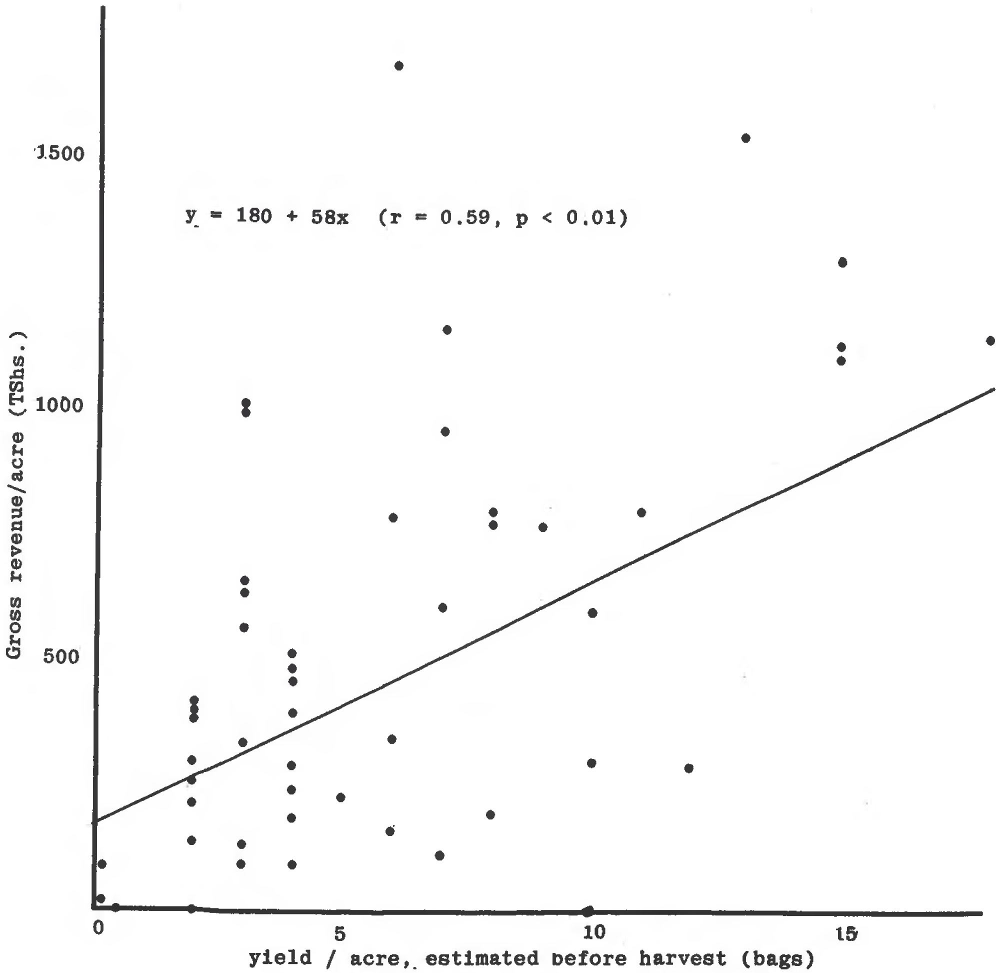
The value of spraying smallholder cotton with DDT *plus* Dimethoate is confirmed by the survey data. The

Table 2: Results of multiple linear regression of estimated cotton yield against the number of spray applications (x_1) at four sites

Site 1: (n=18)	y = 2.4 (0.93)	+ 0.56 X_1 (1.77)	+ 0.50 X_2 (0.77)	R^2 = 0.17	ns
Site 2: (n=17)	y = -7.5 (-1.65)	+ 1.2 X_1 (2.61)	+ 1.7 X_2 (2.22)	R^2 = 0.42	$p < 0.05$
Site 3: (n=20)	y = -20 (-2.89)	+ 2.7 X_1 (3.92)	+ 1.3 X_2 (1.88)	R^2 = 0.48	$p < 0.01$
Site 4: (n=18)	y = -0.11 (-0.66)	+ 0.34 X_1 (2.66)	+ 0.21 X_2 (0.62)	R^2 = 0.32	$p < 0.05$

y = Estimated cotton yield (bags/acre), see legend to Table 1
X_1 = Number of spray applications
X_2 = Sowing date, early January = 1 etc.

Figure 3: Gross Revenue (TShs.) received by individual cotton farmers as a function of the estimated yield before harvest (in bags), n = 52.

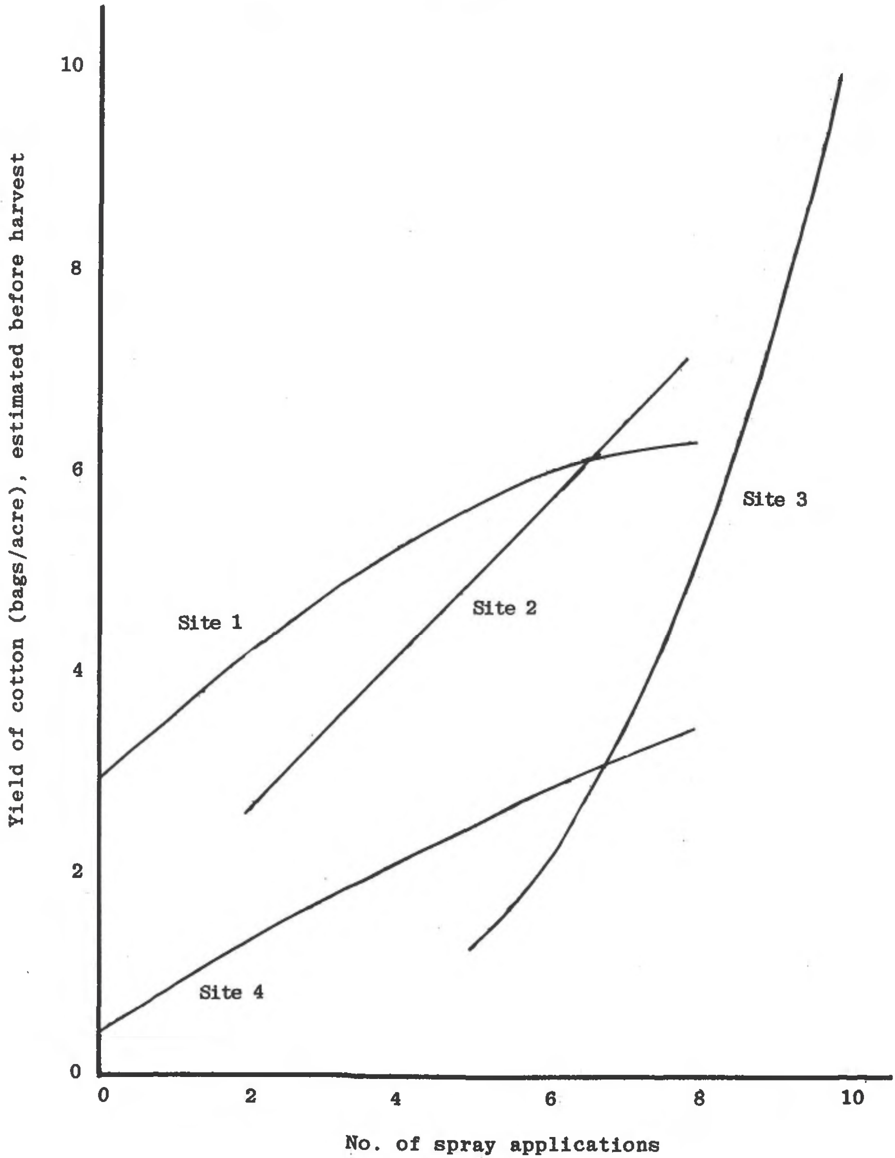


simple pesticide use/yield response curves in which a power transformation is used appear to justify the adoption of a linear response model (Figure 4) since the curvature of the production surface is not particularly marked nor is it consistently either concave or convex to the origin. Results of a multiple regression analysis of a polynomial expansion of the data in Table 2 (of the form $y = a + bX_1 + cX_1^2 + dX_2 + eX_2^2 + fX_1X_2$) also failed to demonstrate any consistent curvature in the response surface or any significant improvement in the index of determination (R^2).

It is not possible therefore, from these data, to suggest an 'optimal' number of pesticide applications at any site in the manner suggested by Hillebrandt (1960) (see Figure 10, page 45). It would be unwise to base such a recommendation on a single year's data, but the yield response does appear to be increasing with high levels of pesticide use at site 3 and this may justify increasing the recommended number of spray applications at that site.

In a farm level survey of cotton yields in Sukumaland, Saylor (1970,1974) found it difficult to explain yield differences in terms of the three cultural practices emphasised by the cotton research station in Western Tanzania: sowing date, plant density and ridging. He suggested that farmers are more aware of the risk and uncertainty associated with crop production by various methods and in different years than the research station, and consequently have developed a farming system which specifically incorporates the vagaries of weather into the decision-making process. The way in which groups of cotton farmers in Morogoro District manipulate both the sowing date and the number of sprays used, to suit local conditions, supports this idea. They appear to be aware of the risks associated with the adoption of recommended

Figure 4: Estimated yield of cotton (bags/acre) versus number of applied sprays of DDT plus Dimethoate at four sites in Morogoro District, July 1981



Site 1: $y = 2.9\ (x + 1)^{0.37}$ $r = 0.44$, ns

Site 2: $y = 0.95(x + 1)^{0.92}$ $r = 0.46$, $p < 0.05$

Site 3: $y = 2.9\ (x + 1)^{3.4}$ $r = 0.66$, $p < 0.01$

Site 4: $y = 0.47(x + 1)^{0.91}$ $r = 0.77$, $p < 0.01$

practices and modify their behaviour accordingly. The results of our survey do suggest that the behaviour of farmers *as a group* at each site is conditioned by their expectations regarding the magnitude of the physical yield response to pesticide use.

The positive correlation between the actual gross revenue realised by individual farmers (proportional to the yield they finally got) and their yield estimates before harvest (Figure 3) supports the use in the survey analysis of farmers' estimates of their yield in place of actual yields. It is also clear from Figure 3 that, even by the time spraying stops for the season, farmers' yield estimates are not very precise (a lot can still go wrong).

Coffee

The choice of Moshi District (350 miles from Dar es Salaam) was an obvious one: the slopes of Mt Kilimanjaro are an important coffee growing area and the headquarters of the Coffee Authority of Tanzania (CAT), the parastatal responsible for all aspects of smallholder coffee production, are also in Moshi.

Cultivation of arabica coffee by smallholders on the slopes of Mt Kilimanjaro is a complex affair (Acland, 1971). It is invariably inter-cropped with bananas and often with cocoyams and/or beans and/or maize as well. It is a perennial crop, which permits lag effects of treatments applied in previous seasons, and successive crops, at different stages of growth, may occur simultaneously on the same bush. A well-known biennial cyclical variation in yield is superimposed on the (random) annual variation, associated with differences in weather conditions, and (non-random) variation resulting from severe pruning and deliberate attempts at pest and disease control. Farmers claim to know the number of coffee bushes on their holdings and pesticides are allocated to them by CAT according to this number. However, the number of bushes may be consistently under-estimated (increasing the apparent yield per bush) because of previous attempts to tax coffee farmers on this basis.

Several insect coffee pests are well-known by farmers, including the Antestia bug (*Antestiopsis* spp), leaf miner (*Leucoptera* spp) and berry borer (*Prophantis* spp) (Bohlen, 1978). Fenitrothion 50% EC or Thiodan 35% EC is supplied by CAT for use against these pests; Dieldrin 18% EC is supplied for topical application against white stem borer (*Anthores* spp).

Two diseases are of particular importance: coffee berry disease (*Colletotrichum coffeanum* Noack, see Firman and Waller, 1977) and leaf rust (*Hemileia vastatrix* Berk & Br). In 1981, blue copper (copper oxychloride 50% WP) was supplied by CAT for use against leaf rust, and red copper (cuprous oxide 50% WP) for use against coffee berry disease (CBD) (Okiaga, 1978). Copper sprays also have a physiological 'tonic' effect on coffee production even in the absence of disease. Other CBD chemicals, kept from the previous year, were sometimes used by farmers in the survey, including benomyl (as Benlate 50% WP) and captafol (as Ortho-difolotan 80% WP)

Survey - During August 1981, when spraying was almost complete and harvesting of some bushes had begun, ten coffee farmers in each of eight villages in Moshi District were interviewed about their cultivation practices, including pesticide use, and their expected yield from the 1980/81 crop. One village was selected at random in each of the sub-divisions of Moshi District recognised by CAT. Farmers were then chosen at random from a register kept by village officials. In cases where the farmers chosen were not available, their neighbours were substituted. A follow-up survey, to obtain final yield data, was carried out during January 1982.

Results and discussion - The number of coffee bushes per holding, the number of blue and red copper sprays applied during the 1980/81 season and the farmers' yield estimates (adjusted to kg per bush x 10^{-2}) at each site are given in Table 3. Also shown is the CBD Index, defined as the proportion of farmers interviewed who claimed to have CBD in their coffee in 1981.

It is clear that the relationship between yield and the use of copper sprays is complex. If the estimated yield (y) is regressed against the total number (x) of copper sprays applied (blue plus red), aggregating the data over all sites, the regression equation is: $y = 18 + 2.8x$ $r = 0.21$, df = 64, ns). Although the correlation coefficient is positive, it is not statistically significant ($p>0.05$).

However, by disaggregating the data, several significant correlations are obtained. The mean number of red copper sprays used at each site is directly proportional to the CBD index: $y = -0.084 + 3.1x$ ($r = 0.86$, df = 6, $p<0.01$). This clearly demonstrates that use of red copper sprays by farmers *as a group* in different parts of Moshi District is adaptive to the incidence of CBD.

The yield response to blue copper can be detected by aggregating data from non-CBD sites only (sites 5, 7 and 8; CBD Index <0.1): $y = -7.3 + 8.6x$ ($r = 0.67$, df = 26,

Table 3: Results of a survey of pesticide use on smallholder coffee in Moshi District, Tanzania, August 1981

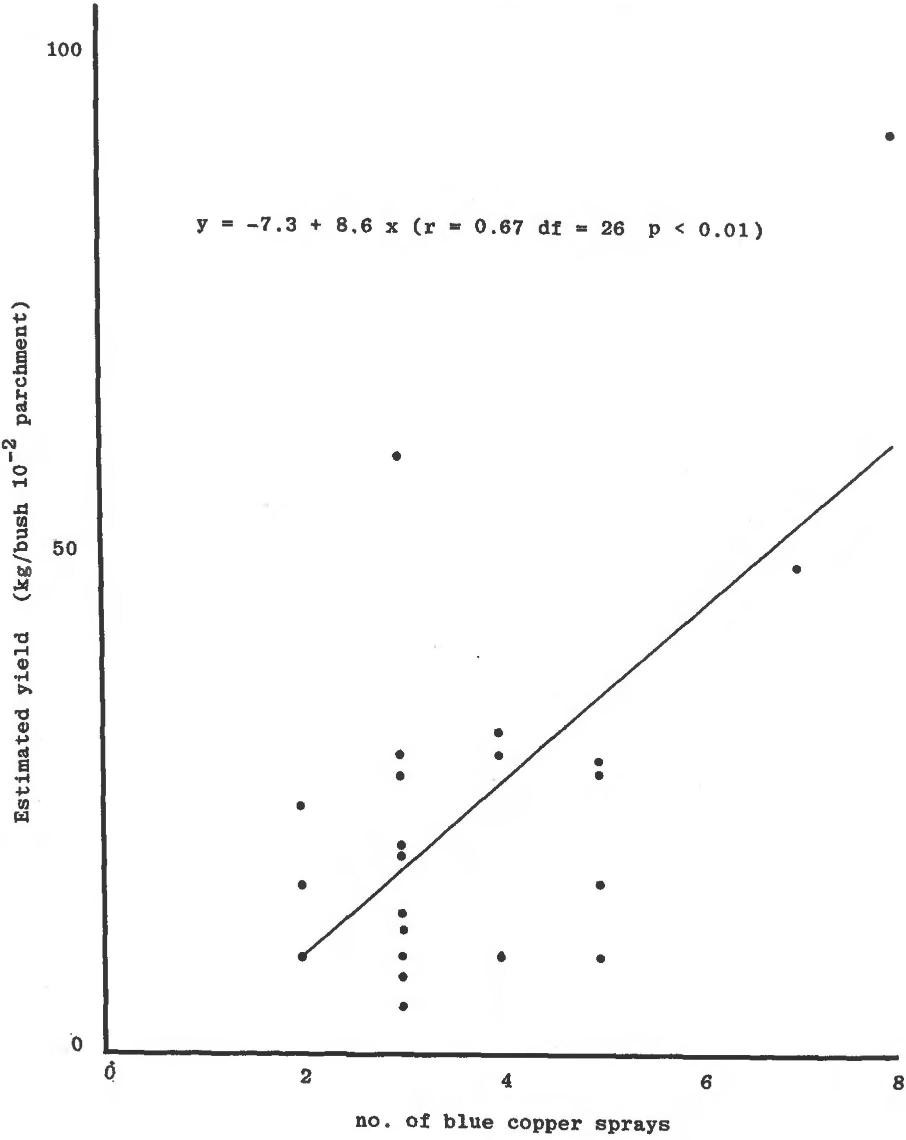
Site	Village	Sample	CBD Index[a]	No.of bushes holding		Estimated yield[b] (kg/bush 10^{-2} clean coffee)		No.of red copper sprays[c]		No.of blue copper sprays[c]	
				mean	sd	mean	sd	mean	sd	mean	sd
1	Kindi	10	0.5	-	-	-	-	1.8	1.8	4.2	2.6
2	Msuni	10	1.0	2283	1726	32	18	4.3	2.0	3.0	1.2
3	Uchau Kusini	10	0.8	944	831	30	27	2.2	1.3	3.7	1.6
4	Tsuduni	10	0.4	405	331	52	50	0.5	0.8	3.2	1.2
5	Yamu	10	0.1	1387	900	18	7	0.0	0.0	3.0	1.2
6	Makame Juu	10	0.9	353	166	28	21	1.5	1.5	1.9	1.0
7	Rauya	10	0.0	549	227	24	17	0.1	0.3	3.2	0.4
8	Kondeni	10	0.0	1234	605	34	26	0.3	0.7	5.0	1.6
	TOTAL	80	0.5	1022	1037	31	27	1.3	1.8	3.4	1.6

a. CBD Index = proportion of farmers in sample who reported CBD in their 1980/81 crop

b. Calculated by dividing the farmer's estimate of the yield of his 1980/81 crop in kg or bags (1 bag = 50 kg) by his estimate of the number of bushes he has

c. If red and blue copper were sprayed together, this was counted as 0.5 red plus 0.5 blue.

Figure 5: Estimated yield of coffee parchment (kg/bush 10^{-2}) against the number of blue copper sprays used at sites 5, 7, and 8 (aggregated data)

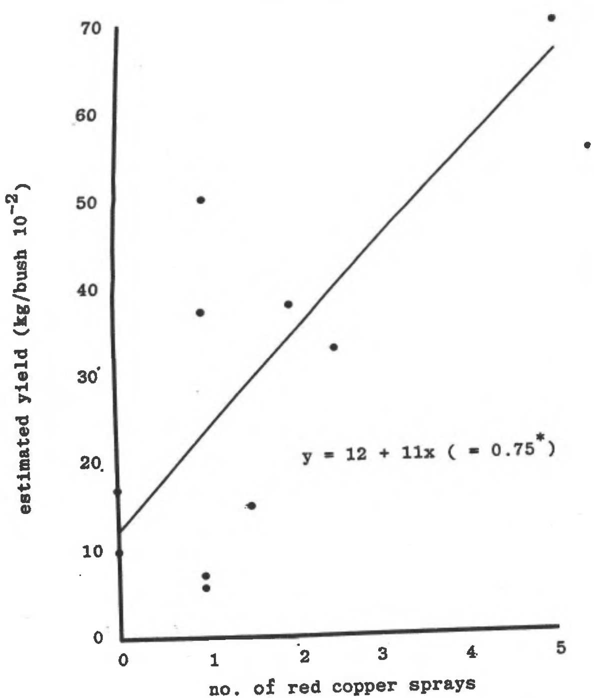


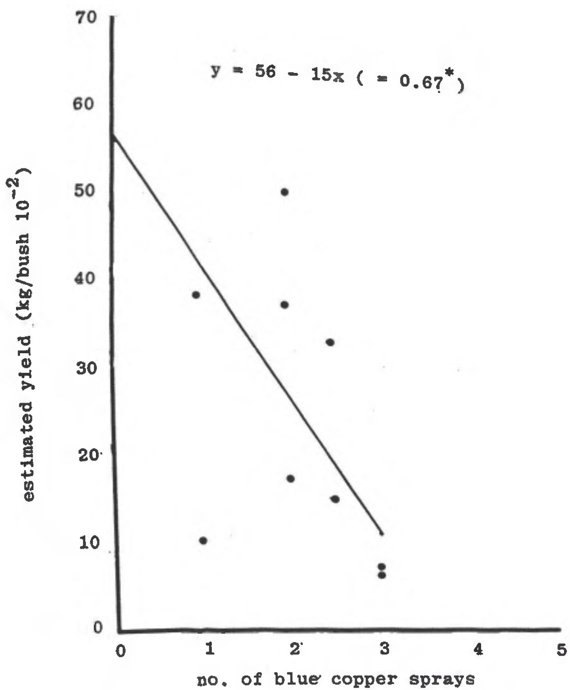
$p<0.01$), Figure 5. A similar result is obtained if site 4 (which has an intermediate CBD Index) is also included: $y = -3.2 + 9.7x$ ($r = 0.44$, df = 35, $p<0.01$). At all these sites, leaf rust is a common disease; the yield response to the use of blue copper can be interpreted largely in terms of its control.

Site 6, which is at a particularly high altitude, was unusual amongst the sites visited; although CBD was severe (CBD Index = 0.9), there was little sign of any leaf rust. The yield expected by different farmers at this site is proportional to the number of red copper sprays used: $y = 12 + 11x$ ($r = 0.75$, df = 8, $p<0.05$), but inversely proportional to the number of blue copper sprays ($r = -0.67$, df = 8, $p<0.05$), Figure 6. This can be explained by the negative correlation between the numbers of the two kinds of spray used ($r = -0.51$, df = 8, ns): a blue copper spray reduces yield if it is used where CBD is the preponderant disease, and where a red copper spray could have had a greater effect.

If data are aggregated at sites 2 and 3 (where both CBD and leaf rust occur, and both red and blue copper sprays are used extensively), there is an inverse correlation between yield and the total number of copper sprays ($r = -0.13$, df = 17, ns), between yield and the number of blue copper sprays ($r = -0.12$, df = 17, ns) and between yield and the number of red copper sprays ($r = -0.04$, df = 17, ns). This is a remarkably similar result to that obtained by Mbilinyi (1974) and there are undoubtedly several reasons for it. It may partly be a real phenomenon involving biological lag effects associated with changes in the fungal ecology of the coffee bush following substantial pesticide use (Firman and Waller, 1977). But the positive response obtained at sites where the pest population is more uniform

Figure 6: Estimated yield of coffee (kg/bush 10^{-2}) versus number of red copper sprays and number of blue copper sprays at site 6 (Makame Juu, Moshi District) August 1981





(a) Where red and blue copper were sprayed together, this was counted as 0.5 red <u>plus</u> 0.5 blue;

(b) There is no significant correlation between yield and the total number of copper sprays ($y = 13 + 4.2$, $r = 0.27$ ns)

(c) The number of red and blue copper sprays used are inversely correlated ($y = 2.4 - 0.34x$, $r = -0.51$ ns) suggests that it may be an artifact of the regression procedure resulting from the adaptive use of pesticides by *individual* farmers in response to variations in the kind and level of pest attack.

A significant positive correlation was found between the yield estimated before harvest and the actual yield obtained ($r = 0.89$, $df = 28$, $p<0.01$), Figure 7.

Maize

Survey - During April/May 1982, about twenty farmers at each of four villages in different parts of Mbeya District were interviewed concerning their use of DDT to control stalkborer infestations in maize. Mbeya was chosen for the survey because: i. stalkborer damage is particularly bad in the southern highlands of Tanzania; ii. within Mbeya District there is a considerable variation in altitude (which it was thought might be reflected in differences in yield response); and iii. Mbeya is a Regional as well as a District centre with good communications. It is 530 miles from Dar es Salaam.

Results and discussion - At three sites there was no significant correlation between yield and pesticide use; even the sign was not consistent (Table 4). The one site where a significant positive response was obtained (Insitu) also had the lowest average number of pesticide applications; this in itself is consistent with the hypothesis that individual farmer behaviour is adaptive, since where the level of pest attack is lower, the possibility of adaptive behaviour is less. Differences between farmers in the number of pesticide applications they use are more nearly random and not related to the potential yield response.

Figure 7: Actual yield of coffee obtained versus estimated yield before harvest (kg)

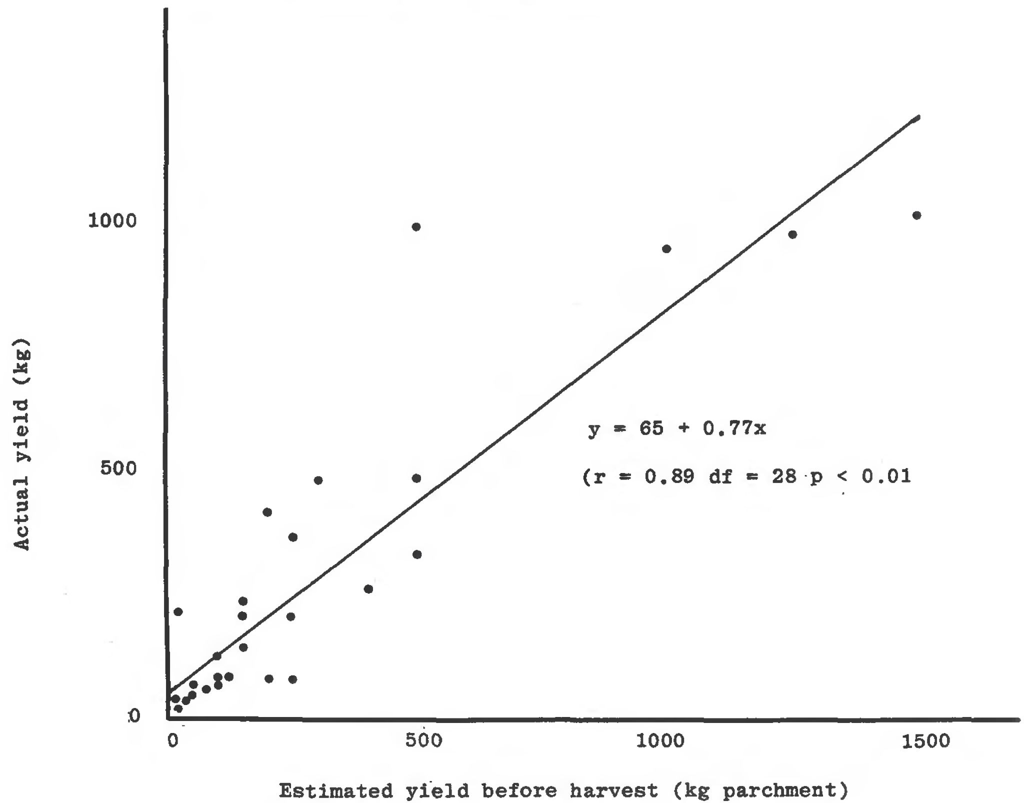


Table 4: Results of survey of the use of DDT on maize in Mbeya District, April/May 1982

Site	Village	Altitude	No.of farmers interviewed	Maize yield (bags/acre)[a] mean	sd	No.of DDT applications[b] mean	sd		
1	Iwala	> 1500 m	20	9.4	4.9	1.5	0.76	$y=10-0.44X$	$r=-0.069$ ns
2	Nsongwi/ Mantanji	> 1500 m	15	15	7.6	1.7	0.46	$y=11+1.9X$	$r=0.11$ ns
3	Inyala	ca.1500 m	20	7.6	3.8	0.75	0.64	$y=7.0+0.84X$	$r=0.14$ ns
4	Insitu	< 1500 m	20	5.5	3.6	0.6	0.75	$y=3.3+3.7X$	$r=0.78$ $p<0.01$
	aggregated data		75	8.9	5.9	1.1	0.81	$y=5.6+3.1X$	$r=0.42$ $p<0.01$

a. The maize yield (in bags/acre) is based on farmers' estimates of the total yield and size of plot (1 bag = 50 kg)

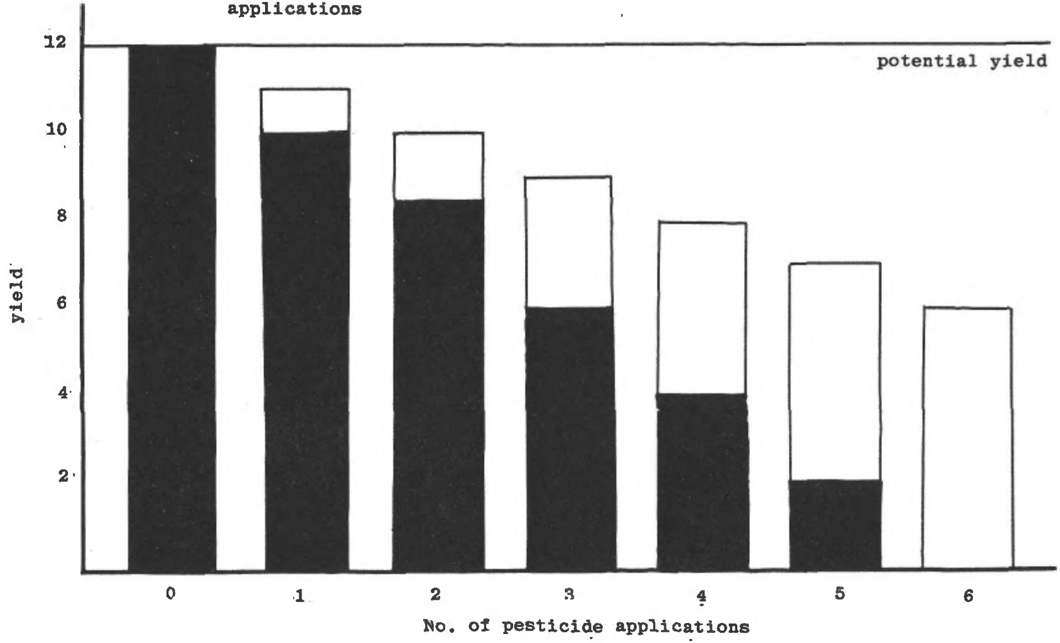
b. DDT 5% dust

There are other indications in the data of the adaptive behaviour of farmers as a group at different sites: first, the apparent relationship between the average number of pesticide applications at each site and altitude (the incidence of pest attack is also thought to be correlated with altitude); and, secondly, the correlation between the average number of pesticide applications and the average yield at each site ($r = 0.94$, $df = 2$, ns).

It was possible to detect a positive yield response to pesticide use in *cotton* at individual sites (presumably where the potential yield and the potential level of pest attack were uniform); differences between sites were explained in terms of adaptive behaviour by farmers as a group to variations in the potential yield response. The average number of pesticide applications at any site is an adaptive response, variation about the mean is not.

The results of the *coffee* survey failed to reveal any significant correlation between yield and the number of pesticide applications using aggregated data, but group behaviour by farmers was clearly adaptive (in that the number of red copper sprays used at each site was proportional to the level of CBD). It is possible to demonstrate significant yield responses to blue copper where there is no CBD and red copper where there is no leaf rust. In these situations, individual farmer behaviour is not obviously adaptive (thus it is possible to detect the response) and is, therefore, apparently analogous to the use of DDT by cotton farmers. In both cases, the use of pesticides according to a standard regime is recommended by the Crop Authorities: pesticide user recommendations are not conditional on the appearance or the severity of the pest in particular fields -

<u>Figure 8</u>: Adaptive use of pesticides on maize produces an inverse correlation between yield and the number of pesticide applications



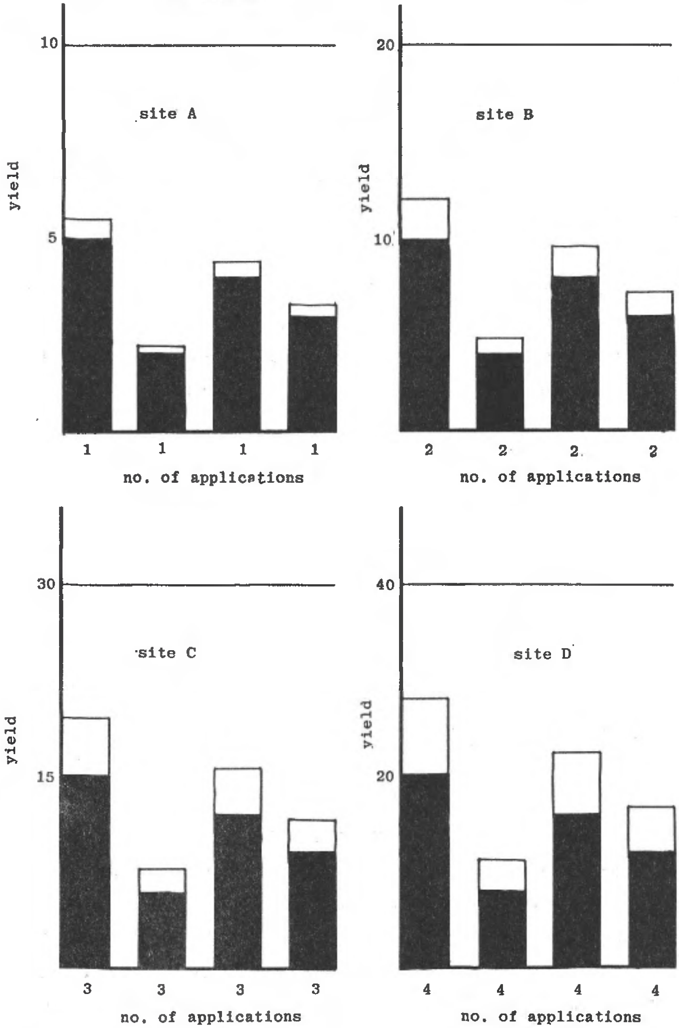
Note:
(a) The potential yield is the same at each site (12 units)
(b) The shaded area represents the yield if no pesticides are applied. It varies from site to site because of differences in the level of pest attack.
(c) The unshaded area represents the yield response to pesticide use. Each spray increases the yield by one unit.
(d) Enough pesticide applications are made to recover 50% of the yield which would otherwise have been lost-
(e) $y = 12 - x (r = -1, p < 0.01)$.

they are routine. The persistent lack of correlation between yield and pesticide use in those areas where both CBD and leaf rust are present (and both red and blue copper fungicides are used) suggests a complex situation. It is possible that this might be explained by adaptive behaviour on the part of *individual* farmers in the kind and number of pesticide applications they use in response to differences in the type and level of pest attack in their fields.

In the *maize* survey, circumstantial evidence showed that group farmer behaviour was adaptive; the average number of pesticide applications was related in a general way to the altitude of each site and the average yield of maize obtained there. At three out of the four sites, no significant correlation between yield and pesticide use was demonstrable (cf cotton, where at three out of four sites it was). It is suggested that this results from adaptive behaviour by individual farmers, precisely analogous to the adaptive group behaviour found in cotton and coffee cultivation (Figure 8). The formal recommendation to use DDT on maize is conditional on pest attack both in an all-or-nothing way (depending on the presence of the pest in a particular field) and in a quantitative sense (a third application is only recommended in cases of extreme attack) (Ministry of Agriculture, 1977).

But if this is so, why does aggregation of the data (Table 4) generate a significant correlation between yield and pesticide use? After all, this is the reverse of the situation found in the coffee survey. Figure 9 is an attempt to explain this. With maize, it is argued, the way in which *individual* farmers use pesticides is analogous to the *group* behaviour of farmers who grow cotton or coffee: the response at individual maize sites

Figure 9: Adaptive use of pesticides on maize at different sites produces a spurious positive correlation between yield and the number of pesticide applications, if the data are aggregated



Notes

(a) The potential yield at the four sites (A, B, C, and D) varies, but the distribution of the potential yield loss as a percentage of the potential yield is uniform.

(b) The number of pesticide applications at each site is proportional to the potential yield.

(c) Each pesticide application increases the yield by 10% of the base yield. The base yield is represented by the shaded area, the yield response by the unshaded area.

(d) At each site, there is zero correlation between yield and the number of pesticide applications because the number of applications is uniform.

(e) If the data are aggregated, there is a positive correlation between the yield and the number of pesticide applications ($y = -1.8 + 5.3\ x$, $r = 0.82$ **). This has nothing to do with the yield response to pesticide use (which is uniformly 10% of the base yield/application). It reflects differences cannot be detected for the same reason that it cannot be shown using aggregated data for coffee. However, group behaviour by maize farmers is also adaptive and there are substantial differences in the maize yield between sites (Table 1).

Figure 9 shows how these biological and behavioural constraints can combine to simulate the results of our maize survey: no correlation between yield and pesticide use at individual sites, but a significant positive correlation using aggregated data. This partial model almost certainly underestimates the strength of the effect because it assumes a constant relative frequency distribution for proportional loss from pest attack at different sites: the proportional loss appears to be greater where the potential yield is higher (as might be expected from a system exhibiting other characteristics of biological homeostasis).

Unfortunately, it also follows that the apparent yield response to pesticide use in maize obtained by aggregation of data from different sites must be largely spurious. It is an artifact resulting from multicollinearity between the number of pesticide applications and the potential yield in a situation where there is considerable variation in potential yield. This applies even though the apparent response is both positive and statistically significant; it does *not* mean that there is no significant response to the use of DDT on maize, only that the procedure for estimating it is inappropriate. This is particularly important where survey methods are proposed to estimate the yield response (eg Pinstrup-Anderson *et al*, 1976).

2

CLASSIFICATION OF PESTICIDE USE PATTERNS

Differences in the pattern of pesticide use by farmers, both as individuals and as groups, determine the usefulness of survey data as a basis for designing appropriate user recommendations for pesticide application. Sometimes survey data can be used, sometimes they can not, but in general, the more highly aggregated the data, the less useful is the analysis. These ideas are summarised in Table 5. Five different patterns of pesticide use are recognised:

a. Adaptive individual behaviour, but group behaviour non-adaptive. This is not thought to be a feasible configuration since, if individual behaviour is adaptive, group behaviour must also be.

b. Non-adaptive behaviour at both individual and group levels, eg. the use of blue copper sprays against coffee leaf rust in non-CBD areas of Moshi District. Pesticides are used routinely and farm survey data will provide reliable information about the yield response.

c. Non-adaptive behaviour by individual farmers at any given site, but adaptive behaviour by groups of farmers at different sites, eg. the use of insecticides on cotton by farmers in Morogoro District. There is good correlation between yield and pesticide use at individual sites but

Table 5: Patterns of pesticide use

	Individual farmer behaviour	Behaviour of farmers as a group	Example	Use of regression analysis of farm survey data	Basis for pesticide user recommendation
a.	Adaptive	Non-adaptive	Non-feasible configuration	-	-
b.	Non-adaptive	Non-adaptive	Coffee/leaf rust/ blue copper in non-CBD areas of Moshi District	Good correlation between yield and pesticide use both at individual sites and with aggregated data	Extensive survey data provide reliable information on farm-level yield response for general recommendation
c.	Non-adaptive	Adaptive	Cotton/insects/ DDT in Morogoro District	Good correlation between yield and pesticide use at individual sites	Village level survey data provide a reliable basis for local recommendations
d.	Adaptive	Adaptive	Maize/stalkbroker/ DDT in Mbeya District	Low correlation between yield and pesticide use at individual sites, but there may be a (spurious) positive correlation using aggregated data	Guideline recommendation based on empirical experimentation involving the withdrawal of pesticide cover at selected locations
e.	Complex situations		Coffee/copper fungicides in parts of Moshi District where CBD and leaf rust both present		

aggregated data will underestimate the potential yield response. Village-level survey data would provide a basis for local recommendations.

d. Situations where both individual and group farmer behaviour are adaptive, eg. the use of DDT on maize in Mbeya District. Farm survey data are of no value as a basis for user recommendations in spite of any positive correlations between yield and pesticide use obtained from aggregated data.

e. Complex situations, eg. in coffee growing areas where both leaf rust and CBD are present and both blue copper and red copper are used extensively. This is similar to the previous situation in that no conclusions can be reached from farm survey data, but in this case even aggregated data suggest a negative correlation between yield and pesticide use (believed to be spurious).

Two particular aspects of this analysis require additional clarification: i. the use of farmers' estimates of yield in place of actual yield data, and ii. the assumption of a linear response curve. These points also have implications for any formal structural model which may be formulated of the way in which farmers actually make decisions about whether or not to treat their crops.

Expected yield versus actual yield

A farmer considering the use of pesticides can only base his decision on the available data and since he must apply the chemicals before harvest, he cannot know what the final yield will be; he must estimate it. Farmers' estimates of their yield, made at about the time of spraying, are of greater relevance to their decision-making process than the actual yield harvested.

In the cotton and coffee surveys described above, a sub-sample of the farmers interviewed during the growing season about their cultivation practices were re-interviewed after harvest, to obtain final yield data. In both cases, a statistically significant positive correlation was found. (No attempt was made to repeat this in the maize survey because of time and budgetary constraints.) These correlations support the use of yield estimates in the analysis as a proxy for actual yield data.

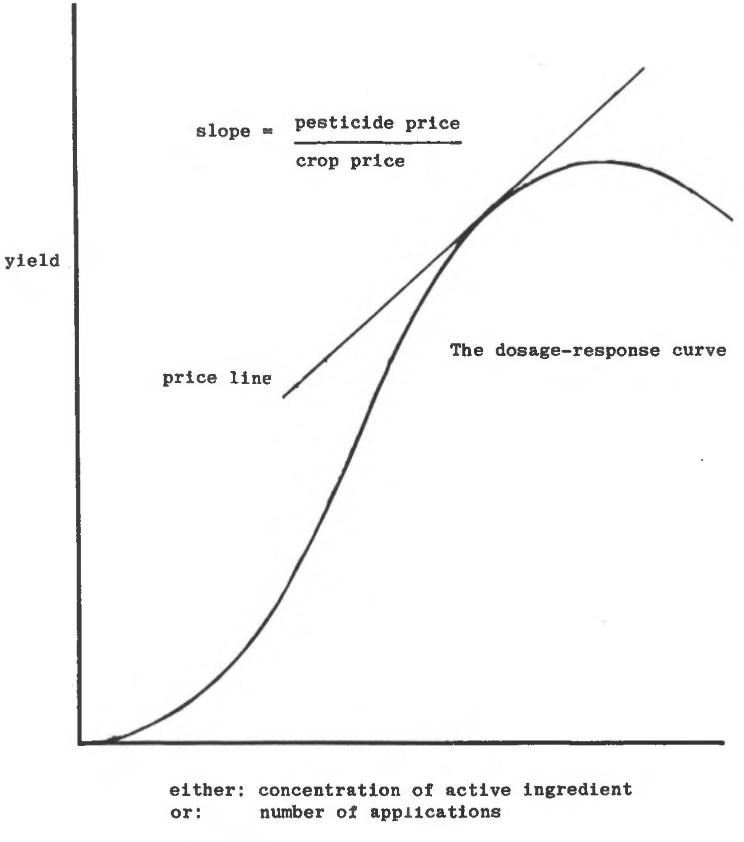
There are, however, considerable discrepancies between these alternative parameters: the correlation is by no means perfect, and the slope of the regression line is not 45°. But this merely emphasises the difficulty of the decision the farmer has to make; he can be very far out in his yield estimate.

Curvature of the response surface

The analysis also assumes a linear response model. The cotton survey data were tested extensively for any curvature of the response surface. Use of a simple power transformation of the yield data at the four sites showed that what curvature could be detected was neither very marked (there was no substantial improvement in the index of determination, R^2) nor of consistent sign (sometimes convex to the origin, sometimes concave). A multiple regression model of a polynomial expansion of the survey data yielded a similar result. Occam's well-known principle alone would suggest the use of a linear model.

There are other points to be considered, however. If the sophisticated mathematical techniques of regression analysis can not detect the curvature of the response surface, nor can the farmer. Such curvature can not, therefore, be an important component of the decision over the range of pesticide application levels found in practice.

Figure 10: The traditional model of the economics of pesticide use (after Hillebrandt, 1960). The 'optimum' level of pesticide use is defined by the point where the price line (with slope equal to the ratio of pesticide price/ crop price) is tangential to the dosage response curve.



3

ECONOMICS OF PESTICIDE USE

The traditional economic model

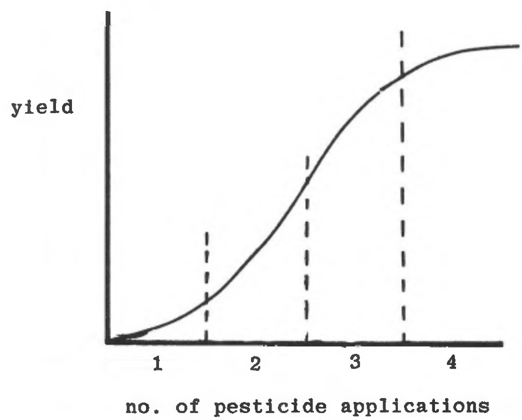
The traditional approach to the economics of pesticide use is given by Hillebrandt (1960), Figure 10. She assumes that the dosage-response curve is sigmoidal, as biological responses often are. At constant producer price, the total revenue curve is similarly sigmoidal. The 'optimum' level of pesticide use is then defined by the point on the dosage-response curve where the price line (with slope equal to the ratio of pesticide and product prices) is tangential to it; at this point, marginal revenue is equal to marginal cost. The marginal cost of pesticide application is assumed to be constant.

This simple model of the decision is deficient in at least two ways:

a. The typical pest control decision is 'nested' ie. a decision has to be made simultaneously about the number of sprays to use and the concentration of the active ingredient in each one. Successive decisions in a complicated spray programme are not independent of each other (Figure 11).

b. The economic optimum will depend on the level of pest infestation (Figure 12). This will

Figure 11: The dosage response curve is 'nested'.



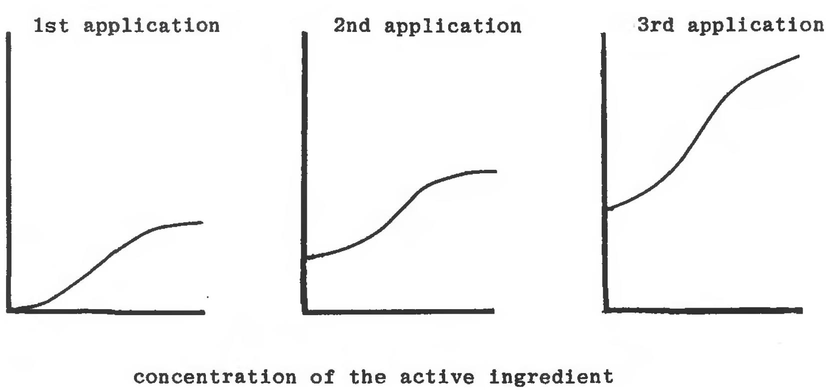
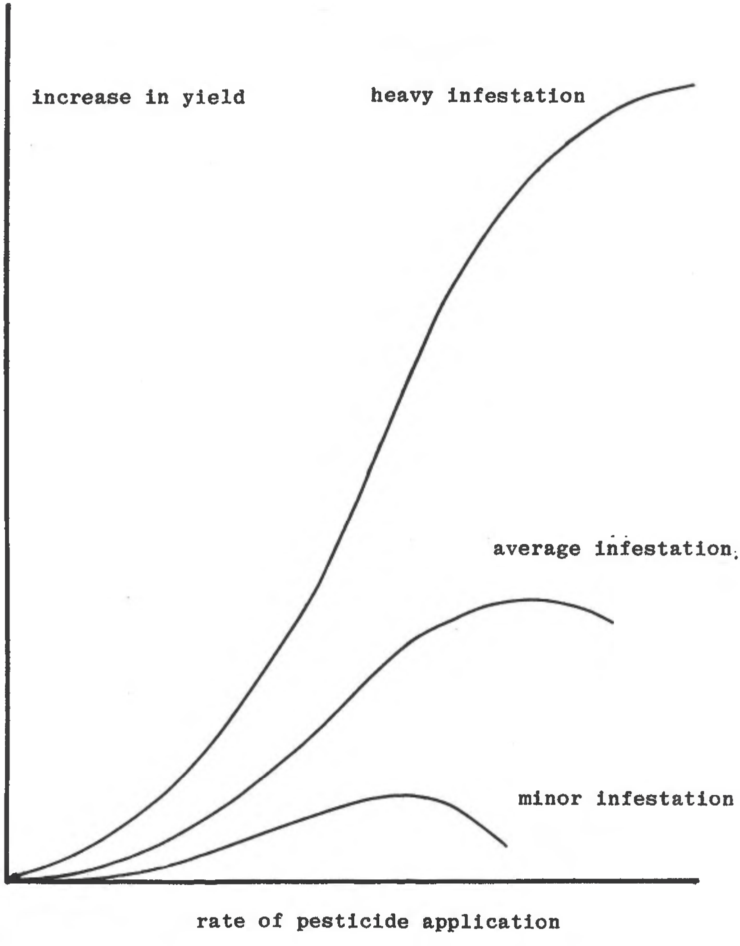


Figure 12: The shape of the dosage response curve depends on the level of pest infestation.



vary from place to place and from year to year, and over the course of a single crop season. The way in which an infestation will progress as harvest approaches will not be known with any certainty at the time when a decision on whether or not to treat a crop has to be made.

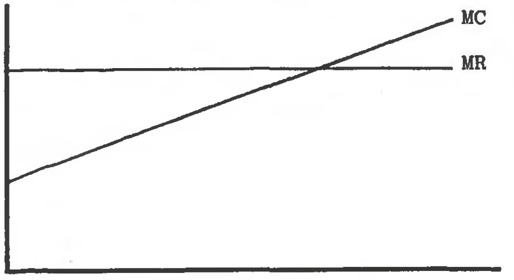
Alternative economic models

If the curvature of the response surface is not limiting pesticide use (because it cannot even be detected), then what is? Three possibilities are shown in Figure 13:

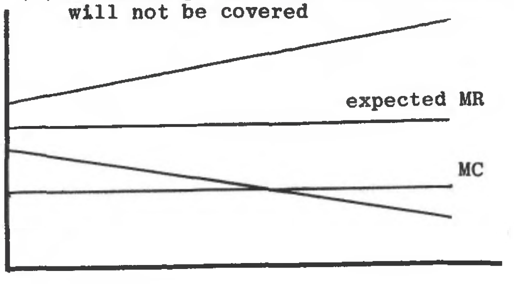
a. *Increasing marginal cost.* Instead of constant marginal cost (MC) as assumed by Hillebrandt, the MC increases as the season progresses, eventually intersecting the marginal revenue (MR) curve at some finite level of pesticide use. Possible reasons for an increasing MC curve are not hard to find. The total cost of each pesticide application has two components: i. the cost of the chemical and depreciation of the sprayer (with constant MC), and ii. labour for spraying. Peasant farmers use family labour predominantly and grow a wide variety of crops with different labour requirements. The opportunity cost of labour will not be constant throughout the crop season, but will vary depending on what else there is to do on the farm. Although it is unlikely that the MC of pesticide application will increase smoothly as the season progresses, it may sometimes be sufficiently great to exceed any possible MR and the crop will not be sprayed.
b. *Increasing risk.* Even though the expected MR may be constant, the confidence limits containing it may diverge as the number of pesticide

Figure 13: Alternative models of the economies of agricultural pest control:

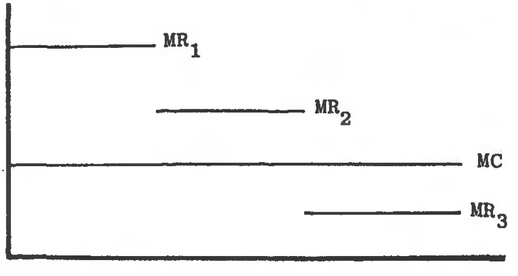
(a) Increasing marginal cost



(b) Increasing risk that the (constant) marginal cost will not be covered



(c) Successive revisions of estimated marginal revenue



no. of pesticide applications

applications increases. In other words, successive pesticide applications simultaneously augment the expected yield and increase the risk that the MC will not be covered. At some point, this possibility becomes so great that further pesticide applications are curtailed. The idea that pesticide use may increase yield variance has been proposed on theoretical grounds by Cox (1981). The significant positive correlation between the mean cotton yield and its standard deviation at different sites supports this idea, particularly since pesticide use is an important explanatory variable of the yield.

c. *Continuous revision of yield estimates.* Deciding the number of pesticide applications to make is an iterative process. As the season progresses, farmers' estimates of the final yield (and the yield response to additional pesticide applications) become more reliable. At any given time, the farmer may face a linear total revenue curve (constant MR), but his estimates of the MR will be continually revised. If successive estimates of the MR decline during the season, eg. because of drought, the spray programme may be stopped prematurely when the MC is no longer covered.

Our interviews with cotton farmers in Morogoro District suggest that all three of these partial models may be valid representations of farmer behaviour. When asked why they did not spray more times, farmers were rather cagey and usually simply asserted that they knew that the recommendation was to spray their cotton eight times (even if they had not in fact done this). Seven farmers gave 'other work on the farm' as a reason, and three said 'shortage of water'(ie. increased marginal cost). Seven farmers said that they 'were afraid of additional debt' or that 'the chemical is very expensive' (ie. they were aware of increased risk). One farmer stated

'I can spray more times, it depends on the growth of the crop that year' (ie. revised yield estimates). And one farmer even said, 'there is no effect if I spray more times' (implying that the MR decreases as assumed by the traditional model of the economics of pesticide use).

It seems probable that there is no simple economic model of the decision whether or not to spray one more time; there are several partial models any one of which might be dominant in a particular situation depending on what other crops the farmer is growing, the availability of labour, the extent of his debt, and the growth of the crop (with its attendant pest population) that season.

4

USER RECOMMENDATIONS

Clearly it will often be difficult to devise a uniform, unidimensional recommendation for use in different locations and at different times. A uniform recommendation, if adopted, will almost always involve a cost: either too much pesticide will be used needlessly when the potential yield and/or the potential level of pest attack is low *or* too little will be used in situations where greater use would have given an economic return.

Where uniform recommendations are made, they will often tend towards too high a level of use:

a. Recommendations originating on research stations do not usually take into account the risk aversion of small farmers, but are based on the mean response averaged over a few selected seasons (in developing countries, pesticides may be the only bought input on some crops).

b. Manufacturers and distributors do have an interest in higher levels of use eg. by being able to demonstrate clean fields free from pest damage.

c. The costs of applying the chemicals may be underestimated, particularly the opportunity cost of labour in complex farming systems.

d. Where several sprays are applied, the concentration of the active ingredient in each one may reasonably be set at the level of the technical optimum. This simplifies the problem relating to the number of spray applications to use when the total cost includes the fixed costs of spraying a crop at all, in addition to the variable costs associated with differences in concentration of the active ingredient.

Another problem is the difficulty of ascertaining, from available published sources, just how the current recommendations for pesticide use in Tanzania were developed. However, the development of a recommendation for use of DDT on cotton in Uganda is comparatively well documented and, since the Tanzanian recommendation is apparently partially based on earlier work in Uganda, this may perhaps be used as a general model of the process.

Reed (1976) describes the development at Namulonge of insecticide use recommendations for cotton in Uganda from 1950/51 onwards. Early trials were unconvincing. In a seven year trial ending in 1959, using a single row experimental technique, sprayed cotton outyielded unsprayed by 11% on average, but the differences were not consistent - in two of the years, the sprayed yield was less than the unsprayed. The second series of trials (1965 through 1972) used a randomised block design with unsprayed controls and plot sizes of 0.1ha. The response to spraying in this seven year series was almost identical to that obtained in the first: a mean increase of 11%, but with two years in which the sprayed cotton yielded less than the unsprayed.

In four seasons, between 1966 and 1972, a block of cotton on the Namulonge farm was left unsprayed. The yield differences between this unsprayed block and sprayed cotton were much greater than the differences between sprayed and unsprayed plots in the spraying trials in those years. It became clear that the comparison of yields from sprayed and unsprayed cotton must be made between plots large enough and sufficiently well isolated from one another to prevent interference. This makes the design of a statistically valid experiment much more difficult. Attempts at statistical accuracy (using smallplot experimental techniques to permit replication of different treatments) held back the development of crop protection at Namulonge for over ten years.

The final recommendation over most of Uganda was the use of a fixed regime involving four sprays of DDT at 1.1kg/ha. It was known that more effective control of pests than that afforded by the four DDT sprays could be worthwhile on well-grown cotton; up to twelve sprays, using a variety of insecticides, could be used with profit. It was also appreciated that a fixed regime throughout the country could not be ideal because of variations in the level and kind of pest attack; a fixed regime would be inadequate when pest attack was heavy and wasteful if it was light. Reed states that

> 'The method ... in which cotton is scouted for pests and sprayed according to the pests present is obviously (*sic*) the most economic means of pesticide use ... [But] the extension of a spraying recommendation based upon pest counts to Uganda's cotton farmers was not, however, acceptable. Such a recommendation would have involved a huge exercise in farmer education which was beyond the resources of the already overstretched extension service, and would have involved a major and costly modification to the existing scheme subsidies for insecticides'

Packs of DDT, each sufficient to spray an acre of cotton four times, were heavily subsidised by the Ugandan government and sold cheaply to farmers through the Co-operative Unions.

Ingram and Davis (1965) also describe the way in which the DDT user recommendation for spraying cotton in Uganda was developed. They state

> 'Reducing the dosage showed that half a pound of actual DDT per acre per application was just as effective as one pound, however it was thought that using half a pound of DDT would probably lead to the more rapid development of resistant strains of [pests] on the cotton crop and the heavier rate remained the standard'.

The idea of using DDT at high dose rates in order to prevent resurgence of insecticide-resistant pest populations appears to be based on a false analogy with medical and veterinary situations in which the concentration of a chemotherapeutic agent in the host organism is maintained at a uniformly high level for long enough to kill all pathogens present; a person or a cow is a well-integrated system which it is possible to saturate in this way. This is not true of agricultural systems; the concentration of the active ingredient in the environment can not be uniform - it will fall off around the edges of each application site. Excessive local concentrations of a pesticide will not preclude the development of resistance; it may even encourage its development by increasing the selection pressure in favour of resistance. The farmer is being asked to double his raw materials costs on the basis of a dubious technical argument.

But even if this effect were real, and use of high dose rates did prevent the development of insecticide resistance in the pest population, it would still not be justified to recommend such high rates to individual farmers because this confuses two different benefits: a. the immediate yield response which is appropriated by the farmer (and which can be obtained just as easily using half the recommended dose rate), and b. a much less well-defined yield response which may or may not be realised at some unspecified time in the future and which would in any case be largely delocalised over the surrounding area (insects can fly). It would seem inappropriate to expect individual farmers to bear the cost of realising this second benefit, which has the nature of a common good and cannot be appropriated.

So, the use of DDT on cotton in Uganda was long delayed because of an inept experimental approach to the problem of estimating yield response, the final recommendation on the number of pesticide applications to use was a compromise solution, and the recommended dose rate was pitched at far too high a level, on the basis of misleading technical and economic arguments. Nevertheless, the fixed spray regime (at high dose rates) was institutionalised by the rigid arrangements for marketing the chemical.

Agricultural scientists often complain that peasant farmers do not adopt, or use properly or sufficiently extensively, the technological innovations which are developed. For example, Hadelich-Bauhoff (1974) describes a survey of cotton production by five German agronomists in (the former) Ulanga District:

> 'Farmers are advised to spray cotton eight times at weekly intervals starting from flowering. This advice of the extension service was repeated unanimously by all the interviewed farmers, which shows the consciousness of the farmers of the advice. However, it was found that the actual performance was not as encouraging. Some farmers did not spray at all, some did so only four times, and almost half the farmers expressed their belief that forgetting spraying would not harm their cotton. This is very astonishing as the damage caused by the bollworm and other insects is so obvious'.

This view is commonly expressed. But perhaps the farmers are right.

Saylor (1974) has suggested that cotton farmers in Tanzania know very well the value of innovations and that this explains their behaviour. The surveys described here, of the patterns of pesticide use on cotton, coffee and maize, suggest that variation in the level of pesticide use is often an adaptive response to differences in the expected yield response either by farmers as a group at different sites (cotton) or even perhaps by individual farmers (maize). Although the rigid user recommendations are approximated by farm practice, they are usefully modified. If farmers do know better than the rigid recommendations originating on research stations, can their experience be used to generate alternative recommendations for local use?

In some situations (eg. use of DDT on maize, and in areas where both red and blue copper are used on coffee exposed simultaneously to CBD and leaf rust), regression analysis of farm survey data is of little value in estimating the yield response to pesticide use. But elsewhere it is possible to detect significant (non-spurious) positive correlations between yield and pesticide use (eg. use of DDT on cotton, use of blue copper on coffee in areas not liable to CBD), although the precise form of the relationship does, as one might expect, vary from site to site. In these cases, the collective experience of local farmers provides important information about the yield response which individual farmers might expect.

Collection of village-level survey data could be organised either through the village production committee or by the *bwana shamba*. Even regression analysis relating yield to the number of pesticide applications should not pose too formidable a problem with modern calculators (and these can be obtained quite cheaply for less than £20 including VAT). If farmers are encouraged to work out for themselves the average yield response to pesticide use in their village using their own production data, this will promote (even) more rational use of chemical pesticides than has hitherto been the case. The procedure would be virtually costless.

The relationship between yield and pesticide use should be examined over several seasons to provide a more balanced idea of the response which might be expected in any one. The results should be discussed in detail with extension staff at an open meeting of as many farmers in the village as care to attend. The proposed procedure would not tell any farmer how many times he should spray, but it would give him a much better idea of the additional yield he might expect by expanding his spray programme and how variable the response is both from farm to farm and from year to year. He would then be in a much better position *to decide for himself* what to do depending on his work load with other crops, his exposure to debt, and his estimates of the response characteristics of his crop for the coming season.

The proper role for agricultural research is the development of novel innovations for use at a later stage in the process of agricultural development. It can define the parameters within which a particular innovation can be used with profit; eg. it might say that an otherwise well-grown cotton crop can usefully be sprayed with DDT between two and ten times, and it might suggest an appropriate dose rate for each pesticide application. (The dose rate is more susceptible to control by external agencies since changes in it do not involve any concomitant changes in labour input. The appropriate decision model for fixing the dose rate is the traditional one, Figure 10.)

If user recommendations are to be made more flexible, rigid arrangements for marketing pesticides themselves become an anachronism.

5

PESTICIDE MARKETING POLICY

Pesticide marketing arrangements are based on both distribution and pricing policies. Although this study of the patterns of pesticide use in Tanzania cannot provide specific answers to such questions as, 'What should be the price of DDT for use on cotton?', it does suggest directions in which both distribution and pricing policies should move.

Distribution policy

DDT and Dimethoate are supplied to cotton farmers in the ECGA in packs sufficient to spray one acre eight times. If a farmer only has one acre, the pack is enough to fulfil the standard spray recommendation. Of course, if a farmer has more than one acre, he can spray his crop correspondingly fewer times. However, the mode of the area relative frequency distribution found in the cotton survey was one acre (mean area = 1.2 acres standard deviation = 0.63; and 19% of the cotton farmers interviewed grew less than one acre of cotton). Farmers with holdings of less than an acre can share with their neighbours, or save some of the chemicals for the following year. In spite of the rigidity of the marketing arrangements, farmers as a group manage to use pesticides more effectively than if they all followed the standard recommendation, since they adapt the number of applications to the potential yield response.

The standard recommendation for cotton (to spray eight times) is greater than the number of applications found in practice (mean = 5.5 in the survey). The recommendation is put forward as a target, albeit developed in a risk-neutral drought-free environment, which may be approximated only if conditions are suitable. The supply of packs with a minimum size too large for most farmers' requirements is a coercive device to induce greater pesticide use than farmers believe to be justified.

Farmers would have greater flexibility to adapt their spray regime to suit their particular circumstances if the standard pack size were reduced to half the present size, ie. enough to treat one acre four times. If the user recommendations are to be relaxed, so must pesticide distribution policy.

The way in which copper fungicides are distributed by the CAT is even more rigid. The distribution of red copper is virtually restricted to areas liable to CBD. Sufficient chemical (both blue and red copper) for each spray round is supplied by the CAT to farmers according to the number of bushes they claim to own.

Once again, in spite of this rigidity there is considerable variation in the number of pesticide applications each farmer does in fact use. Sometimes two rounds may be combined to give sufficient chemical for a single application - one round is usually insufficient because farmers have deliberately underestimated the number of bushes on previous occasions when an attempt was made to use the number of bushes as the basis for tax assessment. Sometimes, thé chemicals are sold (perhaps after being smuggled into Kenya). Some farmers, perhaps with good reason, may deliberately not use their allocation because they do not care to supply the labour required to apply it. Some of the chemical is not used on coffee at all but, for example, to treat an army worm infestation in a maize plot, and some farmers even buy in extra quantities of pesticide from the Tanganyika Farmers Association (TFA) shop in Moshi to supplement their allocation from the CAT.

The rigid bureaucratic pesticide distribution policy adopted by the CAT thus does not induce a uniform pattern of pesticide use. It invites misuse because pesticide allocations do not go to those farmers who will make best use of them. A chemicals package sufficient to spray the median size holding a sub-multiple of the recommended number of times and supplied on credit by the crop authority (analogous to the DDT *plus* Dimethoate package for cotton) would certainly appear to be a superior solution.

Maize farmers purchase their DDT requirements over the counter, eg. from the TFA. The distribution policy is flexible; the behaviour of maize farmers in adjusting the number of pesticide applications used to their specific needs is pronounced.

Pricing Policy

In addition to the design of appropriate user recommendations and a corresponding distribution policy, there are other policy variables concerned with pricing: a. the way in which pesticides are charged out to the user, and b. the extent to which they should be subsidised.

Insecticides for use on cotton are supplied on credit by the TCA; farmers are only charged for chemicals actually supplied and the charges are deducted from their crop receipts after the harvest.

The situation operates differently for coffee growers. Farmers are allocated agro-chemicals by the CAT according to the number of bushes they own, and a levy is deducted from the producer price to cover the cost of chemicals whether they are used or not. There are, in this procedure, several implicit cross-subsidies which have little allocative value:

a. farmers who do not have CBD in their crop (and who do not therefore use red copper) subsidise those who do;
b. farmers whose yield/bush is high, subsidise those whose yield is low (since the recommended spray programmes are identical in the two situations, but the pesticide charges are proportional to yield), and
c. good years (when the yield is high) subsidise bad years (when it is less).

The use of a standard charge-out rate in this way might be justified, in order to reduce administrative costs, if all farmers used the same number and kind of pesticide applications. But they do not; CBD chemicals are only used in areas liable to CBD, and the number of red and blue copper sprays used by different farmers varies considerably. Farmers whose yield is low (perhaps because of CBD, or maybe due to poor cultivation practices which reduce the potential yield response to pesticide use) get chemicals at a reduced price; farmers who get a high yield (because they are lucky enough not to have CBD, or perhaps because they take extra care of their bushes) are penalised.

It must be recognised that standard user recommendations can only provide a guide for actual practice and must not be followed slavishly. Peasant farmers can often gauge differences in the potential yield response and modify their behaviour accordingly. The cotton charge-out model is therefore preferable to the coffee model because farmers only pay for what they use and this might reasonably be expected to lead to a greater degree of adaptation between the number of pesticide applications and the potential yield response on individual farms.

There are several possible justifications for subsidising agro-chemicals.

a. Dynamic (or temporary) subsidies used to facilitate the adoption of a novel innovation by farmers who are not familiar with it (cf. free samples of consumer products). This does not apply in any of the situations considered here as in each case the technology is well-known.

b. Static (or permanent) subsidies which may be required because social benefits are greater than private benefits or social costs are less than private costs:

    i. Because of the Law of Large Numbers, the state will be less risk averse than individual farmers and the number of pesticide applications which is socially optimal will be higher than individual optima. Individual behaviour can be induced to move in the direction of the social optimum by reducing the transfer price.

    ii. There may be external economies resulting from pesticide use which are not appropriated by individual farmers. For example, pest control in one field may reduce the level of inoculum in neighbouring fields or more extensive use of a chemical might lengthen its effective field life before insecticide resistance builds up in the pest population (the importance of both these effects is doubtful).

    iii. The producer price of the crop does not always adequately reflect the value of that crop to the nation, particularly in the case of export crops like cotton and coffee, but also for food crops

> if these are substituting for imports; the shadow price of foreign exchange may be much greater than the official exchange rate in a situation of acute foreign exchange shortage.

However, these arguments for *subsidising* pesticides in order to encourage farmers to use more of them (coupled with high user recommendations which exhort greater use and are re-inforced by rigid marketing arrangements penalising deviant behaviour) must be balanced against other arguments for *taxing* pesticides to restrict excessive use because of any environmental damage they might cause.

The two groups of pesticides considered in our surveys (DDT, inorganic copper fungicides) have two common characteristics: a. they are commodity chemicals (and therefore cheap compared with possible alternatives which, being more recently developed, are subject to monopoly pricing under patent protection), and b. they are persistent in the environment.

There *are* social costs associated with the accumulation of chlorinated hydrocarbons and inorganic ions in the soil and run-off water. Ak'Habuhaya and Kassio (1979) investigated the concentration of pesticide residues in soil and water samples near Arusha. Water samples collected from wells, which supplied drinking water for children at a primary school and nearby villagers, contained 'unacceptably' high levels of chlorinated hydrocarbons compared with WHO standards. Pollution with long half-life residues does occur. The effect of, for example, a high level of DDT in Dar es Salaam tap water originating as run-off from sprayed cotton fields in the ECGA, is *not known*.

Even if we were able to correlate the use of DDT with a concomitant increase in human mortality, it would still be very difficult to include this in any kind of social cost appraisal in order to work out an 'optimal' level of pesticide use. What is the shilling equivalent of a human life? Is it infinite, because individual people are infinitely precious? Or is it equivalent to the present value of the potential net income of a 'typical' individual discounted at the social rate of time preference over his expected life span? Or is it zero (or even negative) because the marginal productivity of labour in a predominantly subsistence economy approaches zero?

There is a further problem: even though copper fungicides and chlorinated hydrocarbons such as DDT are persistent in the environment and their use may be associated with chronic toxicity at an indeterminate rate and at some unspecified time in the future, these chemicals do have a comparatively low acute dermal toxicity to pesticide operatives. How are we to balance differences in acute and chronic toxicity?

The difficulties of applying the techniques of social project appraisal to agricultural pest management have long been recognised in the literature. Wharton (1967), in a standard text on the economics of agricultural development, states 'Expenditures for plant and animal protection and disease and pest control do not lend themselves to cost-benefit analysis. One is forced to use minimal and standby criteria'. Any attempt to incorporate the various costs and benefits associated with pesticide use into a formal CBA model would surely be 'nonsense on stilts'.

As a second-best, minimal standby criterion, it is suggested that pesticides should only be used where the private benefit clearly exceeds the private cost, and the private cost of pesticides (ie. the charge-out rate) is sufficient to cover all *immediate* social costs. Very little is known about the long-term social costs associated with general environmental pollution or the way in which common goods such as insecticide resistance (or its lack) should best be exploited. In the meantime, farmers want to spray their crops.

SUMMARY OF POLICY RECOMMENDATIONS

1. Subsidies on commodity agro-chemicals should gradually be withdrawn to bring social and private costs more into line.
2. Pesticide marketing policy should be less rigid to allow farmers more easily to match the number of pesticide applications made to the potential yeild response.
3. User recommendations should also be made more flexible. Farmers should be encouraged to work out their own ideas of the appropriate number of pesticide applications to use, on the basis of collective village experience.
4. Reduction of the recommended dose rate for each application should be considered.

The skill of its farmers is one of the greatest assets Tanzania has. With help and encouragement, it can be made even more effective.

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