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COST EFFECTIVENESS OF PESTICIDE PRODUCTION AND APPLICATION IN DEVELOPING COUNTRIES*

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* The views expressed in this paper are those of the author and do not necessarily reflect the views of the Secretariat of UNIDO. This document has not been edited.

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Food - the main problem for mankind

The future of mankind depends on the ability to provide sufficient food for all. Shortly there will be 100 million additional people to feed every year, and although overall average food production has increased slowly over the past few decades enormous differences still exist between the various regions, with the developing regions usually being in a disadvantageous position.

One way to increase food consumption in a specific country is through food imports -- and huge surpluses of cereals, meat and butter in the developed countries seem to justify hopes for such possibilities. However, for most developing countries it is not desirable to be dependent on imports from the developed countries due, inter alia, to the huge costs involved, and self-sufficiency in food supplies is usually aimed at, causing the problem of increased home production.

1. AGRICULTURAL PRODUCTION AND PRODUCTIVITY

Agriculture produces less than 10 per cent of world GDP. However, its role is much more important than this figure would imply, since in addition to providing food, it provides for many other needs (clothing, industrial raw materials, such as cotton and rubber) of our modern society. Table 1.1 summarizes the world output of the main agricultural products for the years 1981-1986 and Tables 1.2 and 1.3 give the same information for the industrialized and the developing countries, respectively.

It can be seen that the developing countries produce roughly half of the world's total crops, but taking into account the population, this gives only one third in the per capita production. The yields as will be seen later are much lower than in the industrialized countries, due to the low level of agriculture, including the very low use of pesticides.

Widely differing farming methods are encountered in developing countries. Two main types can be distinguished: subsistence farming and cash crop production. The first is usually done on small parcels with family labour and little other input, while the second is usually realized on big estates using intensive manual work, but with much higher inputs of modern techniques: machines, improved and selected plant species, fertilizers and insecticides. The market requirements in quality and also in yield make the introduction of modern agricultural methods in this field mandatory.

1.1 The situation in selected crops

In order to give a more complete picture, some selected crops were investigated.

Rice

World production is concentrated in the most part in the developing countries (about 95 per cent). The difference in yield is striking: in Japan over 6 tons are produced per hectar, while in India it is only 1,8 tons, and the insecticide use per hectar in Japan is nearly ten times more that in India.

Wheat

About 60 per cent of the production is in the industrialized countries. In Western Europe the yield is more than twice that of Asia and three times as much as some other countries.

Soybean

The production is distributed between industrialized and developing countries in balanced ratio. Against 2,44 tons/ha in Canada, India produces only 0,7 tons/ha, but Argentina 2,1 tons/ha and China 1,42. These figures reflect the effect of the local conditions (weather etc.), but mainly that of the level of agriculture.

Cotton

Two thirds of the world production are in the developing countries. Here the yields are more balanced. USA, China and the USSR all have a production level over 700 kg/ha. The lowest values are in India with 223 kg/ha and Brazil with 313 kg/ha. Cotton is already a cash crop and the more export-oriented production becomes, the smaller become the differences, due to the application of similar agricultural methods, i.e. the increased use of pesticides.

Table 1.1

World Production

1000 MT

	1981	1982	1983	1984	1985	1986
TOTAL CEREALS	1651065	1710470	1644416	1803797	1847118	1867116
WHEAT	455729	482687	494243	516457	506034	535842
RICE PADDY	412493	424032	451950	470284	474728	475533
COARSE GRAINS	782844	803751	698224	817056	866355	855742
MAIZE	450463	450398	347722	452753	488325	480609
BARLEY	152301	164259	162157	171828	176435	180441
ROOT CROPS	556231	557513	561215	591833	586522	592418
POTATOES	288965	288387	287645	312079	300274	308548
TOTAL PULSES	41197	45313	47042	49104	50779	55200
VEGETABLES AND MELONS	356928	370666	372528	395985	403678	414101
FRUITS	292906	315373	313537	313636	307438	325806
GRAPES	61999	72942	67786	65141	59665	66990
CITRUS FRUIT	56042	54975	58738	56706	56058	59948
BANANAS	38697	38908	38227	40667	40063	41299
APPLES	32742	41438	39317	39860	38072	40923
TOTAL NUTS	4114	3880	3956	4032	3949	3882
OIL CROPS (OIL EQUIV)	53676	57119	53408	59296	64544	64759
OIL CROPS (CAKE EQUIV)	115272	120350	108970	123749	134777	130471
SUGAR (CENTRIFUG. RAW)	93264	102740	97231	99976	99052	100090
COCOA BEANS	1736	1611	1608	1748	1963	2002
COFFEE GREEN	6036	5053	5692	5225	5923	5188
TEA	1875	1945	2045	2192	2313	2296
VEGETABLE FIBRES	21053	20427	20042	24041	26045	21006
COTTON LINT	15287	14851	14315	18275	17166	15048
JUTE+JUTE-LIKE FIB.	3553	3333	3458	3598	6551	3681
TOBACCO	5966	6894	5963	6465	7018	6109
NATURAL RUBBER	3779	3803	4103	4195	4299	4372
TOTAL MEAT	136069	137258	141629	145308	150439	154974
TOTAL MILK	469802	480814	498841	502797	513028	521088
CHICKEN EGGS	27543	28339	28875	29718	30501	31385
WOOL GREASY	2817	2845	2879	2872	2966	3005

Source: FAO Production Yearbook 1987

Table 1.2

Industrialized countries' production
1000 MT

	1981	1982	1983	1984	1985	1986
TOTAL CERELAS	839334	878056	750585	883617	919165	920277
WHEAT	294132	301952	298622	311766	300080	317796
RICE PADDY	26107	25019	22368	26465	26312	26162
COARSE GRAINS	519095	551085	429594	545386	592774	576319
MAIZE	292293	300062	186873	281083	318211	308085
BARLEY	130313	141460	141546	151120	152576	154736
ROOT CROPS	209969	205693	204161	226193	215904	226322
POTATOES	207117	202820	201430	223420	212882	223394
TOTAL PULSES	9328	12009	13579	15142	16912	18842
VEGETABLES AND MELONS	141763	148876	145514	155471	150895	152113
FRUITS	124103	142441	137420	129756	123350	133682
GRAPES	47913	58322	53342	51505	46238	53028
CITRUS FRUIT	26895	24528	27711	21935	23586	24719
BANANAS	835	823	851	823	794	766
APPLES	23502	32160	28570	29000	26867	28943
TOTAL NUTS	2072	1873	1680	1876	1895	1658
OIL CROPS (OIL EQUIV)	21109	23167	19433	22203	24082	23921
OIL CROPS (CAKE EQUIV)	61190	66486	52846	60865	67316	66061
SUGAR (CENTRIFUG. RAW)	42229	42605	38892	42433	41454	42254
COCOA BEANS						
COFFEE GREEN	1	1	1	1	1	6035
TEA	244	246	256	252	257	262
VEGETABLE FIBRES	7320	6560	5526	6432	6985	6077
COTTON LINT	6753	5816	4683	5634	6203	5317
JUTE+JUTE-LIKE FIBR.	46	51	56	59	61	64
TOBACCO	2244	2263	2057	2208	2133	1964
NATURAL RUBBER						
TOTAL MEAT	89902	89506	92322	94037	95539	97142
TOTAL MILK	360370	367607	382237	383668	386138	390418
CHICKEN EGGS	18234	18474	18491	18586	18684	18893
WOOL GREASY	1967	1969	1979	2004	2081	2097

Source: FAO Production Yearbook 1987

Table 1.3

Developing countries' production
1000 MT

	1981	1982	1983	1984	1985	1986
TOTAL CERELAS	811731	832415	893831	920180	927953	946839
WHEAT	161597	180736	195620	204692	205955	218046
RICE PADDY	386386	399013	429582	443819	448417	449371
COARSE GRAINS	263748	252666	268630	271669	273582	279422
MAIZE	158171	150336	160849	171670	170114	172524
BARLEY	21988	22799	20611	20708	23859	25705
ROOT CROPS	346263	351821	357053	365640	370618	366096
POTATOES	81848	85567	86215	88659	87392	85155
TOTAL PULSES	31869	33304	33462	33962	33987	36358
VEGETABLES AND MELONS	215165	221790	227014	240514	252783	261989
FRUITS	168803	172932	176117	183880	184088	192124
GRAPES	14086	14620	14443	13636	13427	13961
CITRUS FRUIT	29147	30447	31028	34771	32472	35230
BANANAS	37861	38084	37376	39843	39269	40533
APPLES	9240	9278	10747	10860	11205	11979
TOTAL NUTS	2042	2006	2276	2156	2055	2224
OIL CROPS (OIL EQUIV)	32567	33952	33975	37093	40463	40838
OIL CROPS (CAKE EQUIV)	54082	53864	56124	62884	67461	64410
SUGAR (CENTRIFUG. RAW)	51035	60135	58339	57543	57599	57836
COCOA BEANS	1736	1611	1608	1748	1963	2002
COFFEE GREEN	5053	5691	5225	5923	5187	
TEA	1630	1699	1789	1940	2056	2035
VEGETABLE FRUITS	13733	13867	14516	17609	19060	14930
COTTON LINT	8534	9035	9632	12641	10963	9731
JUTE+JUTE-LIKE FIBR.	3507	3281	3401	3559	6490	3616
TOBACCO	3723	4631	3906	4257	4885	4145
NATURAL RUBBER	3779	3803	4103	4195	4299	4372
TOTAL MEAT	46166	47752	49307	51271	54899	57832
TOTAL MILK	109432	113207	116604	119129	126890	130670
CHICKEN EGGS	9309	9865	10364	11131	11817	12492
WOOL GREASY	850	876	899	868	885	907

Source: FAO Production Yearbook 1987

2. IMPACT OF VARIOUS INPUTS ON AGRICULTURAL PRODUCTION

In view of the present pattern of agricultural production and productivity and of the food requirements in the developing countries, increasing agricultural production can be considered as the only means to solve food problems. This goal can be reached by increasing yields, the size of the cultivated areas, and the harvested part of the cultivated areas.

The latter two possibilities involve high investment costs and therefore, especially in case of the developing countries, they cannot play a significant role in the solution of the problem. The FAO forecasts (Agriculture 2000) no significant increase in cultivated area in the developing countries. Therefire, the only remaining way is to increase the yields. This can be achieved by:

- better management,
- better selection of seeds (high yield species),
- irrigation,
- increased use of manure/fertilizers,
- mechanization/increased energy consumption,
- plant protection.

These factors can substantially improve the natural yields defined by the ecological conditions. Therefore we have first to consider these basic conditions.

2.1. Yield-influencing factors

2.1.1 Ecological factors

- Soil: fundamental factor of crop production. Scientific investigations have demonstrated that the role of soil far exceeds that of merely supporting plants and storing nutrients for them. Important biological processes take place which influence plant growth. Soil is a biologically living medium under permanent transformation induced by external environmental factors. An essential task of agriculture is to regulate and shift these factors in favourable directions (e.g. to prevent formation of more deserts, control of erosion, soil conservation, etc.). There is a close relationship between the type of soil and the crop it produces. Almost all types of plant have their favourite soil, from the saline desert to the marshy deep-soils.

This natural law is observed during crop production, growing the proper plant in a particular soil. That is how the significant major growing regions of the world have been formed. (Wheat-growing areas in Canada, the Soviet Union, the Corn Belt in the midwestern USA, etc.). But if the farmers are forced to grow major crop plants in a soil inadequate for the purpose, lower yields will be obtained even if all other requirements of the plant are met (e.g. water, nutrients, etc.). If a list of priorities influencing yields were drawn up, soil would take first place.

- Climate: to some extent this is related to the soil types because climatic influences have affected soil formation during millions of years, and the current phenomena of soil formation and erosion have been induced by climatic factors.

Similarly to the soil types, characteristic associations of plants may be identified for the climatic regions (zone of conifers, zone of deciduous forests, grasslands, deserts, etc.). All crops have optimal growing areas, i.e. annual temperature ranges, yearly sums of temperature, hours of sunshine, and, most important, rainfall. All these are decisive factors for the living conditions of a plant.

The above two ecological factors determine 50 per cent of the success of plant production, which can be modified only in a limited area over longer periods (land reclamation, irrigation, revegetations, etc.) because of the labour and capital demand involved. These modifications are considered as "transformation of the nature" and the costs are so high that they can be undertaken only with the assistance of government projects and subsidies by international organizations.

2.1.2 Agricultural factors

Species, variety

Careful selection of adequate plant species and variety is essential. Significantly differing biotypes are available within each variety, with several months' difference in the growing periods and the harvest dates, (e.g. hybrid maize with FAO number 400-600) or their frost tolerance may vary so that they can be grown without problem between the poles and the tropics (e.g. wheat, rye). The potential yields vary with the varieties: for maize it may range between 3 t/ha and 14 t/ha. Every variety has its specific soil, climatic, and nutrient requirements. It has a given resistance to pests and diseases, as well as sensibility. Other varietal properties of secondary importance are tolerance to monoculture, sowing density, time. If, therefore, a country wants to intensify agricultural production and to increase the average yields within a short period, the first measure to be taken is to select a variety responding to the local conditions and to meet its fertilizer requirement, at the same time applying proper soil tillage and mechanical treatment. Plant protection may only come after that, because pesticides are mainly used to protect the higher yields.

2.1.3 Fertilizers

Application of fertilizers/manure is one of the most efficient methods of soil management. It supplies the plants with the essential macro-elements, nitrogen, phosphorus and potassium.

All crops have determined nutrient requirements. Several of them, e.g. potatoes, sugarbeet, have high nutrient requirements and there are also those giving good yields without fertilizer application (sorghum, millet, rye). The nutrient requirement of the high-yielding selected crops is usually high, and higher supply is recommended even in soils with a good nutrient content.

In technology, application of fertilizers as a yield-influencing factor should have top priority because it significantly increases the yields of both the native varieties and the high-yielding hybrid varieties. Low-average yields can be doubled within a couple of years. It should be noted that above a certain limit the rate of fertilizer application does not improve the average yield. The rate of nutrient/hectare can be a characteristic figure of the agricultural intensity of the country. Fertilizer use closely correlates with the other elements of the production technology.

2.1.4 Mechanization

Although it would seem that mechanical tillage and other agricultural methods only replace and facilitate human work, in reality they have a great effect on the yields. Deeper tillage, faster harvesting, etc. considerably improve the production and productivity and also enhance the effect of the other factors.

2.1.5 Plant protection

As this study demonstrates, 25 to 45 per cent of the potential yield becomes unavailable for human use due to damage by different pests. Although the various plant protection methods cannct cope with the total elimination of these losses, an important part of the damage could be prevented. Plant-protection methods, especially the application of chemicals, could raise the available yield by 10 to 20 per cent.

Several methods and equipment are available for the control of pests and diseases. Plant protection techniques can be divided into three major groups which, although not equal in importance under current conditions, are all widely used. These are agrotechnical control, chemical control, and biological control.

The history of plant protection did not start with sophisticated chemical control techniques but with the simplest, oldest methods of tillage such as ploughing, hoeing (having the dual effect of insect and weed control), burning of the harvested area which, in addition to the above-mentioned effects also kills fungi, and flooding (in certain tropical regions). Insect control has also been effected by collecting and burning of plants. All the above methods have subsequently been mechanized.

Agricultural control was introduced later. It includes the selection and breeding of species resistant to a certain kind of pest (for example the vine-pest in the 19th century); crop rotation with the selection of plant sequence; and selection of sowing time.

The use of the natural agents also goes back to the early history of mankind, as well as the application of chemical substances like sulphur or potassium nitrate. Synthetic pesticides, however, made their entry into this field only in the 19th century, whilst the biological methods are products of our time. The agrotechnical methods are outside the scope of this study. Biological methods are promising but will arrive at significant application only after several decades. Therefore, in this study, plant protection will be restricted to the chemical agents.

2.2 Synergetic effect

The modernization of agriculture in view of yield increases needs the simultaneous and co-ordinated application of all five factors enumerated above. Not only is a synergetic effect always observed, but neglec of one factor could completely destroy the beneficial effect of all the others. It is very hard, therefore, to attribute the yield improvement to at individual factor and define what is the share of each of them in the results obtained. It would seem that a fundamental difference would exist between plant protection and all the other factors. The others effectively improve the yields and one would think that plant protection only hinders or eliminates the partial destruction of the crops already grown. In reality the damage inflicted by the pests is not restricted to that. Insects and fungi attacking the roots or leaves do not allow proper development of the plant; weeds leave less nutrients and water for the cultures, etc. which means that the crop produced will in most cases benefit more with the use of pesticides than without them.

It is thus necessary to consider all factors in close co-ordination. Nevertheless, every partner in this co-operation (fertilizer manufacturer, irrigation investor, seed seller, etc.) would like to demonstrate the merits of his product, and the use of pesticides should also have its own economic justification. Experiments, long-term experience and estimates show the same picture, as can be seen in detail in this study: the use of pesticides can bring benefits ranging from two to ten times the cost involved.

The lower the general agricultural level, which means low input of the other agrotechnical factors, the lower is the yield from plants on which pesticides were used. On the other hand, in highly efficient cultures using maximum inputs in fertilizers, seeds, etc., the cost of plant protection can bring in up to ten times their cost. In addition, inefficient cultures and neglect of plant protection would also deprive us of the results hoped for.

2.3 Summary. Place and role of plant protection

The foregoing has shown us that plant protection has a special place among the factors influencing agricultural production because of its multiple effects on yields, crop quality and market conditions, depending on the development level of the agriculture of the country.

In a situation with extensive agriculture, plant protection can save only a relatively small quantity of products gained from low-yield species grown under adverse conditions.

At a higher level of intensification, investment per unit area will increase but the crops produced will also increase at a progressive rate. In such cases one can no longer only consider protection of the increased quantities of crops, but must also take into account the capital investment required for the higher yields (fertilizer, machines, etc.). Finally, if intensification reaches the level where crops are not solely grown for self-sufficiency in food supply but are also a source of income (cash crops, tropical fruit plantations, avocado, kiwi, etc.), plant protection becomes an integral part of the production technology, since only completely sound and pest-free products can be exported.

In spite of all these advantages, it is well-known that pesticides can also have adverse effects. Their use, therefore, requires skill and expertise both on the side of the users and of the manufacturers. In order to minimize these unfavourable effects, adequate plant protection laws are drawn up in most countries, and special institutes are established under the supervision of the governments to check the observation of the laws and regulations, from the manufacture (toxicological tests) to the use (residue analyses). The costs incurred in preventing the negative effects of pesticide use on health and environment will also be taken into consideration in the economic calculations.

2.4 Yield losses

The yield losses caused by various pests, diseases and weeds are high even in the developed countries - ranging between 25 and 30 per cent compared to the potentially obtainable quantity of products, but they are higher in the developing countries, where losses reach 33 to 45 per cent.

The yield loss caused by insects, fungi and weeds is shown in Table 2.4.1. Quantitative data of yield loss for some major crop plants are shown in Table 2.4.2.

Tables 2.4.3 and 2.4.4 compare data of the various geographical zones, with special attention given to the damages caused by pests, diseases and weeds.1/

As there are no modifications in the biology of the pests and diseases within a term of ten years, the data of the survey of 1979 can be accepted. Data of the tables show that the occurence and infestations of the insect pests are significantly higher in regions with rainy and warm climates than in the areas with cold and rainy weather conditions, or under dry-continental or desert climates. The same trend is observed for damages caused by fungal diseases.

Furthermore, it is well known that the intensification of agriculture in the different geographical zones is not the same, therefore, pesticide consumption also varies.

Even in the zones of Europe and North America with high pesticide consumption, the infestation/infection level is high in spite of the modern chemical methods used to control pests.

Thus the chemical control is a process keeping the damages at a low level, but not capable of fully eliminating them.

1/ Information Research Limited Co. "The emerging markets for pesticides in the developing countries", 1979.

Table 2.4.1

Yield losses caused by insects, fungi and weeds
(% of the potential yield)

Crop and pests	Africa %	Latin America %	Asia %
CEREALS:	30-70	25-44	22-50
- weeds	15	11	11
- fungi	10	11	10
- insects	12	10	10
SUGARBEET:	66	37	71
- weeds	17	10	22
- fungi	17	10	22
- insects	22	17	27
POTATOES:	62	44	49
- weeds	12	4	10
- fungi	28	23	28
- insects	22	17	11
VEGETABLES AND LEGUMES:	39	30	36
- weeds	13	4	13
- fungi	15	18	11
- insects	11	8	12
FRUITS;	28	34	27
- weeds	7	8	6
- fungi	12	18	13
- insects	9	8	8
COFFEE, COCOA:	56	47	43
- weeds	17	17	16
- fungi	22	17	16
- insects	17	13	11
TEA:	18	18	37
- weeds	8	8	10
- fungi	4	4	18
- insects	6	6	9
TOBACCO:	51	38	36
- weeds	11	10	9
- fungi	26	11	16
- insects	14	17	11
OIL CROPS:	35	38	41
- weeds	10	10	12
- fungi	9	12	14
- insects	15	11	15
COTTON:	45	42	36
- weeds	8	6	7
- fungi	17	20	12
- insects	20	16	17
RUBBER:	29	29	29
- weeds	6	6	6
- fungi	17	17	17
- insects	6	6	6

Table 2.4.2

Yield losses in the developing countries
(thousand tons/year)

Crop	Yield loss
Cereals	45.474
Rice	235.870
Millet and sorghum	38.638
Sugarbeet	16.156
Sugarcane	964.089
Potatoes	26.591
Vegetables	62.589
Fruits	103.109
Coffee	4.276
Cocoa	1.427
Tea	618
Tobacco	1.457
Oil crops	32.117
Cotton	10.722
Rubber	1.439

Table 2.4.3

Comparison of the various geographical regions based on the damages caused by pests (%)

Region	Insects	Fungi	Weeds	Total
Asia	20,7	11,3	11,3	43,3
Africa	13,0	15,7	12,9	41,6
South America	10,0	7,8	15,2	33,0
Soviet Union, China	10,5	10,1	9,1	29,7
North and Middle America	9,4	8,0	11,3	28,7
Oceania	7,0	8,3	12,6	27,9
Europe	5,1	6,8	13,1	25,0

Table 2.4.4

Average weed species with different level of infection on the various continents

Region	Cyperus rotundus	Cynodon dactylon	Echinocloa crus galli	Elusine indica	Sorghum halepense	Emperato cylindrica	Eichhornia crassipes	Digitaria sanguinalis
Africa	H	H	-	H	L	H	M	L
N-America	L	L	L	L	L	L	L	L
India	H	M	M	L	M	L	H	M
SE-Asia	L	M	M	L	M	L	H	M
Malaysia	M	H	M	M	L	M	M	L
Polynesia	L	L	L	L	L	L	L	L
S-America	H	H	M	H	L	M	M	H
Central America	H	H	L	H	H	L	H	H
S and E Europe	-	H	H	-	H	-	-	H

Note: H = heavily infected, M = medium infection, L = lightly infected.

Comment: The weed infection for South and East Europe is taken from Hungarian sources.

Tables 2.4.5, 2.4.6 and 2.4.7 show

- the number of species of pests, fungi and weeds damaging different crops,
- the percentage of infestation/infection,
- the distribution (%) of the groups of pesticides used in the various crops.

Table 2.4.5

Number of pest species regularly occurring in crops
(IRL: Future trends in the world market of pestices)

Plant	Insect pests	Fungi	Weeds	Total
Wheat	10	10	12	32
Maize	15	5	20	40
Rice	19	5	20	44
Millet, sorghum	3	–	10	13
Potatoes	4	10	12	26
Sugarbeet	12	4	12	38
Rape	5	–	–	5
Sugarcane	22	11	–	33
Fruits	25	16	–	41
Grape	12	5	–	17
Cotton	19	5	–	24
Tea, coffee, cocoa	10	4	–	14
Other tropical (bananas, coconut, olive)	5	8	–	13

Table 2.4.6

Percentage of infestation/infection caused by
different pests in major crops
(IRL: Future trends in the world market of pesticides)

Plants	Insects %	Fungi %	Weeds %	Total %
Maize	12	12	10	34
Sorghum	9	9	13	31
Rice	4	7	17	28
Wheat	6	14	12	32
Potatoes	14	19	3	36
Cotton	14	12	8	39
Sugarcane	15	23	13	51

Table 2.4.7

Percentage of pesticide application in major crops
(Wood McKenzie, 1977, Agrochemical Review)

	Crop plants %				
	Cotton	Maize	Rice	Wheat	Fruits Vegetables
Herbicide	26	78	35	75	10
Insecticide	71	20	47	10	38
Fungicide	3	2	18	15	52
Total:	100	100	100	100	100

It can be concluded that the crops under study can be divided into three groups as far as their pesticide requirements are concerned (see also Table 2.4.8).

- High pesticide requirement:
  - rice
  - cotton
  - grapes
  - fruits (deciduous)

- Moderate pesticides requirement:
  - maize
  - potatoe
  - sugarbeet
  - sugarcane
  - tea, coffee, cocoa
  - tropical fruits, citrus spp.

- Low pesticide requirement:
  - wheat, cereals (barley, rye)
  - millet, sorghum
  - rape

Table 2.4.8

Specific pesticide requirement based on groups of modes of action

Plant	PESTICIDE REQUIREMENT Insecticide	Fungicide	Herbicide
Wheat	L	M	M
Maize	M	L	H
Rice	H	M	H
Millet, sorghum	L	-	L
Potatoes	M	M	L
Sugarbeet	M	L	M
Sugarcane	M	-	M
Rape	M	-	-
Fruits			
deciduous	H	H	L
Citrus spp.	M	M	-
Grapes	H	H	L
Cotton	H	M	L
Coffee	-	M	L
Tea	M	-	L
Cocoa	M	M	L

Note: L = low, M = moderate (medium), H = high

3. METHODOLOGY

The economic effectiveness of pesticide application is not easy to determine. In principle, this assessment should be based on the well-known general methods of budgeting. This means that the net returns of farming should be calculated, both with and without the use of pesticides, and the results compared. The same procedure should be applied when pesticide use is compared with other plant protection methods. It is also possible to confront the additional income from pesticide application with the additional costs involved. In the first case total budgets are compared and in the second a partial budget, involving only the additional costs and benefits. However, for all methods the budgeting process has to be agreed as well as the ways to assess the individual cost and benefit factors.

3.1 Budgeting

To evaluate a pesticide it is necessary to examine the differences in costs and benefits associated with and without its use. This can be done by a complete tabulation of costs and returns for both cases and by their comparison.

Since many other production activities, and the associated costs will not change when a new pest control practice is introduced, it is not necessary to consider all these costs and returns. In this sense, the budget is a partial budget in that it only considers items that change. The costs that change when a new practice is introduced can be called variable costs. Fixed costs are the expenditures for other production resources that do not change with a decision to use a new practice. (Not to be confused with the fixed and variable costs usually including in production cost calcuations).

In the case of a partial budget, net returns or revenues are total variable revenues, less total variable costs. It must be remembered that net revenue figures are not profits, since many other costs have not been deducted. It is therefore necessary to analyse all factors in revenues and costs alike.

3.1.1 Revenues

Revenue can be compounded from two factors: first, the value of crop saved, or the difference between the crop produced with and without pesticide use, and second, the difference in quality, which can be expressed in terms of unit price difference.

Quantities

The crop quantity increase due to pesticide use is not always easy to define but its value is even more difficult to assess. With cash crops the market price is available and poses no problem. But the valuation of products, if they are consumed by the family, can be made only by using the so-called opportunity field price. This is the money price that the farmer would have to pay for an additional unit of the product for consumption. Money prices less transport costs can serve as a guide to crop yield valuation, even in primarily subsistance agriculture.

Quality

Crop losses frequently occur through reduction of crop quality as well as in yield loss. Experiments and market observations are usually needed to evaluate the effects of pests on crop quality. Experiments can establish the effect of various pest densities as physical measures of crop quality, such as percent of damaged seed, seed size, degree of sticky cotton lint or percent of blemished fruit. Price reductions associated with these physical damage measures can then be observed in large samples of crop purchases. These quality effects must be included in the computation of total benefits of the various options in the partial budgets.

This procedure is in many cases not so simple. Many fruits and other products cannot be sold on the export market if the pests have not been eradicated, since an untreated product presents a serious infection hazard. There is often no alternative from the quality point of view, to pesticide utilization which signifies that the comparative data are not available.

3.1.2 Costs

In budgeting, the following costs have to be considered: labour, pesticide, interests, subsidies and taxes.

Labour

When labour is hired, there is a money factor. When farm labour is used to control pests, no money is involved: one must compare time used to control pests with that used to earn income with another crop, to work on the farm or in some other activity. This is done with the aid of the concept of opportunity cost. Opportunity cost is the value of any resource (labour, machinery, land) in its best alternative use. For family farm labour the opportunity cost may be the wage that could be earned in off-farm work or the value of time spent on another farm crop. Of course it is not easy in many subsistance and other farming economies to find alternative uses for the labour and thus to assign a value to this cost item.

Frequently, labour from migrant workers is scheduled by crop and area. Family labour is also likely to be more scarce at some periods than others, e.g. extra weeding time for soybeans is much more expensive in terms of opportunity costs during critical planting and harvesting times of other crops. As indicated above, the appropriate rate to charge for labour is its value in the next best activity. This may involve finding local wage rates for specific tasks and for specific times of the year, since labour costs per day or per hectare can easily change with the season and influence pest control calculations.

Machinery and power

Machinery and power costs are usually not too difficult to compute. It is generally accurate enough to divide the purchase cost of a spray machine or tractor by the number of hectares on which it is used during its life to get an average machine cost per hectare. The total cost of pesticide application rises rapidly for relatively inexpensive application machines if they are purchased by farmers who only farm and treat small areas. To illustrate this, in Table 3.1.1 total costs per pesticide application are compared for three sizes of farm that treat each hectare once per year. Here, the machine's life is assumed to be five years. For a machine that costs $100, with relatively low pesticide material ($3/ha) and applicator labour ($1) costs, the total cost per application is almost five times as high for the small (1 ha) farm as for the larger farm (20 ha). This example shows why informal rental or sharing arrangements are very important when equipment or other capital items are being evaluated. The main feature of this type of resource is that it may not be available in small units and leads to lower costs in larger-scale farms.

Table 3.1.1

Pesticide treatment cost per hectare by farm size

Farm size (ha)	Machine cost/ha $/ha	Pesticide cost per/ha $/ha	Labour cost/ha $/ha	Total Cost per ha $/ha
1	20	3	1	24
5	4	3	1	8
20	1	3	1	5

Pesticide material

Within the costs the most easy to calculate is the pesticide itself. It should be calculated at the farm gate, as a formulated product.

Interest

A type of cost that is often overlooked is that of borrowed money (interest cost) to carry out pest control actions. If the pesticide applicator machine is purchased at a cost of $100 with a loan that has an annual interest cost of 20 per cent for each of the five years of its life, the total cost of the applicator would be $200 ($100 + $100 (0.2) x 5 totalling $200. Therefore, the appropriate charge per 100 hectares for which the pesticide application is used during its life on a 20-hectare farm should be $2.00, and not $1.00 which is the net figure whithout interest.

Payment for pesticides is made at the beginning of a season, whereas the benefits only come with the harvest. In the case of trees, this can take several years. In some areas, production loans - with the harvest from the trees used for security - are given to finance pesticides, labour for weeding, cultivating and other pest control activities. In these cases, the interest costs of such loans must be added to the end cost. When yield increases occur subsequently to a control action has already been paid, the costs and revenues from the yield increase should be placed on an equal time scale by charging interest on the costs or adjusting the returns for interest lost.

Subsidies and taxes

Pest control resource costs can also vary from area to area with different subsidies and taxes. A subsidy occurs when some part of a resource is paid for by a government unit or some other agency. An example would be pesticides sold to farmers at 60 percent of usual market costs. In the presence of such a subsidy, the budgets should reflect the cost of the pesticide to the farmer. Of course, the direct effect of such a subsidy would be to make pesticide-using options economically more attractive to the farmer.

Sometimes resources and crops are subjected to taxes, such as export levies collected by export boards. Crop taxes are reflected in the field prices that the farmer receives for his crop by subtracting them from crop revenues. Yield-increasing practices, such as pest control, can be discouraged by reducing crop values to farmers through taxes.

3.2 The pest attack forms and their effect on the control methods

The methods used for evaluating of the economic efficiency of pesticide application are of a general nature. However, its use depends greatly on the the type of pest for which the protection is needed, i.e:

- pest attack levels can be assumed constant at average levels;
- pest attack level varies greatly, but action can be taken efficiently according to the actual level determined;
- pest attack level varies, but the decision for action must be taken before information is available on the actual level of attack;
- plant protection measures must be taken to avoid catastrophic consequences.

The first three cases will be discussed in the next paragraphs. The last does not need economic analysis since the disastrous consequences of no action are apparent.

3.2.1 Constant average pest attack level

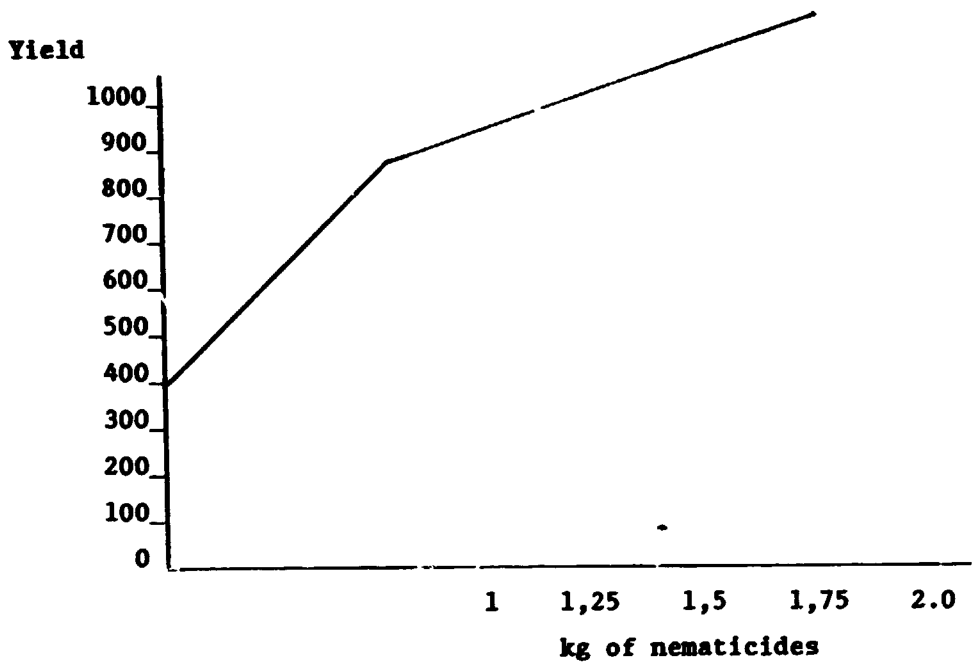
In this case pesticide application is a regular practice with the whole economics of pesticide use depending on the level and quantity of pesticide used on a hectare.

The relationship between pest control level and its effect or cost is not linear. If a higher dose is applied, the application costs remain the same, only the material cost of the pesticide used increases. When the number of applications is raised, the relationship becomes more equal. However, the difference is relatively small and an average unit cost for pesticide application for every kg used can be assumed.

Diminishing returns

The yield response to various rates of a nematicide is plotted in Figure 3.2.1. This type of response, known as diminishing returns, is typical for the use of numerous pesticides and other inputs in agriculture. There is a sharp increase in yield with the application of the lowest rate and then gradual yield gains with additional amounts of the pesticide. In some cases, negative responses to higher pesticide levels might result, especially with non-target or direct crop damage effects. If only the yield response data is examined, the tendency is to choose the pesticide level that maximizes yield (2 kilos in Table 3.2.1). However, this does not consider the cost of achieving this yield which is not in monetary terms.

Figure 3.2.1: Yield response curve for nematicides



Total revenues, total cost and net revenues are computed for each nematicide rate in Table 3.2.1. The net benefit calculations show that the 1.5 kilo nematicide rate gives the highest net revenue. If we tried to reach maximum yields with 2 kilos of nematicides we would obtain $1.80 per ha less because of the higher nematicide costs than at the 1.5 rate ($18 compared to $22). Any nematicide rate other than 1.5 kilos would lead to less than the highest net revenues.

Table 3.2.1

Dry bean production with various nematicide rates

Nematicides (kg/ha)	Yield (kg/ha)	Total revenues *) ($/ha)	Total variable cost **) ($/ha)	Net revenues ($/ha)
2.00	1 010	141.40	28	113.40
1.75	1 000	140.00	25	115.00
1.50	980	137.20	22	115.20
1.25	950	133.00	19	114.00
1.00	900	126.00	16	110.00
0	400	56.00	0	56.00

*) The value of bean is $0.14 per kilo at the farm gate.
**) The value of the nematicide is $12 per kilo with an application cost of $4.

Marginal analysis

Another type of analysis based on the idea that yields and benefits will increase at a declining rate is known as marginal analysis. This concept allows us to see that it is economically wise to add further resources, as long as the gain in output is worth more than the extra costs of adding the resources.

The marginal rate of return to a given increment of input expenditure, such as nematicide expenditure, is the marginal revenue divided by the marginal cost. Marginal revenue is the increase in total revenue as pesticide is increased to the next higher level. Marginal cost is computed in the same way. When marginal benefit and marginal cost are equal, then the net revenue is highest. If more pesticides are applied, the extra cost exceeds the additional revenue. It is shown using the same example as before for each change in nematicide use in the last column of Table 3.2.3. Adding the 0.25 kilos to move from the 1.25 level to the 1.50 level will give a 40 per cent return. At the 1.75 rate the marginal return is -.07 (.93-1.00). Returns above costs are 337 per cent for the first kilo (4.37 - 1.0) x 100), 133 per cent in moving from 1.0 to 1.25 and 40 per cent in moving from 1.25 to 1.50 kilos. Marginal return per unit of expenditure is a good guide for choosing between pest control alternatives, when interest costs are included or money for pest control is limited. The latter condition is often characteristic of many situations in developing countries.

Table 3.2.3

Marginal analysis of nematicide use

Nematicide (kg/ha)	Total revenues	Total cost	Marginal *) revenues	Marginal **) cost	Marginal rate of return
2.00	$141.40	$28	$ 1.40	$ 3.00	$0.47
1.75	140.00	25	2.80	3.00	0.93
1.50	137.20	22	4.20	3.00	1.40
1.25	133.00	19	7.00	3.00	2.33
1.00	126.00	16	70.00	16.00	4.37
0	56.00	0			

*) Total revenues of next higher nematicide rate less total revenues; for example, 141.40-140.00=1.40

**) Total cost of next higher nematicide rate less total cost; for example, 28-25=3.

3.2.2 Variable pest attack controllable by monitoring

In the foregoing the level of pest attacK was assumed to be constant at average levels. Clearly, a change in the level of pest attack can greatly affect pest damage and the returns from taking crop protection action. Thus, in many cases it is desirable to relate pest control action to information on levels of pest or pest damage, as determined through monitoring by farmers and pest-control specialists. This is obviously applicable only where the pesticide action has an immediate effect and can be taken efficiently at the time when the information on the pest damage level is available. The case where a decision on pest control action has to be taken before the information on the pest attack level is available will be discussed in the next chapter.

It is of utmost importance to establish the maximum tolerable pest level in order to determine when control action should be taken, with a view to securing the highest net returns possible. This is also the minimum pest level that economically justifies treatment.

Budgeting and marginal analysis can be used to combine economic and biological information to find action threshold recommendations for major pests or pest complexes.

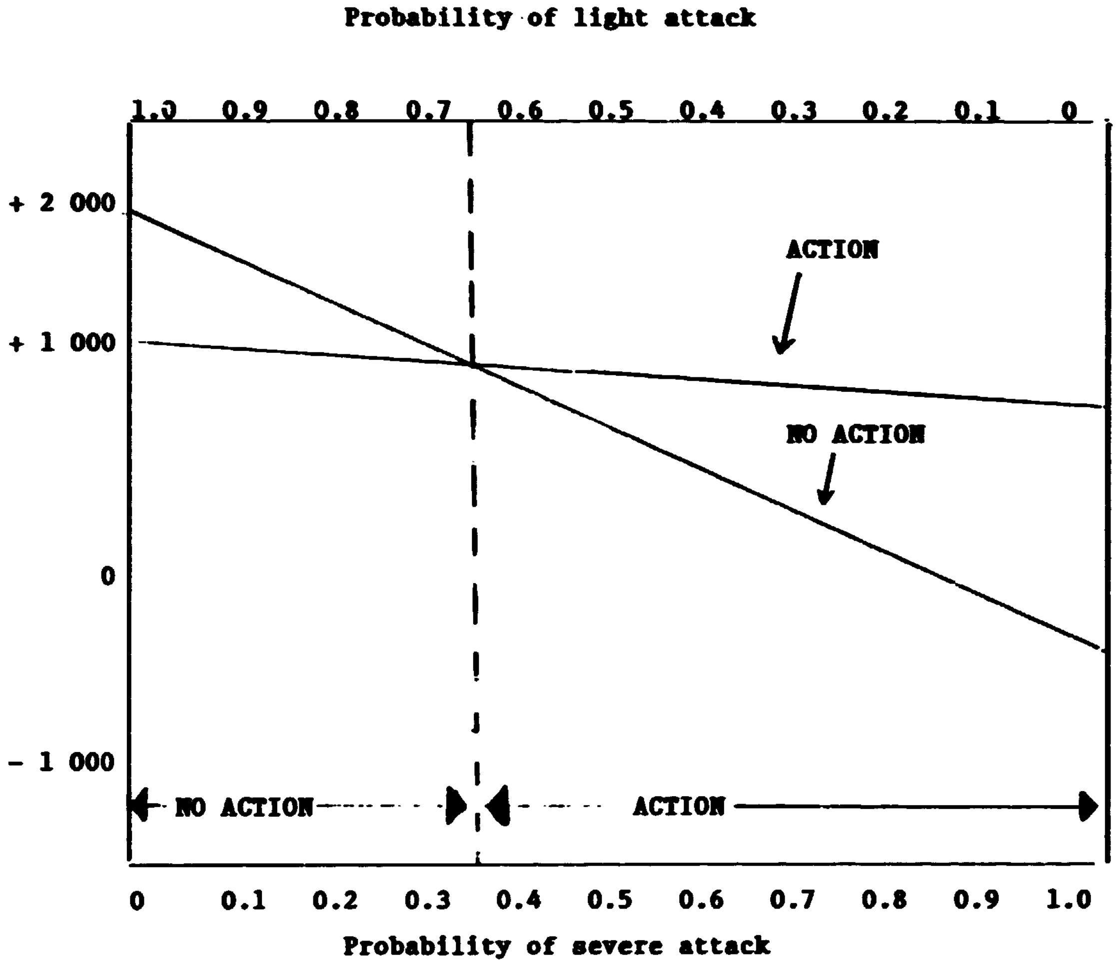
3.2.3 Pest control under conditions of uncertainty

For certain pests, such as soil-borne diseases and nematodes, the ability to monitor the level of pest attack may be limited, while the level of attack of other, fast-growing, pest organisms may change rapidly under favourable conditions. In these cases the level of pest attack is unlikely to be apparent at the time when the pest control decision is made. Consequently, net income, associated with a pest control decision will be one of a range of possible results, rather than a single one, depending on the level of pest attack that occurs. Uncertainty regarding level of attack complicates the economics of pest control action.

Two methods are used to cope with this uncertainty. The first is a variant of the sensibility analysis. By appropriate changes in the economic threshold calculation, corresponding to the possible variations in the pest attack level, the effect of the different possible parameters is evaluated on the threshold values. This method gives an indication on the extent of the effects but no direct economic evaluation. The second uses the concept of the probability, or percentage chance, of the occurence of a particular outcome. The probability of a given pest entering a given field in a specific year, for example, is the percentage odds of that pest's occurrence. If it typically occurs only once every four years, the probability of it entering the field in a coming year is 25 per cent (0.25).

The method used to convert the probability distribution of the results of a particular strategy to a single monetary figure is to weigh the possible results by their probability. This method gives the break even point in money terms, where the outcome of both routes - no action and a given action - are equivalent in economic terms. This money term corresponds to a defined probability value as Figure 3.2.2 shows. This is the point where the two lines representing the action and no-action respectively intersect. Any probability above will justify action (and at a constantly growing rate) and vice-visa, any probability below will incite no-action.

Figure 3.2.2: Break-even probabilities for action versus no-action



3.3 Factors influencing the possible pest damage

The economics of pesticide use depend on the extent of the potential damages caused by the pest. This is influenced by the geographical position, climatic conditions, and the crop. The following is a short overview of these factors and their effect on possible pest damage and the control action to be taken.

Perhaps the most important factor is the definition of the nature and extent of the pests and damages to be prevented, and the nature and application of the pesticides to be used. It has a decisive influence on the crop structure, the latter being the second most important factor of economic pesticide use.

The level of infestation/infection caused by the pests/diseases of the crops varies according to geographical zones. In regions with arid climates and eroded, sandy soil, pesticide use is practically non-existent or insignificant.

The climatic conditions influence not only pesticide consumption as a whole but also its structure, i.e. the relative importance of the different product groups (insecticide, fungicide, herbicide).

All species of pest (insects), diseases (fungi) and weeds have characteristic environmental requirements, the most important being (a) the annual sum of temperature necessary for the breeding and development of any pest (insects) and (b) the minimum temperature/year (in geographical zones with four seasons) to enable the pests to survive winter temperatures, and (c) the number of sunshine hours which has an important effect on the feeding and reproduction of the insects. The relationship between rainfall and temperature determines the infection period and intensity of fungi. The development of some fungal species is dependent on dry weather and warm temperatures (e.g. powdery mildew, Erisyphy) while the spread of other fungi is helped by cold and wet weather (potato blight, Phytophthora).

In addition to temperature and rainfall, the spread of some weeds is greatly determined by various soil types. It must be noted, however, that the 20 or 30 most dangerous pests, diseases and weeds causing damage in almost all the geographical zones of the world adapt themselves well to the changing environmental conditions (e.g. aphids (Aphididae), locusts, Fusarium species, Agropyron species).

In this section only the five geographical and climatic zones will be described with their distinct and different pests. No special attention will be paid to hilly regions or monsoon areas, because they are listed under the temperate or tropical regions.

- <u>TEMPERATE ZONE</u>: as far as the occurrence of pests and the number of generations are concerned, this zone can be divided into two subzones:

- <u>Cold, oceanic zone</u>: small number of sunshine hours, low annual sum of temperatures, higher than average annual rainfall (above 1000 mm). Winter is usually cold, the average minimum temperature is below -10°C. Typical regions: western and northern Europe, Canada.

Weeds are of primary concern; grasses and their control in cereals caused severe problems even some years ago. The fungal diseases are also important under wet and cold climatic conditions, e.g. potato blight (Phytophthora). Insect pests cause relatively low damage, because the number of generations of the species with more generations (e.g. Aphididae) ranges between 6 and 7, while in the warmer zones it is between 10 and 14. Major crops of this region: barley, rye, potatoes, sugarbeet.

- <u>Regions with temperate-continental climate</u>: high number of sunshine hours and annual sums of temperature, low rainfall: between 500 and 800 mm/year. Lowest temperature: $-20^{o}C$. Typical regions: eastern and southern Europe (e.g. Bulgaria), USA.

This is the zone most affected by pests, diseases and weeds with similar infestation/infection levels and with the maximum number of generations. Weeds: typical plants of both the cold areas and the southern regions are present, almost all species of pests (insects) and fungi occur. In spite of this, epidemics are relatively seldom as the cold winters exceed the survival capacity of the pests. On the other hand, insects and fungi introduced from other countries can easily spread in this zone (Phylloxera, Leptinotarsa, potato beetle, Sorghum halepense, etc.).

In these areas the amount of treatment used against insect pests is singificantly higher than in the oceanic region of this zone.

Major crops: wheat, maize, sunflower, alfalfa, grapes, fruits, vegetables.

- <u>MEDITERRANEAN ZONE</u>: this term is widely used, not only for the littoral regions of the Mediterranean Sea, but also for other warm but not tropical regions. The occurrence and composition of pest species are of utmost concern. This zone has warm and dry summers and cold winters with moderate rainfall and no frost. The number of sunshine hours is high (but lower than that of the tropical zones), the annual sum of temperature is also high, with minimum temperatures of -1 to $-5^{o}C$. This zone is conducive for the spread of fungi but attacks caused by insects and weeds are of no lesser importance. During the warm and dry summer periods the insects are in diapause, thus the infestation level decreases.

The fungicide demand in this zone is particularly high, followed by the use of herbicides and insecticides, both at a similar level.

Major crops: wheat, maize, tobacco, cotton, sunflower, grapes, fruits, but most of all Citrus spp.

- TROPICAL ZONE: due to the huge size and heterogeneity of this region, two sub-regions are considered with typical pests and diseases: the tropical arid and the wet zone. The spread of pests and diseases is different from the preceding zone, special local pests appear (the so-called regional species), but other species occurring all over the world can also be found. The number of species and the level of damage in this region are, by far, above those of the other two geographical zones.

- Tropical wet zone: there are two seasons, the hot rainy summer is followed by the cold, dry "winter". Most plants have two seasons annually with major pests attacking all the year round, the generations follow each other without diapause. Most losses are caused by insects. Of course, the humid warm weather is optimal for fungal diseases and for continuous infection. Fungi and presence of weeds are of secondary importance.

Major crops: rice, sugar-cane, cotton, tropical fruits, wheat, millet. Regions: some parts of Asia, Central America, Africa and South America.

- Tropical arid zone: here too, the two seasons are characteristic, with very hot, dry summers, and temperate "winters" with low volumes of rainfall.

In this zone, agricultural production is restricted due to irrigation problems and only certain plant species can be grown (millet, sorghum).

The occurrence and the number of species of the pests and diseases are much lower than that in the wet zone; the insects are mostly in diapause during the summer dry period. Large populations of insect occur frequently in the area (locusts). The occurrence of fungal diseases is more limited and only some species are found (e.g. Fusarium). In spite of these factors, the extent of the damage caused is still high. Major crops: millet, sorghum, and in some areas tropical fruits and cotton are also grown. Agriculture is determined by typical self-sufficient family farms. Actual pesticide consumption is very low. Regions: Central Africa and Western Asia.

3.4. <u>Crop structure</u>

Under this subitem, only the general trends of pesticide requirements of the particular crops, and demand for a particular group of products (insecticides, fungicides, and herbicides) will be discussed.

- <u>Wheat</u>: Some varieties are or can be grown in all regions of the world; it has low pesticide requirements, can be grown without chemical treatment, which, however, results in low average yields.

Insecticide demand: In temperate zones, the main growing area of wheat, the plants can be attacked by different soil-borne insects (Elateridae), and fruit flies (Oscinella fruit). However, these do not cause reduction in yield. In the tropical zones, the so-called polyphagous insects (locusts) may destroy the whole yield, but this is not typical.

Fungicide demand: average. In the zones with warmer climates, the powdery mildew (Erisiphae) regularly damages the high-yielding, selected varieties. These varieties need 1 or 2 treatments with fungicides in most parts of the world. As the growing area is large compared with the other crops, the treatment means significant consumption of fungicides.

Herbicide demand: moderate. Most damages are caused by grasses in wheat plants (dicotyledones). The crop can be grown without the use of herbicides, but the yield would be lower. Herbicides are applied mainly in zones with cold rainy climates.

- <u>Maize</u>: This crop plant is normally found in warm zones, due to the high temperature demand. The pesticide requirement is moderate. Many varieties are grown all over the world, with much difference in their external shape, the resistance to pests and diseases is also different.

Insecticide demand: average, but higher than that of wheat. On the one hand, it has more insect pests, and on the other, the plant density is much lower, and the average plant number/unit area is also lower than in the case of wheat, therefore more loss occurs. Most losses are caused by the European corn borer, having increasingly more generations towards the southern regions. Thus, regular treatment with insecticides is recommended in the southern countries.

Fungicide demand: lower than that of wheat. Maize has some important fungal diseases in the temperate zone, but as they do not significantly reduce the yield no fungicides are used for the control. In the tropical wet and mediterranean zones the stored products (grains) are attacked by several fungal diseases (Fusarium), but they cannot be successfully controlled by application of present fungicides.

Herbicide demand is high. Except for the old varieties, maize cannot be grown without weed control. This does not mean the application of herbicides only, because mechanical or manual methods are also effective.

In the main growing areas, in the USA and in southern and eastern Europe, 70 to 80 per cent of the growing areas have to be treated with herbicides. On these areas the weeds can totally destroy the yields (e.g. Sorghum, Amaranthus, Echinocloa, etc.). The high-yielding hybrid varieties are especially sensitive to weeds.

- <u>Rice</u>: Due to the high temperature requirement, rice can only be grown in areas with a warm climate. Nevertheless, the northern boundary of its production is South-East Europe. Irrigation (flooding) is necessary, causing special pest control problems as the range of pests and diseases can be very wide.

Insecticide demand is high, several insecticide treatments (4 or 5) are needed during one season. Rice has many insect pests, mostly local, regional species, therefore no general recommendations can be made on spraying programmes.

Fungicides: Only a few fungal species occur in rice, but they can be harmful. Some of them are "universal" species (Blast, Brown), others are mostly restricted to regions of the Far East, so they are regional species (Frost, Dwart). The demand for fungicides is moderate, but there are areas where they are not used at all. Success has been achieved with breeding new varieties resistant to diseases, but the new rice varieties have not yet been widely used.

Herbicides: high requirements, as for maize. Large damages are caused by the aqueous weeds. Special "rice herbicides" have been developed and are used world-wide. They can control most aqueous weeds in other crops, too.

- <u>Millet, sorghum</u>: These are grown world-wide. They are related to maize. In some regions they are a substitute for cereals (Africa, eastern Asia), in others they are used as forage crops and industrial raw materials. Certain species can be used for sugar production (sugar sorghum).

These plants would need certain pesticides because they have their particular pests (mainly insects), but in practice pesticides are usually not applied. The reason is that in countries with developed agriculture they are not major crops but are mostly grown for forage. Therefore, the costs for pesticide would not pay be retrievable. On the other hand, in countries where they are grown as cereals, the agricultural production has not yet been intensified, and thus no chemicals are used.

Because weeds cause most damage to these crops, an increase in the consumption of herbicides can be expected.

- <u>Potatoes</u>: The plants are mostly grown in areas with temperate, oceanic climates. In these regions potatoes are a major part of the staplediet. Certain varieties are grown in countries with warm climates, but there are so many pests that the plants deteriorate within a couple of years, especially if grown in monoculture.

Pesticide demand is above average.

Insecticide demand: The most severe pest in all parts of the world and established everywhere is the potato beetle (Leptinotarsa decemlineata). This pest totally destroyed crops before successful control measures were applied. Most damages were observed in the warm areas of Europe, where the beetle has a high rate of reproduction. Similar damages are caused by the virus transmitting aphids. The potato is very sensitive to the various viral diseases which no chemical can control. The insecticide demand is rather high; in the major growing areas treatment has to be undertaken three to four times annually. Special insecticide has been produced specifically against the potato beetles (the Sevin - active ingredient: carbaryl). Very high quantities are widely.

Fungicide demand: above average, but the consumption is below that of insecticide. In the major growing areas one severe disease - the potato blight (Phytophthora infestans) - causes serious problems. At the beginning of the century it destroyed the whole crop in most growing areas. One or two sprayings are generally used and the haulm is destroyed at the end of the season with defoliants (e.g. Reglon). This treatment stops spreading of the disease. The probable attacks are forecast by warning systems.

Herbicide demand: Machines are used for weed control together with tillage work. Herbicides are used only in countries with highly intensified agriculture.

- <u>Sugarbeet</u>: These plants are grown in areas with temperate climates (cold and rainy weather) where sugarcane cannot be grown. Major growing areas are the same as for potatoes: Europe and North America, but also Africa.

Pesticide requirements are moderate, but lower than those for potatoes.

Insecticide demand: below average. The young crops (1-2 leaf stage) have several related pests which cause total damage in certain cases. Pests usually concentrate in spots. Various species of aphids cause the most severe damages, and they carry viruses. Sugarbeet is even more sensitive to viral diseases than potatoes. In the major growing areas, insecticide treatment is needed two to three times a year for the control of aphids and young insects. The virus sensitivity of the various varieties is different.

Fungicide demand: below average. No fungus can cause total damage. Yield losses are caused by three or four fungal species. Most damages are found on the leaves. Treatment is undertaken once or twice a year.

Herbicide demand: above average, and rather problematic for the growers because sugarbeet is highly sensititive to all herbicides and the slightest overdosage can result in phytotoxicity and depression of the yield. Specific products have been developed, recommended for use in mixture and following the method of split application (Betanal, Pyramin, NaTA, Goltix, etc.). Further agricultural techniques: mechanical hoeing, use of cultivators.

- <u>Sugar-cane</u>: This crop provides the major part of the world sugar production. It is grown in tropical regions (warm and rainy climate). Several varieties are known, and although the old ones are attacked by pests and fungi to a slight extent, the newly selected varieties are rather sensitive to insect pests. Pesticide requirement is below average in several parts of the world (Africa, some parts of Asia) and the crop is grown without the use of pesticides.

Insecticide demand: moderate. In highly intensified agriculture treatment is undertaken two to four times during a season. The harmful pests are soil insects: aphididae, Diatraea, Aeneolamia species.

Fungicide demand: minimal. The crop has some fungal diseases, but the infection does not exceed the threshold.

Herbicide demand: moderate. The crop has the ability of suppressing the broad-leaved weeds. Damages can only be caused by grass weeds, mostly the aqueous weeds (Rottboelia, sorghum, etc.). Herbicides are used in Cenbtral and South America, but not in Africa or Asia.

- <u>Oil-seed rape</u>: oil-crops of the cold, rainy zones. The pesticide requirement is moderate.

Insecticide demand: above average. A dangerous pest is the Athalia sp. able to cause total crop loss. But there are also several other insect pests. Treatment is needed two to four times a year in the major growing areas in North and East Europe. The last two treatments can be made by aerial spraying, as the ground machines cannot penetrate the crop rows.

Fungicide demand: there are several fungi, but fungicides are not used.

Herbicide demand: low, as the rape suppresses weeds. Damage can be caused by monocotyledonous weeds. 20 to 30 per cent of the growing area in the world is treated.

- <u>Fruits</u>: These crops have to be divided into three main groups according to the various regions because the modes of production, their values and their pests differ considerably:

- Deciduous fruit trees (apple, cherry, etc.);
- Citrus spp. (Mediterranean, round leaves);
- Tropical fruits (banana, pineapple, etc.).

Deciduous fruit trees - trees of the temperate zone; the growing period is adapted to the four seasons. They have many pests, therefore the demand of pesticides is very high. Its use is recommended in order to obtain high yields suitable for export.

Insecticide demand: high. In a moderately warm climate from 8 to 19 sprayings/year are recommended. To the north of these regions, the average number of the sprayings decreases to between 5 and 6, but still the need for insecticides is rather high. The rotation of the products is of great importance. Insecticides with different modes of action have to be used at different times of the season, e.g. during blossoming only special products (non-toxic for the bees) can be used; the various stages of growth of the pests need different levels of toxicity. Therefore a spraying programme has to be established for the treatment of orchards: the phenology of both plants and pests has to be considered and followed. It also varies for each geographical zone and for different fruits. Special expertise is required to work out such a programme.

Fungicide demand: high, because some fruits can be totally destroyed by fungi: apple scab (Venturia), powdery mildew (Podosphaera), and the Monilia which attacks all fruit crops. The control of fungal diseases also needs an adequate spraying programme. The timing of the spraying is an integral part of the control. The warning systems can forecast well the appearance of powdery mildew and scab. Depending on the weather, 7 to 8 sprayings are recommended to control fungal diseases in the temperate zone.

Herbicide demand: Only older plantations can be treated with herbicides without harmful effect; plantations younger than 4 years should not be treated.

The consumption of herbicides is rather low. Even in countries with highly intensified agriculture, only some 20 to 25 per cent of the plantations are treated in bands or stripes. Often lawns of forage crops are sown and cut between the rows of the orchards, and they are ploughed in as green manure once a year.

Citrus species: typical fruits of the Mediterranean region. As the epidermis is rather dense on the leaves, fewer pests are encountered than in the case of deciduous fruits.

Insecticide demand: is among the highest; treatment is recommended 4our to six times during one season depending on the occurrence of the infestation/ infection or the pests.

Most dangerous pest: fruit flies (Ceratitis), Lepidosaphes, Coccus, Planococcus species - their mere presence inhibits the exportation of the consignment.

Fungicide demand: 1-2 treatments depending on weather conditions, mainly to control Phytophthora citrophtova. Therefore the requirement is low.

Herbicide demand: generally no herbicide is used. Plants or simple lawn are sown between the rows and used as green manure.

Tropical fruits: These are the fruits of the tropical wet zones: banana and pineapple. The demand for pesticides is much lower than that of the deciduous fruit trees, but higher than that of the Citrus spp. The local varieties are grown without any use of pesticides because they are mostly grown in countries with no intensified agriculture. In areas with special plantations of high yielding varieties produced exclusively for export, pesticides have to be used. The pests and diseases of banana and pineapple are different:

- Bananas: The demand for insecticide is low, treatment has to be made the moment the pests appear. Major pests: Thripidae and Pentalonia species.

Fungicide demand: moderate, regular treatment is needed on large plantations four to six times during the season. Major fungi: Cercospora and Mycosphaera species.

Herbicide demand: generally no herbicide is used. Areas of double utilization: grass or useful crops are grown.

Attention has to be paid to special pests of bananas: they are nematodes which also attack other crop plants (sugarbeet, potatoes, grapes, etc.), but they cause the most serious damage in bananas.

Specific soil-disinfectants are used (they are considered by literature as insecticides, though they are nematicides).

- Pineapple: Pesticide demand is moderate, but higher than that of bananas. Insecticide has to be used only at the appearance of the pests. The major pests transmitting viral diseases: Disapis, Planococcus, Dismicoccus.

Fungicide demand: Treatment is recommended prior to planting for the control of Phytophthora. Thus the fungicide consumption is lower than that of bananas.

Herbicide demand: usually no herbicide is applied.

As far as the demand for pesticides for orchards is concerned, it can be concluded that it is by far the highest for the three groups mentioned because treatment is needed repeatedly during the season in order to suppress pests and carriers and to maintain export quality. In future, an increase in the consumption of pesticides for tropical fruits can be expected.

- Grapes: They have the highest demand for pesticides. For the control of fungal diseases regular treatment has been carried out for more than a century, thus these are the crops with the longest history of chemical pest control. It can again be pointed out that the ancient, so-called direct-yielding varieties are resistant to pests and diseases and can be grown without spraying. However, these growing areas have been significantly reduced all over the world and sensitivity of the established varieties is rather high. The objective of selection was resistance to fungal diseases and good results have been obtained, but grapes still cannot be grown without pesticides. The amount of treatment can, on the other hand, be reduced by 50 per cent.

Insecticide demand: high. Annually, treatment is needed six to tem times in a temperate climate. Major insect pests: grape berry moth (Clysia, Lobesia species) and grape aphids (Tetranychidae, Eriophyldae species).

Fungicide demand: higher than the demand for insecticides. There are two very dangerous fungi: Uncinula necator (powdery mildew) and Plasmopara viticola (downy mildew). They are spread world-wide.

For the control of powdery mildew special fungicides have to be used: sulphur or synthetic compounds (e.g. benomyl). Annually treatment is undertaken eight to tem times, but 12 to 16 sprayings may be recommended in rainy years. Less treatment is undertaken in zones with dry-warm climates (e.g. Tunisia, Algeria). The local varieties are less susceptible to diseases (species with thick skin).

Chemical control has to follow a well-organized spraying programme established according to local conditions. Short-term forecasts of powdery and downy mildew are regularly issued in countries with developed agriculture, and subsequently, the amount of treatment can be reduced in some years.

Herbicide demand: young plants (up to 4 years) are sensitive to herbicides and therefore only row or stripe treatment (in bands) can be made. Special equipment and formulations have to be used (e.g. Gramoxon, a.i. diquat). Herbicides are applied on 20 to 25 per cent of the European vineyards, in the others the soil is kept free of weeds by agricultural techniques: use of cultivators between the rows (ground machines are used). Green manure is often used. Thus the herbicide demand is low.

- <u>Cotton</u>: An important industrial crop of the countries with a warm climate. As its demand for rainfall is low, it can be grown in most zones of the dry, continental areas, but also in tropical regions. Pesticide requirements are high, because cotton is grown as an industrial crop aimed at the export market in most areas.

Insecticide demand: high, but lower than that of vineyards or orchards. The major pests are Heliothis and other species of Lepidoptera. The amount of treatment is determined by the local harmful fauna. In dry areas two to three, while in humid areas four to five treatments are made.

Fungicide demand: below average. Sprayings are made only in countries with highly intensified agriculture. Fungi are suppressed mostly by seeddressing.

Herbicide demand: low, but higher than that of vineyards and orchards. Cotton suppresses weeds, but plants resistant to herbicides are easily established (mainly monocotyledonous grasses). They are not easy to control. Herbicides are used on 30% of the growing area.

- Coffee, tea, cocoa: they are tropical, industrial crops. The demand for pesticides is moderate. They are basically grown in special plantations, in closed systems. The production level generally exceeds the average standard of agriculture in most of the countries, and accordingly pesticides are applied in 70 to 80 per cent of the total growing area. Coffee and cocoa have special harmful fauna causing enormous damages in plantations. In some cases, pests have reduced the whole production of certain countries (leaf weevil of cocoa in West and Central Africa, Hemileia vastatrix of coffee in South America, etc.). The use of pesticides would result in spectacular yield increases in these crops.

Insecticide demand: average in cocoa and tea plantations, but variable in different climatic zones, and low for coffee. During one growing period an average of three to four treatments are made.

Fungicide demand: average for coffee and cocoa, and low for tea. Necessary number of treatments: 3-4 for cocoa and 12 for coffee. No spraying is made for tea.

Herbicide demand: for the control of monocotyledonous weeds 20 to 25 per cent of the growing area is treated. Thus the demand is rather low.

4. COST EFFECTIVENESS OF PESTICIDE USE

4.1. Assessment methods

In order to evaluate the cost effectiveness of the use of pesticide with the methods described, several ways are open, depending on the source of the data input used:

- Statistical methods, using the data from available statistics, where the yields, production costs and pesticide costs are available, for different pesticide-use levels.

- Experimental methods, using the results of laboratory hothouses, small parcel or (very seldom) field experiments.

4.2. Statistical methods

There are no statistics which would give directly any relationship between pesticide use and its economic effects. This is understandable, since as we have seen, many factors, such as weather, pest occurrence, seed, agricultural methods, fertilizer use, etc., have a role in the crop results. When price fluctuations and exchange rates are also considered the picture becomes even more blurred.

Statistical methods thus do not allow a direct relationship to be drawn between pesticide use and its economic impact. However, the statistics are worked out using the average of a huge number of farms, and so it is worth trying to arrive at a useful conclusion using the available agricultural statistics.

In order to investigate the most important crop productions from this point of view, an overview of pesticide use on different crops has to be assessed.

4.2.1 The distribution of pesticide among different crops

Distribution of pesticide (all three main groups) among different crops shows that the seven crops outlined above account for 85 per cent of total pesticide use (Table 4.2.1). The first group - fruits and vegetables - use more than 25 per cent of the total, the next four around 10 per cent each.

Nearly half the fungicides are used for fruits, around 15 per cent for rice and wheat. The other four rarely use them, although they account for a share of over 20 per cent. Half the insecticide use is distributed nearly equally between fruits and cotton. Rice (17 per cent), maize (8 per cent) are also important, the remainder is not significant. Herbicide use is evenly distributed for maize, soybeans, wheat, rice and cotton.

4.2.1.1 Fruits and vegetables

Data used for Table 4.2.2 was taken from a statistical survey[3/]

3/ Dr. Balint Nagy: The economic basis of the plant protection development, Budapest, 1974.

covering a great number of users. The costs and incomes of two different kinds of agricultural farms were compared. The first was composed of state farms with a high agricultural level, working on great estates. The second includes the co-operatives, using more hand labour and less advanced methods on smaller farms. The specific production value, total specific production costs and specific plant protection costs are given in national currencies, for one hectare. It is apparent that for all fruits there is a very big difference in the values between the groups: the state farms realize a much bigger net return, but with a correspondingly higher cost level. In this case a direct relationship can be drawn between differences in plant protection costs and net returns. It is obvious that the much higher production costs also have their share in better results, but it is also clear that the higher yield would not have given the results obtained had it not been protected from pests in the first place. It can be assumed that the quality difference (pest-free products) has resulted in higher prices on the market which has, in turn, led to higher incomes.

In the last column of Table 4.2.2 an effectiveness factor E_1 was taken as the product value difference between state farm and cooperative divided by the plant protection cost difference between state farm and cooperative.

This factor varies between 1.27 and nearly 17 with an average value of 1.7. It would appear that a nearly twofold return of the higher and better plant protection corresponds to reality.

For all other crops in this study UNIDO made an analysis trying to establish a correlation between pesticide application and yield on the one hand, and economic efficency on the other, using statistical data from different sources (FAO statistics, Wood-Mackenzie, etc.). Efficiency was represented by the factor E_2"Net return". This factor was calculated by partial budgeting as the relative net return of pesticide application. The basis for the relative values were those of the country or region with the least pesticide use.

Table 4.2.1
Pesticide use for different crops
(Million US$, farm gate price, 1986)

	Herbicides			Insecticides			Fungicides			Total	
	M US$	% of all herb.	% of pest. for crops	M US$	% of all insect.	% of pest. for crops	M US$	% of all fung.	% of pest. for crops	M US$	% of total pesticides
Fruits and vegetables	1400.0	16.3	29.1	1625.0	26.6	33.8	1780.0	43.4	37.0	4805.0	25.6
Rice	905.0	10.5	35.0	1040.0	17.0	40.2	640.0	15.6	24.8	2585.0	13.8
Maize	1545.0	18.0	73.9	490.0	8.0	23.4	55.0	1.3	2.6	2090.0	11.1
Cotton	400.0	4.7	19.9	1540.0	25.2	76.6	70.0	1.7	3.5	2010.0	10.7
Wheat	1220.0	14.2	63.9	140.0	2.3	7.3	550.0	13.4	28.8	1910.0	10.1
Soybean	1500.0	17.4	85.5	175.0	2.9	10.0	80.0	2.0	4.6	1755.0	9.3
Sugarbeat	490.0	5.7	66.7	185.0	3.0	25.2	60.0	1.5	8.2	735.0	3.9
Others	1140.0	13.3	39.2	905.0	14.8	31.1	865.0	21.1	29.7	2910.0	15.5
TOTAL	8600.0	100.0		6100.0	100.0		4100.0	100.0		18800.0	100.0

Source: Wood-Mackenzie

Table 4.2.2

FRUITS

Specific production value, production costs, plant protection cost and net returns in state farms and cooperatives in Hungary

(1966) (Ft/ha)

FRUIT	PRODUCTION VALUE		PRODUCTION COSTS		PLANT PROTECTION COSTS		NET RETURN		E*
	State Farm	Cooperative	State Farm	Cooperative	State Farm	Cooperative	State Farm	Cooperative	
Apples	20,233	7,200	15,259	4,293	3,549	1,920	4,974	2,907	1.27
Peaches	16,668	6,800	5,224	5,800	1,441	826	11,444	1,000	16.98
Apricots	6,962	4,420	3,945	2,850	1,421	299	3,017	1,570	1.29
Plums	20,080	12,000	6,184	3,800	1,794	1,366	13,896	8,200	13.31
Average	15,635	8,133	9,926	4,235	2,154	1,098	5,709	3,898	1,71

$$E^* = \frac{\Delta \text{ Net return}}{\Delta \text{ Plant protection costs}}$$

4.2.1.2. Wheat

Figures 4.2.1 and 4.2.2. and Table 4.2.3 give the yields and pesticide use figures for the four leading regions and the rest of the world. Insecticide use is very small and therefore no regional data were found. Therefore, the column of total pesticide use for the individual regions gives values without the, while the line "world" includes them.

As can be seen, all the regions use less than US$10 pesticides/ha, except Western Europe, where this figure is over US$60. Correspondingly, the yields are approximately 2 t/ha; in Western Europe more than double this yield is obtained. More intensive farming, better seeds and more fertilizers also contribute to this result, but it is clear that in this case the cost effectiveness is above doubt. The E_2 factor has a value of nearly US$300 which would give a fivefold return on pesticide use if the other factors were neglected. Assuming a 33 per cent share of the pesticides in the results, a net return of 1.5 times the costs would result. A 50 per cent share gives a net return of 2.5 times the costs..

In Figure 4.2.2 we have taken the minimum of pesticide use as a basis. Consequently, in some regions where more pesticides are used, negative returns occur. It is obvious that in these regions the yield would be even lower, should less pesticide be used. The various other factors (climate, soil, etc.) explain these efficiency differences.

Figure 4.2.1

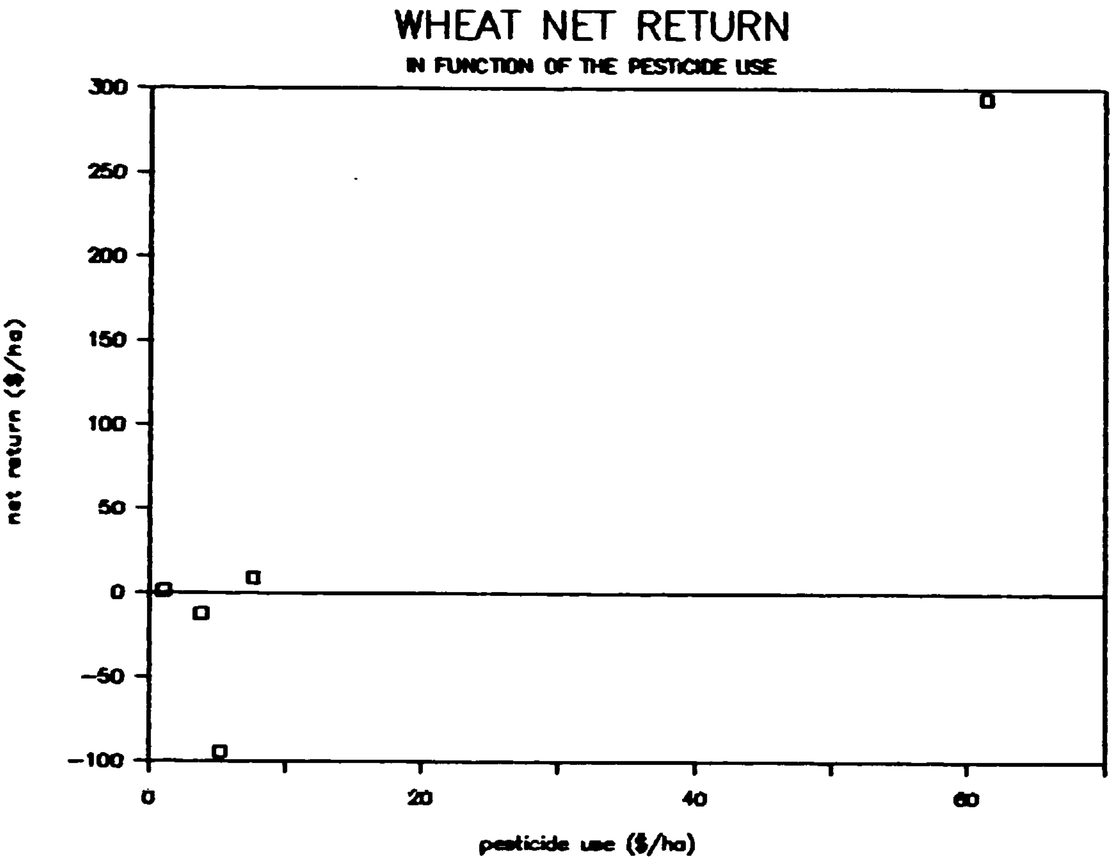
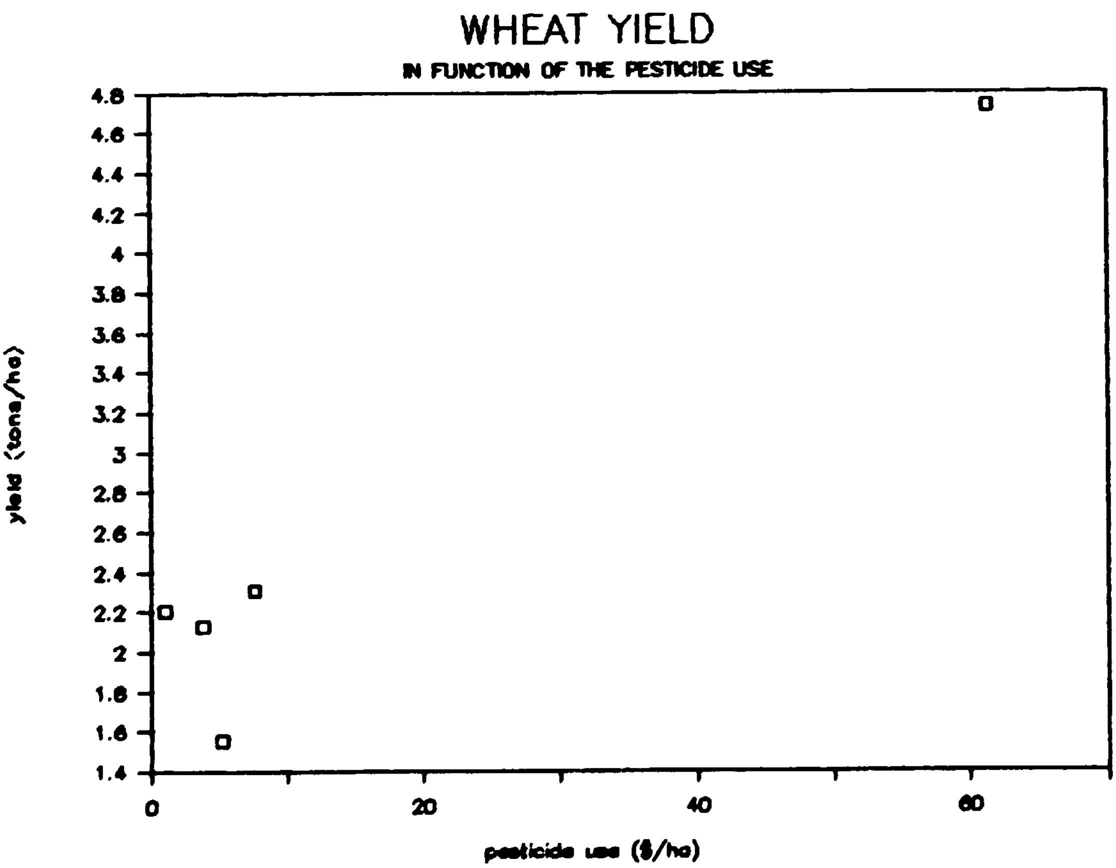


Figure 4.2.2



<u>Table 4.2.3</u>

WHEAT
<u>Yields, pesticide use, effects</u>
(specific values, 1987)

COUNTRY	YIELD t/ha	HERB $/ha	INSECT. $/ha	FUNGI. $/ha	TOT.PEST. use $/ha	E_2
Western Europe	4.7	35.7		25.6	61.3	294.2
North America	2.3	6.9		0.7	7.6	8.4
Eastern Europe	2.1	3.2		0.6	3.8	-12.7
Asia	2.2	0.7		0.3	1.0	0.0
Rest	1.6	4.1		1.2	5.3	-94.7
World	2.3	5.5	0.6	2.5	8.7	94.6

E_2 = net return (variable)
$E_2 = \Delta$ product value $- \Delta$ total pesticides use

4.2.1.3 **<u>Maize</u>**

In maize production, fungicide use is negligible, as can be seen from the last line of Table 4.2.4. Here also no data on the regional distribution were available. Thus the total values of the regions do not include use of fungicide but merely the world total.

<u>Table 4.2.4</u>

MAIZE
<u>Yields, pesticide use, effects</u>
(specific values, 1987)

COUNTRY	YIELD t/ha	HERB $/ha	INSECT. $/ha	FUNGI. $/ha	TOT.PEST. use $/ha	E_2
USA	7.5	36.3	9.1		45.4	570.8
Europe (incl. USSR)	4.7	21.8	7.3		29.1	306.7
Brazil	1.9	2.7	1.6		4.3	47.2
Rest of America	2.3	4.2	0.9		5.2	91.6
Africa	1.4	2.9	1.1		4.0	0.0
China	3.9	3.9	3.0		6.9	243.7
Others	1.6	5.5	2.4		8.0	19.4
World	3.6	12.4	3.9	0.4	102.8	120.6

As can be seen from Table 4.2.4 and Figures 4.2.3 and 4.2.4, five of the seven regions use pesticides with a value of less than US$10/ha. The yield in four of them is around 2 t/ha. China is an exception with nearly four tons per hectare in spite of the very low pesticide consumption (US$6.9/ha). Europe with nearly US$30/ha pesticide use, arrives at 4.7 t/ha yield, while the USA using one and a half times more pesticides than Europe, has the benefit of a correspondingly higher yield.

If we omit China, the relationship between pesticide use and yield is quasi linear. The special case of China can be explained by the use of extensive manual methods both in weed and insect control. The high values of E_2 (calculated as before) show how cost-efficient is the use of pesticides. The statistics and the analysis confirm the fact well known among farmers that with the modern high-yield seeds only a high level of pesticide use can lead to sound agricultural and economic results.

Figure 4.2.3

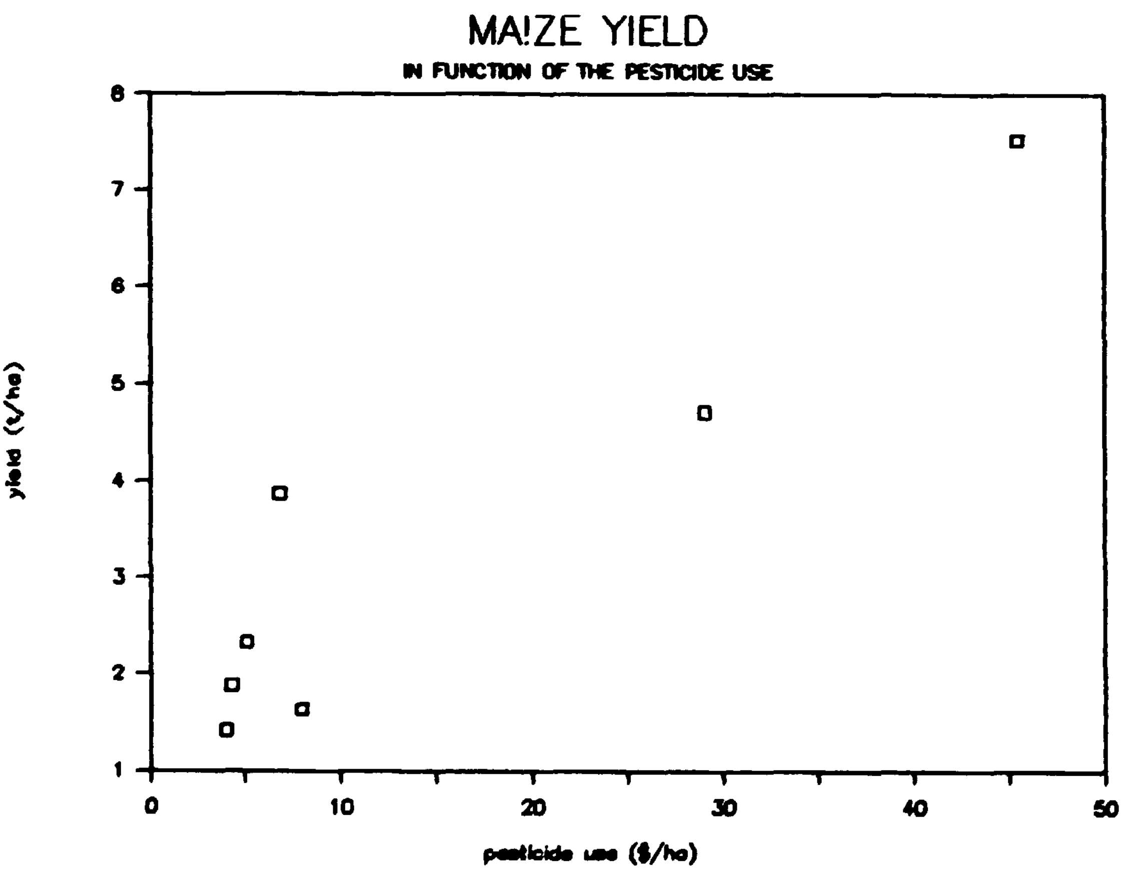
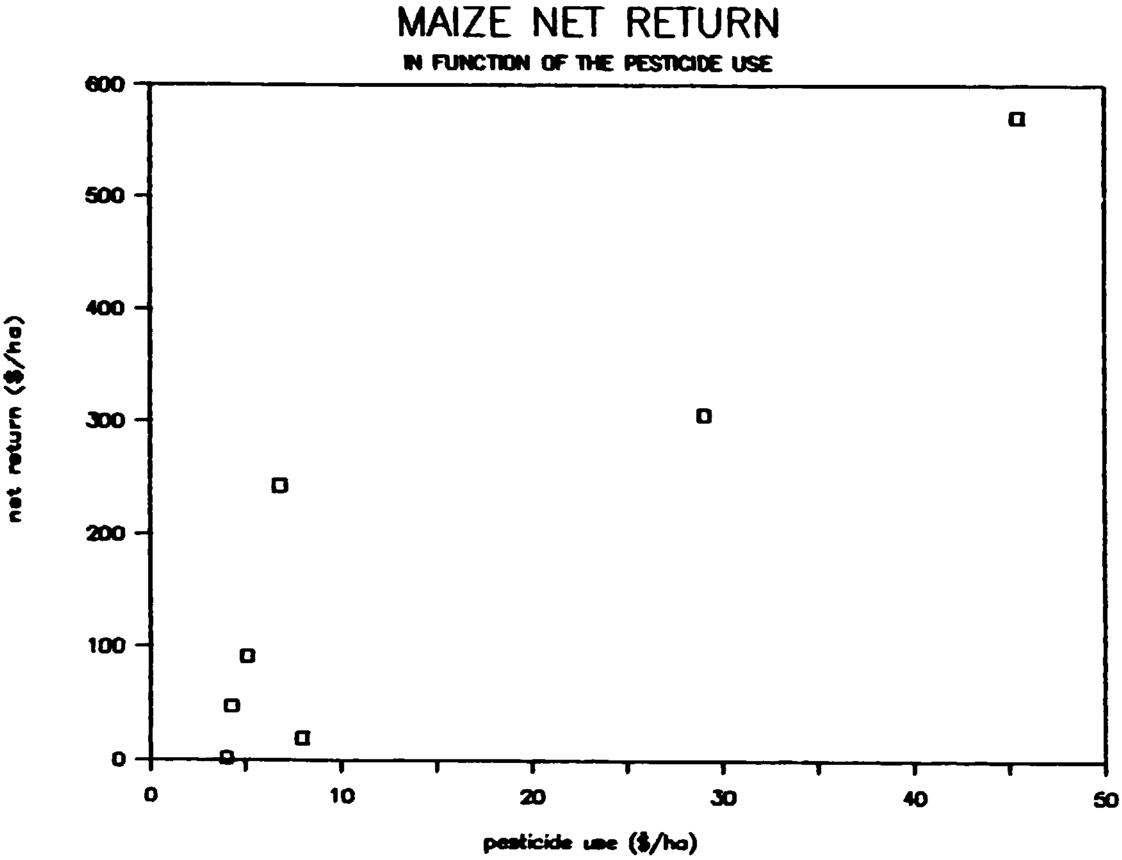


Figure 4.2.4



4.2.1.4 Soybeans

Practically only herbicide is used. The two other pesticide groups together represent less than 15 per cent of the total plant protection agents. Therefore, here, as in the previous cases, the less important pesticide groups are omitted.

Out of the seven countries under study three are obtaining yields over 2 t/ha: Canada, USA and Argentina. The corresponding pesticide uses are: over US$70/ha, under US$50/ha and over US$15/ha. Of the other countries, that with the lowest yield (0.7 t/ha) is India with only US$8.6/ha pesticide application.

Table 4.2.5

SOYBEANS

Yields, pesticide use, effects
(specific values, 1987)

COUNTRY	YIELD t/ha	HERB $/ha	INSECT. $/ha	FUNGI. $/ha	TOT.PEST. use $/ha	E_2
USA	2.3	44.7			44.7	159.3
Brazil	1.8	15.5			15.5	67.5
China	1.4	6.0			6.0	4.7
Argentina	2.1	15.9			15.9	150.3
India	0.7	8.6			8.6	-153.4
USSR	0.9	25.6			25.6	-130.2
Canada	2.4	71.1			71.1	164.7
Others	1.5	26.4			26.4	6.8
World	1.9	28.3	3.3	1.5	33.1	242.4

Otherwise, the picture is rather erratic, China has much higher yields (1.4 t/ha) than India, but with somewhat less pesticide. The USSR uses more herbicides, but the yield is lower. Brazil and the remaining countries are somewhere in the middle.

Since here only herbicides are used which can be substituted by hand or mechanical weed control it would be necessary to have the labour and machine costs for those countries where - as we suppose - such methods allow these yields above the corresponding pesticide application level. But both the yield responses and net returns (Figures 4.2.5 and 4.2.6) (partial budget) show that very high yields and returns can only be achieved by appropriate pesticide application.

The negative values for E_2 come from the same source as explained for wheat.

Figure 4.2.5

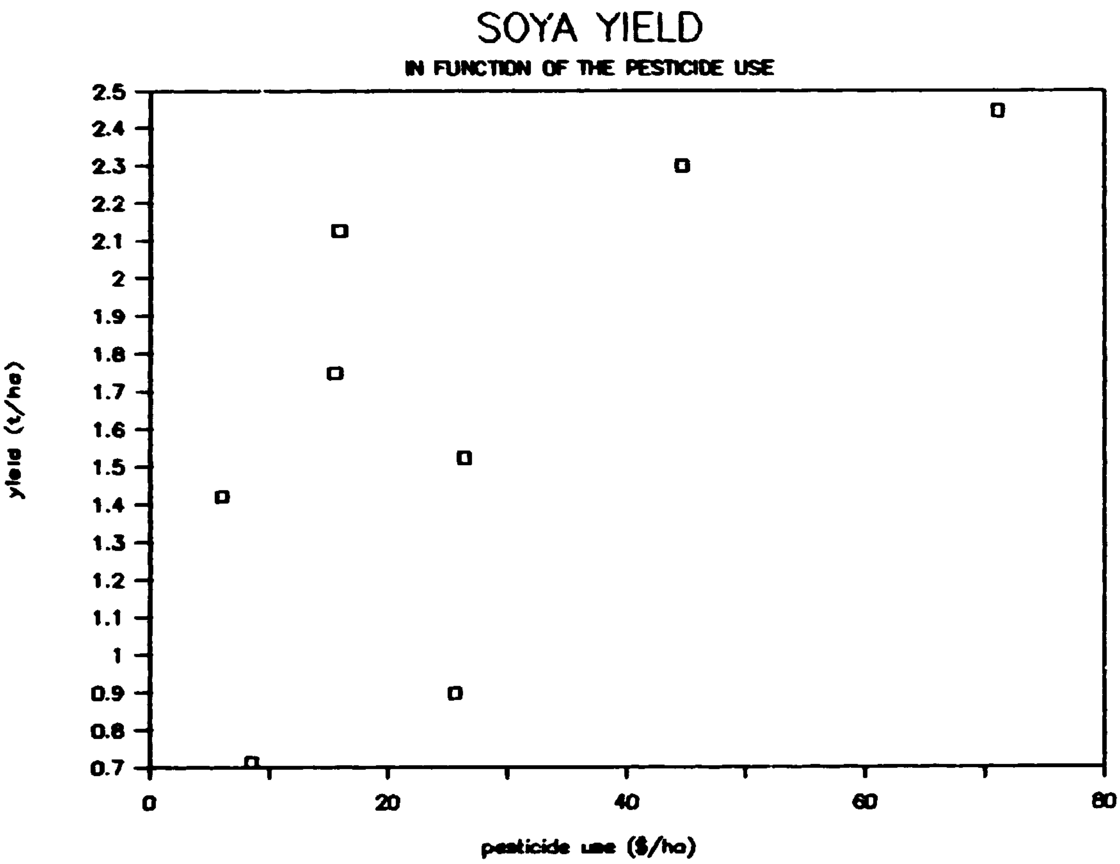
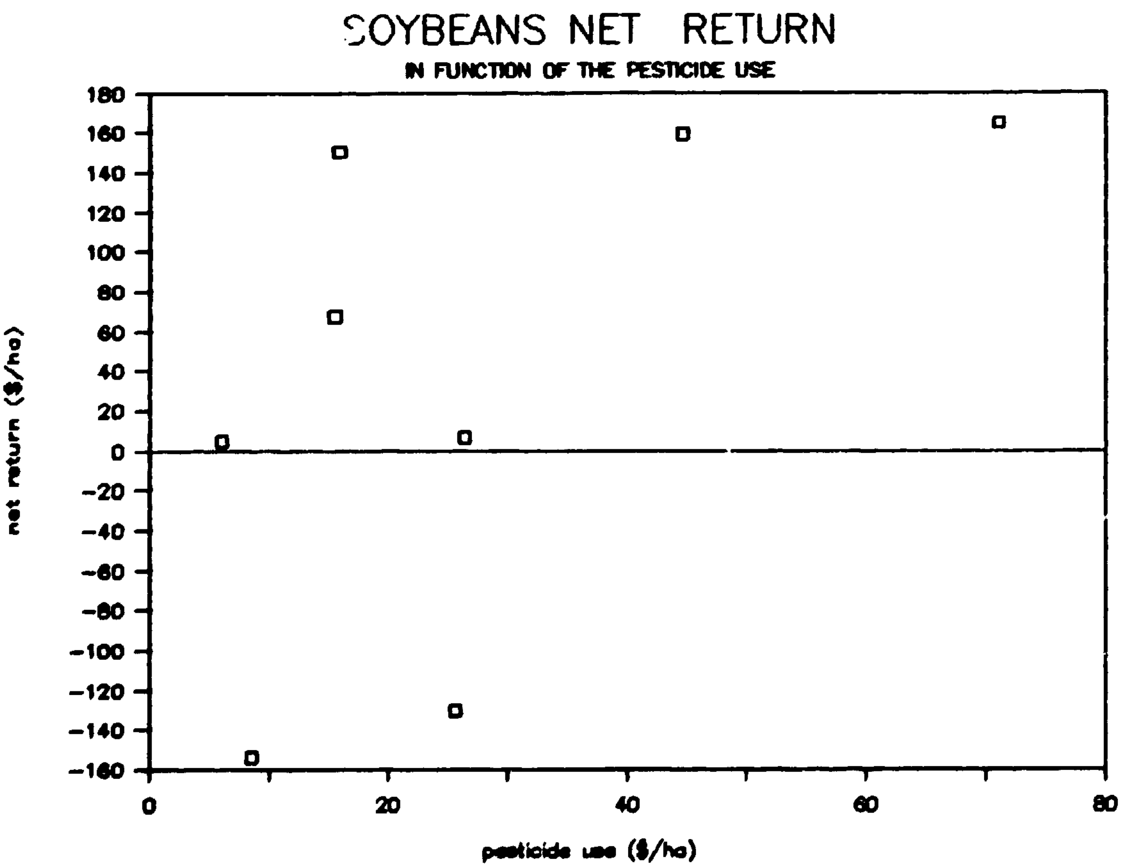


Figure 4.2.6



4.2.1.5 <u>Rice</u>

The statistics for rice include data from 13 countries or regions. The analysis, however, is inconclusive. It is true that the highest yields (over 6 tons/ha) are connected to high pesticide use (over US$80/ha) and that most of the countries using less than US$[illegible]0/ha have yields of less than 3 tons/ha. On the other hand, China could achieve 5.4 t/ha with US$6.2/ha pesticide application, and between the three leading countries with less than 10 per cent difference in yield, there is a sevenfold difference in pesticide use. So neither Table 4.2.6, nor Figures 4.2.7 and 4.2.8 can give useful information by themselves for the cost effectiveness of the pesticides. Only closer investigation, taking into account the local conditions (pest infection level, climate, seeds, agricultural methods) could define the economic relationship between return and pesticide expenses.

<u>Table 4.2.6</u>

RICE
<u>Yields, pesticide use, effects</u>
<u>(specific values, 1987)</u>

COUNTRY	YIELD t/ha	HERB $/ha	INSECT. $/ha	FUNGI. $/ha	TOT.PEST. use $/ha	E_2
India	1.8	0.4	2.8	0.4	3.6	1.7
China	5.4	0.7	3.9	1.5	6.2	792.8
Bangladesh	2.1	1.2	3.9	1.0	6.1	65.2
Indonesia	3.9	1.4	3.1	1.1	5.6	464.0
Thailand	1.9	1.4	3.0	1.1	5.5	15.9
Brazil	1.6	3.8	4.0	0.8	8.7	- 45.4
Vietnam	2.6	1.9	2.6	0.9	5.4	165.7
Burma	2.8	2.2	2.0	0.8	5.1	208.6
Philippines	2.6	4.2	7.6	2.1	13.9	167.0
Japan	6.0	268.2	209.1	206.8	684.1	253.5
Republic of Korea	6.3	20.8	47.5	45.0	113.3	887.6
USA	6.4	64.4	23.3	3.3	91.1	934.3
Europe	4.7	54.0	30.0	3.0	87.0	554.6
Others	2.6	2.4	4.1	0.7	7.2	164.4
World	3.1	6.4	7.3	4.5	18.3	325.6

Figure 4.2.7

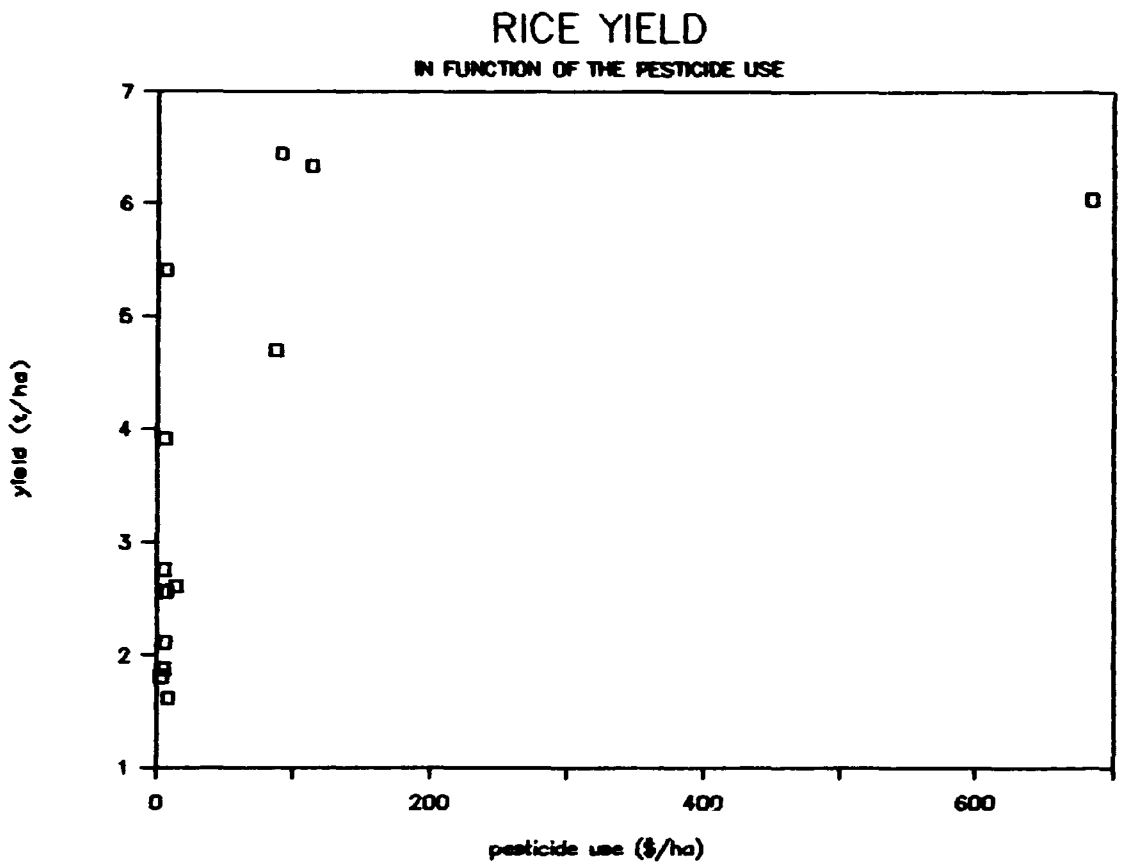
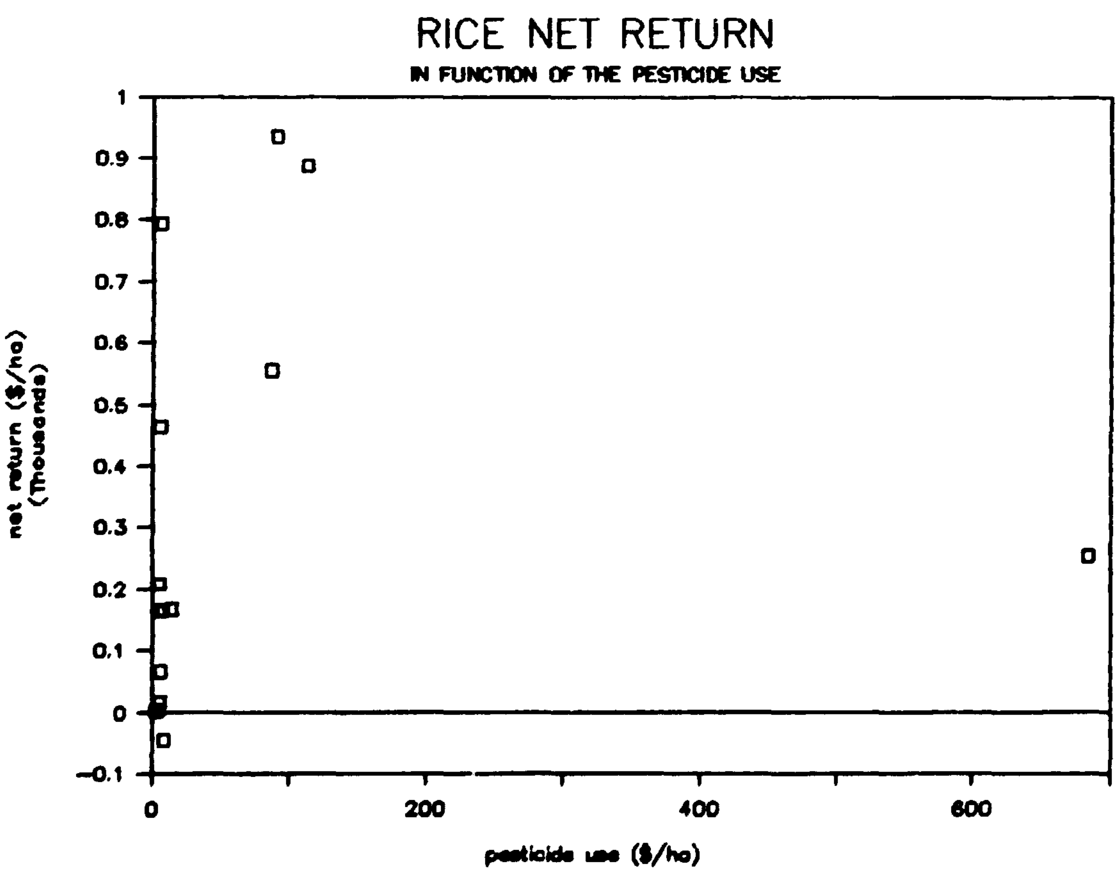


Figure 4.2.8



4.2.1.6 Cotton

Cotton is the least satisfactory crop. First of all, with this product, widely different qualities are produced with prices varying from US$1000/t to nearly US$4000/t. It was not possible to obtain detailed quality and price structure data, so an analysis taking into account these factors could not be made. However, if the data for China and Pakistan are ignored, an approximation of the remaining points can be made with an ascending straight line on Figure 4.2.9 having a slope of 50 kg/US$10 pesticide use. An average price of US$2000/t has been used which would give a return ten times the incremental pesticide costs.

A similar picture is shown in Figure 4.2.10. Evidently, the result cannot be attributed to pesticides only, but even if only 40 per cent of the effect were due to the plant protection, this would give a fourfold return.

Table 4.2.7

COTTON
Yields, pesticide use, effects
(specific values, 1987)

COUNTRY	YIELD t/ha	HERB $/ha	INSECT. $/ha	FUNGI. $/ha	TOT.PEST. use $/ha	E_2
India	223.3	0.5	20.7		21.2	0.0
China	816.7	1.3	40.6		41.9	1166.1
USA	723.8	32.0	65.0		97.0	925.1
USSR	767.6	30.6	86.8		117.4	992.5
Pakistan	532.0	3.2	26.0		29.2	609.4
Brazil	313.0	10.4	26.1		36.5	164.2
Others	502.7	16.8	68.0		84.8	495.1
World	528.8	12.5	48.1	2.2	62.8	6067.4

Figure 4.2.9

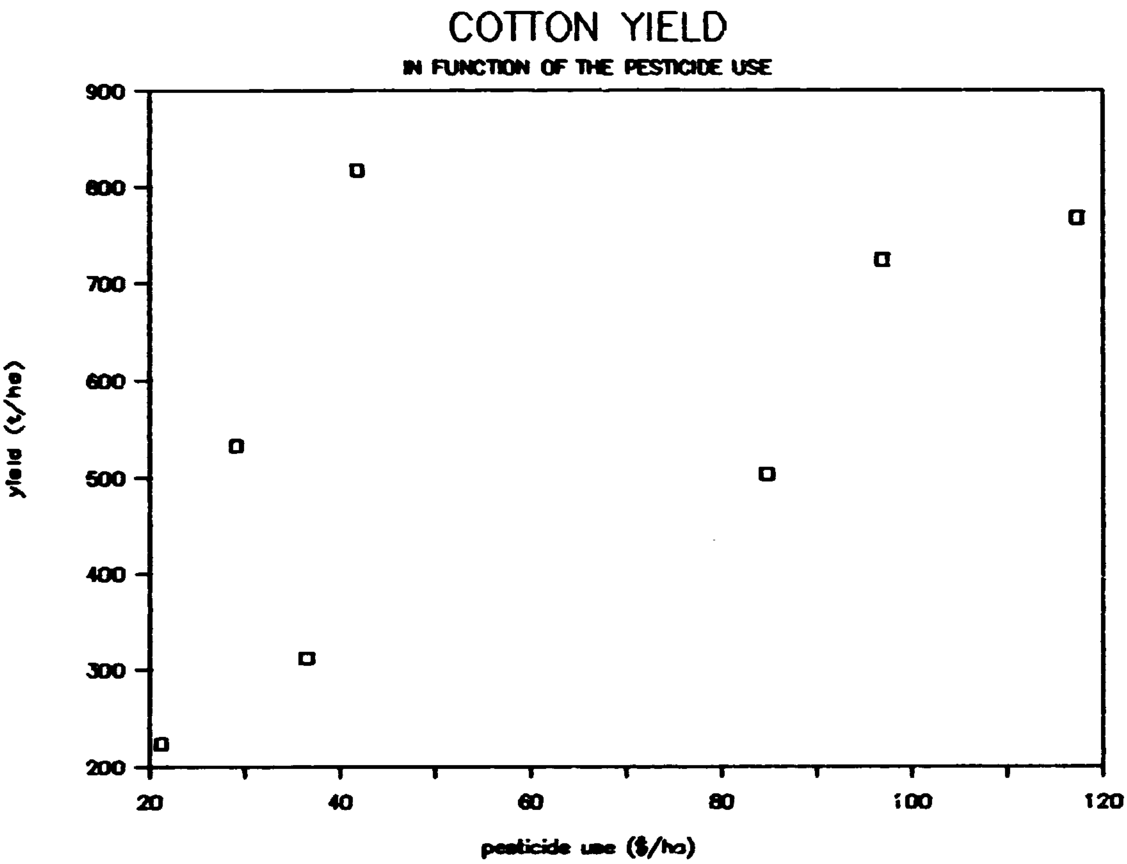
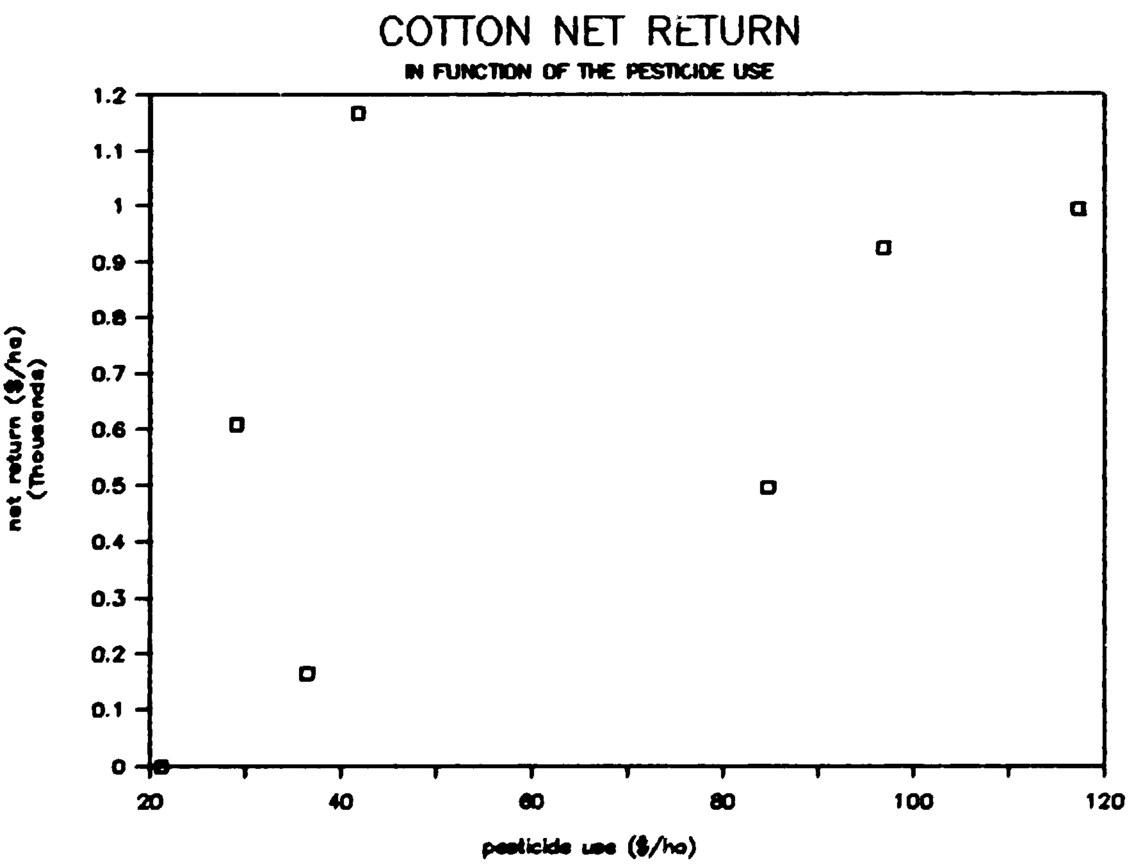


Figure 4.2.10



4.3 Experimental methods

Theoretically the simplest and most reliable method of the economic assessment of pest control methods is derived from experiments. Laboratory, hot-house and field experiments should give a clear answer to all questions. Unfortunately, this is not the case for the following reasons:

- Experiments are always specific: they give useful results only for the specific conditions of the experiment: soil, climate, seed, planting time, actual weather conditions, actual pest infection level, etc. If many experiments were conducted over a number of years in a scientifically designed project covering all possible specified conditions, a relationship could be established between the economic results and the pesticide use under the different conditions. Unfortunately, no such work is known to the writer for any crop or pesticide application.

- Experiments described in literature always refer to specific conditions difficult to implement under other circumstances. They nearly always give very limited information. Usually only the pesticide quantity and application frequency are given, together with the effect on the pest population or the effect on pest damage. On a few occasions crop results are also given (only in quantity, seldom with some information on quality), but information on the cost or crop values is seldom available.

In view of this situation, methods have been devised to arrive at an estimation of the cost effectiveness from the available experimental information. A typical example illustrating the cost effective analysis follows.[4/]

Cost effective analysis

Table 4.3.1 shows some data collected from an experiment designed to compare granular and spray insecticides against early-season bean fly on mung bean. The various insecticides tested have different effects on bean fly and also have different costs associated with their use. In order to compare their relative cost-effectiveness, a common unit measurement of effectiveness per dollar spent must be devised. Without yield/quality data to place a value

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4/ K.H. Reichenfelder, G.H. Carlson, G.A. Norton. Economic Guidelines for crop pest control. FAO plant production and protection paper 58, 1984.

on effect, it is assumed that as bean fly numbers or the percent of mung bean plants infested increases, yield will decrease by the same proportionate amount. (Assumption of linearity).

Table 4.3.1 shows that bean fly infested an average of 57 per cent of the mung bean in the untreated plots. A two-thirds reduction in the proportion of plants infested would imply that only 19 per cent of mung bean plants are infested (57 minus two thirds of 57 = 19). Which of the materials will achieve at least cost this two thirds reduction from the untreated infestation at given use rates? At a dosage of 0.5 kg active ingredient/ha costing US$15.30/ha, carbofurane SG reduces the infestation level from 57 to 30 per cent at a cost of US$15.3/ha. The cost to reduce the infestation level from 57 to 19 per cent, is:

$$\frac{\text{US\$15.30 (57-19)}}{\text{(57-30)}} = \text{US\$21.53}$$

For carbofurane at twice this dosage, its costeffectiveness for a two-thirds reduction in infestation is:

$$\frac{\text{US\$30.60 (57-19)}}{\text{(57-24)}} = \text{US\$35.24}$$

The equivalent calculation for monocrotophos use is:

$$\frac{\text{US\$16.00 (57-19)}}{\text{(57-10)}} = \text{US\$12.94}$$

A comparison of the results of the three calculations shows that monocrotophos costs least for achieving the specified bean fly control objective. Given the assumption of linear damage, it is the most cost effective material tested.

A note of caution: The use of the cost effectiveness analysis ignores the possibility that the pest-damage relationship is non-linear. When data on the benefits of pest control are available, more accurate analytical techniques should be used. However, when these data are unavailable, cost-effective analysis is better than no analysis and does provide a strong clue as to which of a range of tested alternative practice is most likely to give the highest net economic returns.

Table 4.3.1
Comparison of granular and spray insecticides against bean fly on pre-flowering mung bean grown after flooded rice*)

Insecticide	Dosage (kg a.i./ha)	Number of applications	Insecticide cost ($/ha)	Bean fly larvae plus pupae 21 days after emergence (no./125 plants)	Percent infested plants 21 days after emergence
Carbofuran 3G	0.5	1	15.30	1.5	30
Carbofuran 3G	1.0	1	30.60	1.2	24
Monocrotophos 16.8EC	0.25	2	16.00**)	1.0	10
Untreated	-	-	-	4.2	57

*) From Litsinger, J.A., M.D. Lumaban, J.P. Bandong, P.C. Pantua, A.T. Barrion, R.F. APostol, and Ruhendi. (198) "A Methodology for Determining Insect Control Recommendations", IRRI Research Paper Series, Number 46. The International Rice Research Institute. Manila, Philippines. January 1980.

**) A modification of data from Litsinger et al.

The individual experimental results should be evaluted with this or some similar method. Since the data available always have only local value and the evaluation methods give only relative comparison between different pest control methods, the experimental field will not be further elaborated. It should be underlined that experiments are absolutely necessary and give valuable information on pest control methods to be actually adopted.

It is also evident that a programme aimed at an experimentally supported evaluation of the pesticide application in function of the different influencing factors would be extremely useful. The cost involved and the continuous evolution in the pesticide practices will probably postpone the realization of such a programme for quite some time.

5. INDIRECT COSTS OF PESTICIDE APPLICATION

The effect of pesticide is not restricted to the pests and the plot treated. Other effects must also be taken into consideration as follows:

- contamination of the food chain,
- phytotoxicity to the plant,
- damage to the plants caused by the application process,
- persistency and effect on other crops,
- drift and phytotoxicity to other crops,
- resistance inducing effect,
- health damage to the workers,
- environmental pollution.

Contamination of the food chain is not allowed. Registration procedures exclude such compounds from use. That is the reason why DDT, a most powerful insecticide was banned in most countries.

Phytotoxicity to the plant, damage caused by the application process and equipment is of minor importance, otherwise the product would not be used. This minor effect is already taken into account when statistical methods are used, since only the net crop yield increase is accounted for. In small-scale experiments, this factor must be entered separately into the calculation (e.g. spreading equipment wheel damage), but usually this effect is small compared to the accuracy of the method.

The persistency of some pesticides is a serious matter which has to be taken into consideration if different crops are to be planted successively. Triazine type herbicides, for instance, used for weed control in maize will cause significant damage if wheat is sawn on the same plot in the following year. Others are harmless as they decompose in a short time. This is an important agrotechnical factor which must be considered in the overall planning of farming. This means that such damages should be avoided and that their effects should not enter into the economic evaluation.

Drift and phytotoxicity to nearby crops is another matter for proper pesticide application policy, together with resistance-inducing effects. The pesticide application policy cannot be restricted to one farm. The best plant protection methods will be seriously hampered if limited to a single user. Infection from nearby fields can either considerably reduce the effect of the protection or unduly increase the costs and efforts needed. On the other hand, when selecting the products and application methods appropriate consideration should be given to regional interests: formulations with little or no drift, choice of wind-free spraying time in order to avoid damage to neighboring farms.

With time some pests become resistant to a given pesticide. Therefore, co-ordinated action is necessary in a given region otherwise some farmers will try to protect the plants with ineffective products. All these factors must be considered in planning the pesticide application policy; however, the consequences of an ineffective or non-application policy cannot be entered into any economic analysis.

The same must be emphasised for the health and environmental effects. The practice of many farmers and countries has clearly demonstrated that with proper methods all such hazards and damages can be prevented. All the casualties and environmental pollution cases are the result of human carelessness and non-compliance with the established rules and prescriptions. It would therefore not only be improper but counterproductive if instead of fighting for their elimination, the economic consequences of such defaults were taken into account.

Another matter is education and training. The best way to avoid and prevent any damage to health, property, environment or crops, to reduce hazards and secure good economic returns, is to teach what, how and when to apply for a given plant protection task. The costs of education, training, and information dissemination are very important and form an integral part of the pesticide application costs. One part of this work is done by the pesticide manufacturers and distributors. This cost is included in the price of the product and thus enters automatically into the economic evaluation. Another part is done by the national and international organizations (e.g. FAO) and is usually given free with the costs involved covered from other sources. They are therefore difficult to assess. Here the situation is similar to all other cases where education and training are important: the costs involved are not usually accounted for where the efficiency of the process is calculated.

6. EVALUATION OF AVAILABILITY OF PESTICIDES IN DEVELOPING COUNTRIES

To cover its pesticide demand, a developing country has to consider the following possibilities:

- import of formulated products;
- domestic production of active ingredients,
    - a) generic products,
    - b) under licence,
    - c) based on own research.

First the possibilities, conditions, advantages and problems associated with each route will be reviewed.

6.1 Import of formulated products

This route would seem to be free of problems since pesticides are easily available on the world market. Without considering the obvious problem of hard currency limitations, there are other serious ones to be solved, even in the case of imported products, i.e. registration, transport, storage, handling, distribution, marketing and application. The solutions need important inputs in education, training, materials and equipment. The hazardous nature of these products makes it mandatory to establish a network capable of handling safely the products all along the route - from the entry into the country to the site of final application. Every person and organization involved must get acquainted with the knowledge necessary not only for their own work, but also for the advisory and advertising activities needed. Stores, packaging materials, application equipment must be provided, the collection and safe disposal of the empty packing materials, sacks, drums, etc., must be organized.

A slight variation of this route is represented by local packaging, which in reality can be the first step towards domestic manufacturing. Although this is already a real advance over merely importing the necessary products, it poses no big new challenges beyond those caused by normal handling and application. Small packaging plants are simple and inexpensive but the personnel needs basic skills in pesticide operation.

6.2 Import of active ingredients and domestic formulation

This step requires formulation plant(s) only. These can be installed step by step. For a small individual formulating plant with a capacity of a few thousand tons per year the prerequisites are not demanding: little plot area is needed with low utility requirements. A small number of skilled workers and a few white collar people can run such a plant. All carriers, fillers, solvents and adjuvants used in large quantities can at least be partly provided from domestic sources if the necessary R+D work has justified their use for the registration. The advantages are lower foreign currency expenses, lower transport costs, higher domestic added-value, work places, industrialization of the country. The know-how usually comes from the producer of the active ingredient, so it is obviously of advantage for all developing countries to take over the formulation of the pesticides used gradually, as the market requirements allow and the prerequisites can be provided. Experience shows that this activity should be adjusted to the real market possibilities and to the limits set by competitivity. In several developing countries where this condition was disregarded, only a fraction of the existing formulation capacity is utilized.

6.3 Domestic production of active ingredients

The pesticide industry is now entering into a phase when the first main group of products becomes generic. Although the patent owners make every effort to conserve their proprietary position by means of new patent modifications and other methods, more and more valuable pesticides can be produced by newcomers without patent restrictions.

Active ingredients are produced from organic intermediates by rather complex organic synthesis methods and usually involve, besides the end-product required, by-products in various quanitities. It is therefore necessary for the implementation of pesticide production that a sufficiently developed organic chemical industry should already exist in the country. This industry would be capable of:

- delivering, at competitive prices, the most important intermediates and raw materials necessary for manufacturing pesticides. In principle, import of raw materials would also be feasible, but in some cases the key intermediates are hard to procure;

- providing the necessary industrial background from where skilled workers, engineers and managers with sufficient experience can be recruited and whose help can be obtained in case of problems. This background includes not only the industrial sector itself but also the connected scientific basis (universities and/or research institutions) which can give answers to the problems inevitably surfacing in all phases of this work, such as investment, operation, and development;

- absorbing in an economic manner the by-products of pesticide manufacture for other industrial purposes, and thus rendering the pesticide manufacturing competitive.

Another important and indispensable condition is the existence of a well-trained and reliable research organization capable of performing all the tests required for the registration procedure. All products, even those imported, must go through anew at least a part of the registration procedure when manufactured domestically.

Independent development of a generic drug raises no legal problems. The process, however, must undergo a reduced research cycle, the reduction depending on the experience and expertise available. Some laboratory, or pilot and/or full-scale experiments may be necessary.

6.3.1 Manufacturing under license

Manufacturing under license involves negotiations to procure the manufacturing rights without too many limitations both in territorial, technical and commercial conditions, and at a price allowing sufficient margin to make the operation profitable. On the other hand, process implementation and technical/operational problems become very easy and the licensor usually helps in the marketing and application work. The UNIDO study on License Agreements in the Petrochemical Industry can give substantial support to the developing countries in this respect.

6.3.2 Products based on domestic research work

The development of new active ingredients is a very demanding task, quite different from the previous ones. The efforts to be deployed, the means to be mobilized are higher by several magnitudes. The process of research and development is very similar to that of the new drugs. It is not only time-consuming (ten to fifteen years), and capital intensive (US$5 to US$25 million for a new molecule), but needs a very high level of scientific and technical background. All in all, the biggest difficulty for the developing countries to reach this stage is not the high scientific and technical level, but the necessary capital and time to go through the registration process finally leading to a marketable product.

7. CONCLUSIONS AND RECOMMENDATIONS TO THE DEVELOPING COUNTRIES

7.1 Conclusions

A. The knowledgeable and appropriate use of pesticides for plant protection is a technically and economically advantageous method to raise the yields and quality of the crops and thus to help the developing countries in solving their food and foreign currency problems.

B. Pesticide application is an integral part of the agricultural method used. To be efficient and economical it must be co-ordinated with the crop, seed, fertilizer, and other production factors, as well as with the local conditions.

C. Pesticide application is not an individual decision of each farmer; its use should be co-ordinated within the country at the regional level so as to arrive at higher efficiency.

D. The side effects of pesticide utilization can be prevented by proper educational training and discipline.

7.2 Recommendations

A. Economic effectiveness of pesticide use underlines the necessity to extend its application rate in most developing countries and to raise their share in global consumption in order to contribute to the solution of the food problem. Governments should include in their agricultural development programmes measures to be taken to this effect. International organizations should give due priority to the programmes aimed at this purpose.

B. Pesticide use in the developing countries should be based on integrated pest control methods at national or regional levels giving the best economic and agricultural return. Co-operation at the regional level should be aimed at for this purpose.

C. Pesticide application should be integrated into the general framework of modern agricultural methods to be introduced. The synergetic effect of fertilizers, improved seeds, water management and other appropriate methods, on yields and economic results makes the integrated approach mandatory.

D. Direct involvement of farmers in the pesticide application as well as in other modern agricultural methods should be promoted through the use of different tools, such as farmers' associations or co-operatives formed for this purpose.

E. Registration rules and procedures should be created or further improved along the lines set by the FAO recommendations. Identical principles should govern the registration or the banning of products for pesticide use in all countries in order to protect human safety and environment. International co-operation between countries and interested international organizations is needed in this field.

F. Training courses and other educational methods should be used to improve the knowledge of all those involved in the pesticide application chain. Cost effectiveness, agricultural yield and all safety aspects depend to a great extent on the training and knowledge of the persons involved. International and regional organizations and national governments should devote due attention to this problem.

G. Wherever local conditions allow (big market, industrial and infrastructural background, know-how, etc.), the creation of a local formulation plant is recommended. Regional and international co-operation should be used to secure markets, supply of materials and know-how.

H. In pesticide application research work, greater emphasis should be laid on the economic evaluation. In the different tests, pesticide application costs should be registered together with the results expressed not only in pest reduction, but also in yield and quality improved. The result should be convertible to monetary terms. This will allow evaluation of the most economic pest control methods. Collection, analysis and summarization of these results will give tangible proof of the economic effectiveness of pesticide application and thus give more incentive for its use.

The factor E_2 was calculated in the following manner:

We selected the region with the smallest total pesticide use (Mt minimum in this case Asia) and used the formula:

E_2 = product value - total pesticide use

where

product value = (yield of the region - yield of M) x price here 140 \$/L

and

total pesticide use = total pesticide use for the region - total pesticide use for the region M

We named this E_2 "Net return" but we must stress, it is only the result of a partial budget; the costs other than for pesticides are not taken into account. They vary also from region to region and we will try to take into account their effect.

Given this assumption regarding the degree to which the crop is affected by varying pest infestation levels, pest infestation measures can be used as a proxy expression for the benefit of pest control. The objective in cost-effective analysis, then, is to de termine the way to reduce pest infestation by a specific amount, or to a specific level, at least cost. For illustrative purposes, in this case the objective will be to reduce the percent of mung bean plants infested by bean fly by two thirds. (By assumption, this means aiming to reduce mung bean yield loss by two thirds also).