Extent of Pesticide Use, Food Supply, and Pollution

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Abstract: *Only 5%* of this country's total crop acres receive insecticide treatment, and about half of this is applied to cotton and tobacco acres. Despite the large increases in insecticide use, crop losses due to insect pests are also increasing and are now estimated by the USDA to be nearly 13%. In part, these trends are due to the practice of substituting insecticides for sound bioenvironmental pest controls (e.g., crop rotation and sanitation) and also to higher consumer standards.

If pesticides were not used, crop losses, based on available data, were estimated to increase 7% (representing $2.1 billion). Overall, except for supplies of crops such as apples, peaches, and onions, most food crops would not be seriously affected by discontinuing use of pesticides.

Although pesticides should not be eliminated, a need exists to treat only when necessary, to reduce aircraft spray drift, and to reactivate sound bioenvironmental controls. Also, additional acreages of some crops could be profitably planted to offset crop losses due to pesticide reduction.

Concerning the toxicity of pesticides, the prime danger appears to be to those who apply these poisons. Unfortunately, the available data on long-term, low-level effects of pesticides to public health are inconclusive.

Existing levels of pesticide pollution already have been responsible for kills of some species of beneficial insects, fishes, and birds. This serious pollution has occurred when only *a small percentage* of the crop acres are being treated with pesticides.

A systems approach to pest management, in which the multiple factors of pests, crop culture, costs, benefits, and risks to environment and health are evaluated, is suggested as meeting the needs of agriculture and society as a whole.

INTRODUCTION

Early in the sixties Carson (1961) and others warned the public that continued pesticide use would eventually result in a "silent spring" and exact a high "human price." Conversely, Borlaug (1972) and others have warned that if the "use of pesticides in the USA were completely banned, crop losses would probably soar to 50%." Unfortunately, these statements have been made to the public without adequate scientific evidence.

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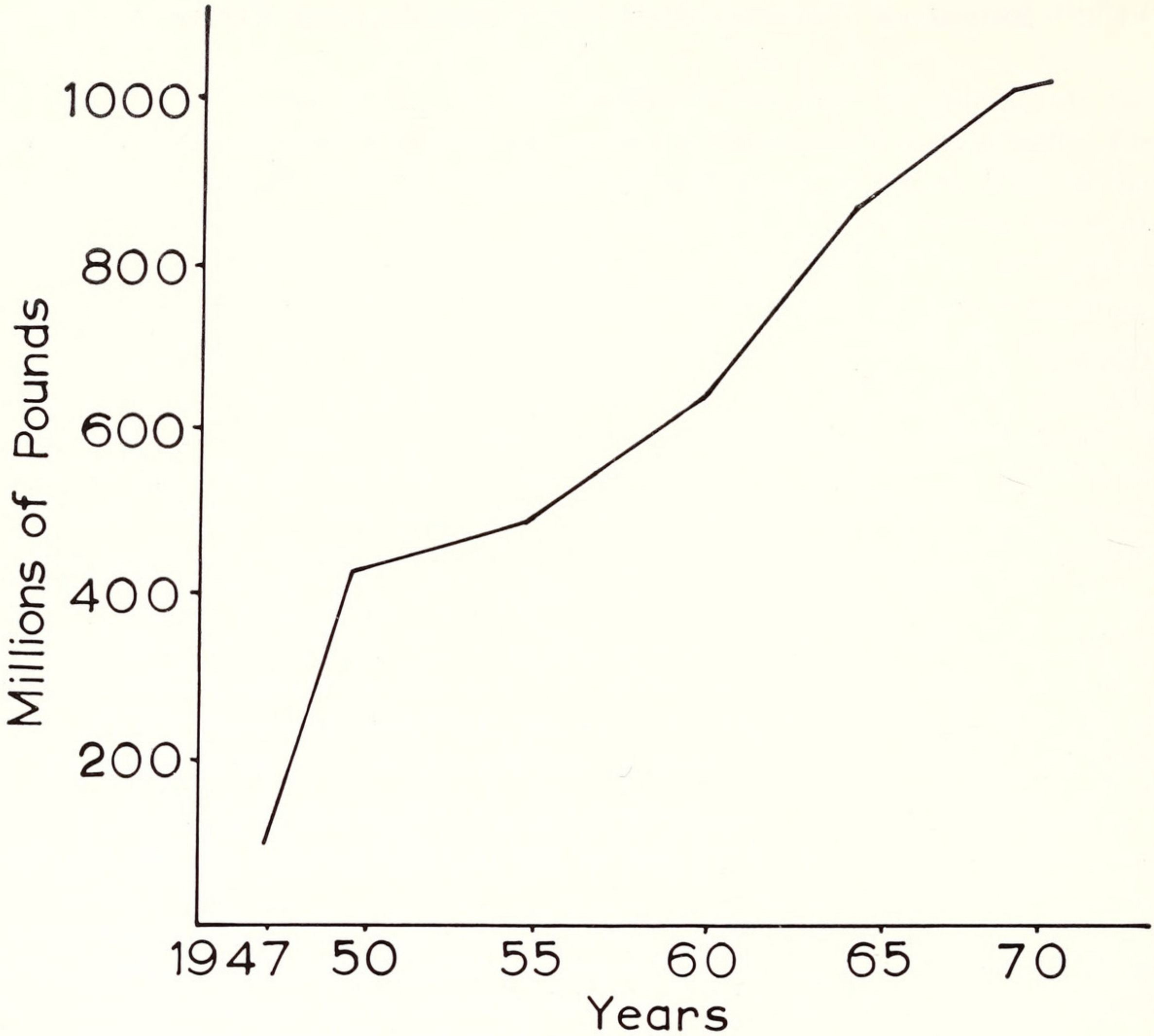

FIG. 1. Quantities of pesticides produced in the United States (USDA, 1971a).

To place the problem in a more balanced perspective, this paper endeavors to evaluate the data concerning use of pesticides in food production and their effects on man's health and his environment. The extent of pesticide applications on various crops and pest losses during the pre- and post-synthetic pesticide eras are compared. In addition, attention is given to the costs and benefits of pesticide use and the risks both to the environment and man's health.

Much of this analysis is based on USDA (U.S. Department of Agriculture) survey data. Some of these data were collected in various studies during the 1960's and unfortunately there are no more recent data available. Furthermore, some of these data are estimates gathered in surveys and so have inherent limitations but again are the most comprehensive available. Despite these reservations, the need remains to conduct an analysis of pesticide use in crop production in order to gain a perspective on pesticide use. Too many claims and counterclaims concerning the risks and benefits of pesticides have been made with little, if any, attention given to available data, however incomplete.

Table 1. Some examples of percentages of crop acres treated, of pesticide amounts used on crops, and of acres planted to this crop (USDA, 1968; USDA, 1970*a*).

Crops	Insecticides		Herbicides		Fungicides		% of Total Crop Acres
	% Acres	% Amount	% Acres	% Amount	% Acres	% Amount	
Non-Food	1	50	0.5	NA[a]	< 0.5	NA	1.26
Cotton	54	47	52	6	2	1	1.15
Tobacco	81	3	2	NA	7	NA	0.11
Food	4	NA	11.5	NA	< 0.5	NA	98.74
Field Crops	NA	NA	NA	NA	NA	19	NA
Corn	33	17	57	41	2	NA	7.43
Peanuts	70	NA	63	3	35	4	0.16
Rice	10	NA	52	2	0	NA	0.22
Wheat	2	NA	28	7	0.5	NA	6.11
Soybeans	4	2	37	9	0.5	NA	4.19
Pasture Hay + Range	0.5	3	1	9	0	NA	68.40
Vegetables	NA	8	NA	5	NA	25	NA
Potatoes	89	NA	59	NA	24	12	0.16
Fruit	NA	13	NA	NA	NA	NA	NA
Apples	92	6	16	NA	72	28	0.07
Citrus	97	2	29	NA	73	13	0.08
All Crops	5	54	12	36	0.5	10	NA

[a] Not available

PESTICIDE USE PATTERNS

Nearly a billion pounds of pesticides, or about 5 pounds per person, are used annually in the United States (USDA, 1971*a*) (Fig. 1). Of the one-half billion pounds of pesticide applied to crop and farm lands, 54% is insecticide, 36% herbicide, and 10% fungicide (USDA, 1971*a*). Nearly another half billion pounds of pesticides are used by government agencies, industries, and home-owners.

Pesticides used in agriculture are not evenly distributed (USDA, 1970*a*); for example, 50% of all insecticide used in agriculture is applied to the non-food crops of cotton[1] and tobacco (Table 1). Of the food crops, corn, fruit, and vegetables receive the largest amounts of insecticide. Of the herbicidal material applied, 41% is used on corn with the remaining 59% distributed among the other crops (Table 1). Most of the fungicidal material is applied on fruit and vegetables with only a small amount used on field crops (Table 1).

According to the latest data published by the U.S. Department of Agriculture (USDA, 1968), crop land (including pastures) in 1966 totaled 890.8 million

[1] Cotton is not strictly a non-food crop; the seed is used as livestock food and in producing vegetable oil.

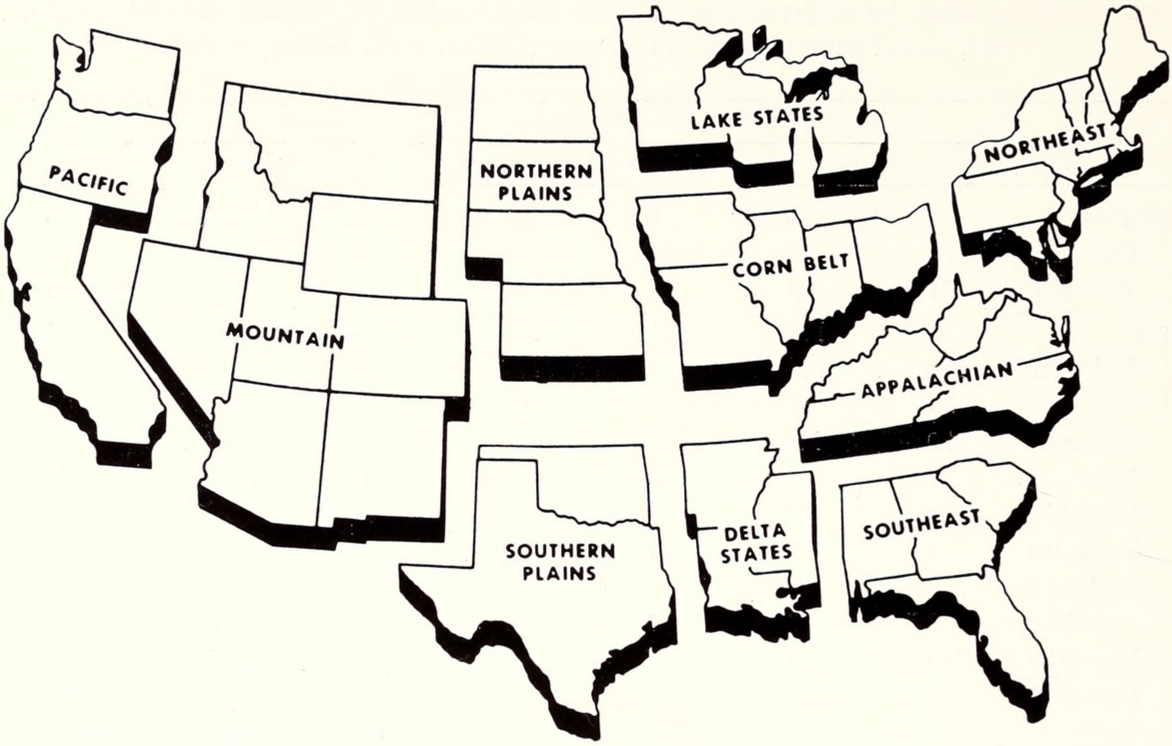

FIG. 2. Farm production regions in the United States (after the USDA Economic Research Service (USDA, 1968)).

acres, of which only 5% was treated with insecticides, 12% with herbicides, and 0.5% with fungicides. If crop land devoted to pastures is removed from the total acreage, then the percentage of crop land (including the non-food crops of cotton and tobacco) treated with insecticides, herbicides, and fungicides is 12%, 27%, and 1.3%, respectively.

Note that although cotton receives nearly 50% of the total insecticide used in agriculture, about half (46%) of the total cotton acreage receives no insecticide treatments at all (Table 1). The largest percentage (79%) of the acres treated is in the Southeast and Delta states; whereas the smallest percentage (37%) treated is in the southern plains (Fig. 2). Of the food crops, only citrus, apples, and potatoes have more than 85% of their acreage treated with insecticides (Table 1). Many acres of small grains and pastures receive little or no treatment with insecticides.

Herbicides are applied for weed control to only 12% of the crop acreage (Table 1). Those crops which have more than half of their acreage treated include peanuts, corn, potatoes, cotton, and rice. Of all pesticides, herbicide use has increased the fastest (USDA, 1971*a*).

Fungicides are used on more than half of the citrus, apple, and other fruit acres (Table 1). Most other crops are grown with little or no fungicide treatment.

In general, the larger growers (annual sales, $40,000 and over) applied more pesticide material to a larger percentage of their acres than did the smaller growers (sales less than $2,500) (USDA, 1968). The difference (excluding pastures) ranged from 6% for the small producer to 21% for the larger producer. Some individual crops, however, were exceptions to these use trends. For instance, the small potato producers used more insecticides or treated about 78% of their acres, the intermediate-size producers (sales, $10,000 to $20,000) treated 98% of the acres, and the large producers treated only 69% of their acres (USDA, 1968). This trend may be explained by the fact that substantially more of the larger potato producers are located in the northern plains where fewer treatments are necessary.

Average insecticide treatment for all crops equals 1% of the crop acreage in the mountain-states region, 3% in the northern plains, 17% in the Corn Belt, and 19% in the Southeast (Fig. 2) (USDA, 1968). This range of 1 to 19% is relatively wide from the mean of 5%. These differences are, in part, due to differences in crops grown, intensity of insect attack, and cultural practices followed in the different regions.

For any one crop, pesticide treatment may vary according to geographic region. For example, in the northern plains where large quantities of potatoes are grown, 42% of the potato acreage is treated with insecticides; while in the Southeast, where early potatoes are grown, 100% of the potato acreage is treated (USDA, 1968). This difference probably reflects the higher intensity of pest attack occurring in the warmer regions.

PEST LOSSES IN AGRICULTURE

According to the latest USDA estimates (1951–60), crop losses due to all pests were $9.9 billion or 33.6% (includes loss in yield and quality, Table 2). Losses due to insects and plant diseases have increased since the previous decade while losses from weeds have decreased significantly (USDA, 1965).

The usage of DDT and the synthetic insecticides has grown in the decades following their introduction in 1946. Although crop losses due to insects have increased despite the significant use of insecticides, important advances have been made in reducing insect losses from certain pests in some crops. For example, losses in yield and quality from potato insects declined from 22% in 1910–35 (Hyslop, 1938), to 16% in 1942–51 (USDA, 1954), and to 14% in 1951–60 (USDA, 1965). This reduction is expected, considering the effectiveness of insecticides in controlling the major potato insect pests.

In contrast, losses in apples caused primarily by codling moth and apple maggot generally have not declined with increased use of organic insecticides. A 10.4% loss in yield and quality was reported for the period 1910–35 (Hyslop, 1938), a 12.4% loss for 1942–51 (USDA, 1954), and a 13.0% loss for the period 1951–60 (USDA, 1965). This loss pattern probably reflects higher-quality standards for salable fruit as well as the decline in sanitation and other cultural controls formerly practiced in orchards for control of these pests.

TABLE 2. Comparison of annual pest losses in agriculture for the periods 1904, 1910–35, 1942–51, and 1951–60 and an estimate of losses if no pesticides were used.

	Insects		Crop Diseases		Weeds		Total Loss		Potential Production
	$[a]	%	$	%	$	%	$	%	$
No Pesticide	4.8[b]	16.3[b]	4.2[c]	14.2[c]	3.0[d]	10.2[d]	12.0	40.7	29.5[e]
1951–60[f]	3.8	12.9	3.6	12.2	2.5	8.5	9.9	33.6	29.5[e]
1942–51[g]	1.9	7.1	2.8	10.5	3.7	13.8	8.4	31.4	26.7
1910–35[h]	0.6	10.5	NA[i]	NA	NA	NA	NA	NA	5.7[j]
1904[k]	0.4	9.8	NA	NA	NA	NA	NA	NA	4.1

[a] Billion dollars.

[b] Assumes that, in addition to total crop losses of $3.8 billion on both treated and untreated acres due to insect attack (1951–60 data), a $1.0 billion loss would occur if 5% of the crop acres receiving insecticide treatment (USDA, 1968) were left untreated. The $4.8 billion (16.3%) crop loss figure if no insecticide were used for insect control is based on the following: An overall 12.9% crop loss due to insects occurs on both treated (5%) and untreated (95%) acres. On the treated acres, 71% are planted to cotton, corn, fruit, and nuts. If all cotton were untreated, losses were assumed to average 32% (USDA, 1968; USDA, 1965; Parencia and Ewing, 1950; Parencia, 1959; Adkisson, et al., 1962; McGarr and Wolfenbarger, 1969; Black, 1971; Adkisson, 1972); losses on all untreated corn assumed to average 15% (USDA, 1968; USDA, 1965; Lilly, 1954; Apple, 1957; Burkhardt, 1962; Peters, 1964; Whitcomb, et al., 1966) and losses on all untreated fruit and nuts to average 60% (USDA, 1968; USDA, 1965; Oatman and Libby, 1965; Asquith, 1970; Glass and Lienk, 1971). A 12% loss was assumed for all the other untreated acres (USDA, 1968; USDA, 1965). The estimated value of cotton was $2.5 billion; corn, $4.4 billion; fruit and nuts, $1.4 billion; and all other, $21.2 billion (USDA, 1961). Thus crop losses due to insects without insecticides are: $32\%(\$2.5 \times 10^9) + 15\%(\$4.4 \times 10^9) + 60\%(\$1.4 \times 10^9) + 12\%(\$21.2 \times 10^9) = \$4.8$ billion.

[c] Assumes that, in addition to total crop losses of $3.6 billion on both treated and untreated acres due to crop disease (1951–60) data, a $0.6 billion loss would occur if the 0.5% of the crop acres receiving fungicide treatment (USDA, 1968) were left untreated. The $4.2 billion (14.2%) crop loss figure if no fungicide were used for crop disease control is based on the following: An overall 12.2% crop loss due to diseases occurs on both treated (0.5%) and untreated (99.5%) acres. On the treated acres, 51% of the acres are planted to peanuts, potatoes, citrus, and apples. Untreated peanut losses were assumed to average 25% (USDA, 1965; 1968; Jackson, 1967; Horne, 1968), losses on untreated potatoes assumed to average 30% (USDA, 1968; USDA, 1965; Manzer et al., 1965; Harrison and Venette, 1970), losses on untreated citrus assumed to average 60% (USDA, 1968; USDA, 1965; Ruehle and Thompson, 1939; Ruehle and Kuntz, 1940; Mokerek, 1970), losses on apples assumed to average 80% (USDA, 1968; USDA, 1965; Palmiter and Forshley, 1960; Ross, 1964), and losses on all other crops assumed to average 12% (USDA, 1968; USDA, 1965; Chester, 1950). The estimated value of peanuts was $0.18 billion; potatoes, $0.61 billion; citrus, $0.46 billion; apples, $0.25 billion; and all other, $28.0 billion (USDA, 1961). Thus crop losses due to diseases without fungicides are: $25\%(\$0.18 \times 10^9) + 30\%(\$0.61 \times 10^9) + 60\%(\$0.46 \times 10^9) + 80\%(\$0.25 \times 10^9) + 12\%(\$28 \times 10^9) = \$4.2$ billion.

[d] Assumes that, in addition to the $2.5 billion loss (1951–60 data) due to weeds, the 12% of the acres receiving herbicides (USDA, 1968) would require $0.5 billion in cultivation and other weed control practices to provide equally effective crop production. The $3.0 billion (10.2%) loss figure due to weeds if no herbicides were used is based on the following:

According to USDA estimates, corn losses due to insects have been increasing. A 3.5% loss was reported for the period 1942–51 (USDA, 1954) and 12.0% loss for the period 1951–60 (USDA, 1965). Factors contributing to increased corn losses due to insects include the continuous culture of corn on the same land year after year (Tate and Bare, 1946; Hill, et al., 1948; Ortman and Fitzgerald, 1964; Robinson, 1966) and the planting of insect-susceptible types rather than resistant-corn types (Painter, 1951; Sparks, et al., 1967; Starks and McMillian, 1967). This latter factor has been implicated in the greater losses in rice and wheat varieties used in the "green revolution" (Pradhan, 1971).

ESTIMATED LOSSES WITHOUT PESTICIDE USE

Estimated crop losses if no pesticides were employed are presented in Table 2. Without pesticides, crop losses due to insects would increase to $4.8 billion (16.3%), diseases to $4.2 billion (14.2%), and weeds to $3.0 billion (10.2%). Total losses without pesticides are estimated at $12.0 billion or 40.7% of potential crop production, an increased loss of 7.1%.

These estimated crop losses are exaggerated because insect, disease, and weed losses were assessed separately and then added together. For example, both insect and disease attacks on one apple were counted as a loss both for insects and for diseases. This approach yields an estimated total loss for apples from insects, diseases, and weeds of 150% (insects 60% + disease 80% + weeds 10%

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A $2.5 billion loss due to weeds occurs on the 890.8 million acres of treated and untreated crop lands (pastures included) (USDA, 1968). On the treated acres, 46% are corn, wheat, sorghum, rice, and pasture (USDA, 1968). If substitute practices of weed control (cultivation and other practices) were employed for herbicides, the additional cost per acre is estimated at $5 for corn (USDA, 1968; USDA, 1965; Drew and Van Arsdall, 1966; Armstrong, et al., 1968; Buckholtze and Doersch, 1968; USDA, 1971*b*); $5 for wheat (USDA, 1968; USDA, 1965; USDA, 1971*b*; Friesen, 1965; Stobbe, 1970); $3 for sorghum (USDA, 1968; USDA, 1965; USDA, 1971*b*); $10 for rice (USDA, 1968; USDA, 1965; USDA, 1971*b*; Friesen, 1965; Smith, 1968); $5 for pasture (USDA, 1968; USDA, 1965; USDA, 1971*b*); and $5 for others (USDA, 1968; USDA, 1965). The millions of acres treated with herbicides are corn, 37.8; wheat, 15.3; sorghum, 0.9; rice, 1.0; pasture, 5.4; and other, 39.3 (USDA, 1968). Thus crop losses due to weeds which includes the alternative control costs are: $\$2.5 \times 10^9 + \$5(37.8 \times 10^6) + \$5(15.3 \times 10^6) + \$3(4.9 \times 10^6) + \$10(1.0 \times 10^6) + \$5(5.4 \times 10^6) + \$5(39.3 \times 10^6) = \$3.0$ billion.

[e] Pest Losses [for 1960] + Actual Crop Production [for 1960 (USDA, 1961)] + Potential Crop Production $9.9 billion + $19.6 billion = $29.5 billion.

[f] USDA, 1965.

[g] USDA, 1954.

[h] Hyslop, 1938.

[i] Not available.

[j] Insect losses and crop production estimates for 1935 (USDA, 1936).

[k] Marlatt, 1904.

= 150%) (Table 2). Obviously, total apple losses cannot be greater than 100% and a more accurate estimate is 90 to 95% without pesticides. Crop losses due to insects, disease, and weeds were estimated separately and exactly how much overlap exists in the loss figures is not known. Recognizing that these loss figures when added together are exaggerated, we can still gain a fair idea about the costs and benefits of pesticide use.

The estimated increased annual dollar loss if no pesticides were used is $2.1 billion ($12.0 billion – $9.9 billion = $2.1 billion). Contrast this estimated $2.1 billion loss with the $3.8 billion spent in 1969 (USDA, 1970*b*) and estimated $4.8 billion spent in 1971 for the farm price support program which also includes diverting nearly 60 million acres from planting crops like cotton, corn, and wheat (USDA, 1970*b*). This analysis is presented to provide a perspective concerning pesticide uses, benefits, and risks. It neither advocates doing without pesticides nor substituting payment to farmers for their losses due to pests if no pesticides were used.

Based on these estimates, overall crop losses would increase from 33.6% to 40.7%, or 7.1 percentage points if no pesticides were used in crop production. In fact, this nation normally produces an estimated surplus of 10% in quantity (USDA, 1970*b*). A 7.1% increased loss without the use of pesticides would not cause starvation. If no pesticides were used, the supply of food for the nation would be ample, but quantities of certain fruits and vegetables such as apples, peaches, plums, oranges, potatoes, and cabbages would be significantly reduced. Because of this, we might have to use substitutes for some of the fruits and vegetables we normally like to eat.

Actually, the loss in some fruits and vegetables would not be quite as large as the estimate if "cosmetic standards" were modified (Southwood and Way, 1970). Although safe and nutritionally sound, some fruits and vegetables are not sold in the market today because of their less-than-perfect outer appearance. For example, oranges with dark blemishes or scales on the peel are not sold, but these skin blemishes do not adversely affect the flesh. Also, cabbages with eaten holes in the outer leaves are not sold, but with these outer leaves removed, the cabbages are perfectly wholesome.

DOLLAR RETURN ON PESTICIDE USE

Using the figure of $2.1 billion (1960) to represent the additional loss incurred without pesticide use, an estimate can be made of the dollar return per dollar invested in pesticides for crop protection. With about $0.56 billion spent (1966) for pesticides in agriculture (USDA, 1970*c*) and assuming application costs for labor and machinery to be ⅓ the cost of the pesticide materials, the return per dollar invested for pesticide control is about $2.82. This estimate is somewhat below previous estimates of $4 to $5 returns, but the latter are based on different methods of calculation (PSAC, 1965; Headley, 1971).

An estimate of the increase in retail food prices due to the additional 7.1% loss of agricultural productivity can be projected. Because farm products have low-level elasticity, for every 1% decrease in quantity of farm products produced there is roughly a corresponding 4% increase in price (Brandow, 1961); therefore, the 7.1% increased loss would result in a possible 28.4% increase in farm product value to the farmer. This would amount to about a 9% increase in retail food prices (Robinson, 1971). If prices did rise, farmers probably would respond with efforts to increase output of the affected crops to establish a new quantity and new equilibrium price. Hence, through farmers' efforts to offset the 9% increase in price, the 7% loss gradually would be reduced.

Headley (1971) has proposed that planting additional acres could compensate for the increased crop losses caused by reduced pesticide use. He suggested that a "12% increase in crop land would reduce insecticide use by 70 to 80% and maintain output." Obviously, to plant and harvest 60 million (diverted acres) additional crop acres would be costly, but additional costs would be more than offset by the economics of the overall changes. For example, an estimated $0.75 billion would be saved by not applying pesticides. Added to this would be the saving of $3 to $4 billion usually spent for diverting acres. Headley did not propose the alternative of increased crop acres planted as the only substitute for pesticide use, but as one sound procedure which could be employed to reduce pesticide use and thereby environmental pollution.

For a few crops like apples, an increase in acres planted would not be a practical substitute for pesticide use because codling moth larvae and apple maggots inside the apples make this fruit unsalable. Oranges also are in the same category as apples, because of the currently high "cosmetic standards" now expected by the consumer. The public could be educated to be concerned more for the quality of their produce and less for the "cosmetic appearance" of the fruits and vegetables.

PESTICIDE POLLUTION

Before 1900 the primary aim in pest control was to eliminate the pest insect by any means short of destroying the crop. Lead arsenate was used in large quantities, and it was common to observe fruits and vegetables for sale which were "powder white" with residues.

Concern for the health of humans consuming these contaminated foods developed during the early 1900s and various regulations emerged. In 1954 tolerances were established for pesticides on raw agricultural commodities and regulated by the Federal Food, Drug, and Cosmetic Act as amended by the Miller Bill of 1954 (Public Law 518). This legislation limited the quantity of pesticide residues found in or on fruits, vegetables, and other agricultural products.

Thus by the mid-fifties, human health became a significant factor in assessing the risks and benefits of pest control recommendations. At present there is increased concern for human health because recent investigations have indicated that some pesticides are carcinogenic, teratogenic, and mutagenic (HEW, 1969). More stringent standards and tests are now included in new pesticide registration procedures.

In addition, public interest in the 1960s focused on the deterioration of the environment caused by pesticides. Governmental legislation establishing the new Environmental Protection Agency followed in an effort to enforce protection of the environment from all pollutants including pesticides. All pesticides registered today by the EPA are carefully investigated for their potential hazard to the environment, as well as to man himself.

The public has demanded, and rightly so, to see the pesticide use "balance sheet"—to know the risks versus benefits relative to dollar economics, public health, and environmental pollution. A gross estimate was made earlier that the return per dollar invested in pesticidal control is $2.82; but this does not include the costs of pollution.

Pesticides may destroy natural enemies of other pests resulting in other pest outbreaks, thereby requiring additional pesticide sprays. The presence of chemical residues is always a risk. If too much pesticide is found on crops at harvest, the crop may be confiscated and destroyed. In addition, high residues may be caused by drift or by a gradual accumulation of the pesticide in a certain region. DDT in milk is an example, not because of any use associated with dairy cattle but because of a general contamination of the environment with DDT. Farmers following recommended treatment schedules on their own crops rarely have had pesticide residues above legal tolerances in their products (HEW, 1969).

Recommended use of pesticides normally results in tolerable residues, which implies that at present there is little or no direct danger to the health of man. Unfortunately, little is known about the effects of long-term, low-level dosages of pesticides on man (HEW, 1969). Furthermore, the possible interaction of low-level dosages of pesticides either with drugs or with the numerous food additives which the public consumes has not been studied.

Another growing public health problem is the hazard involved in the handling and application of pesticides. During 1968, 72 human lives were lost accidentally through the use of agricultural chemicals (HEW, 1971). This number will probably grow with the increased usage of the more toxic pesticides such as parathion. Both Metcalf (1972) and Smith (1972) asked a valid question when they inquired why the agriculturalists responsible for pesticide recommendations were not recommending safer, less toxic pesticides—such as fenthion, dicapthon, or malathion—rather than parathion and similar highly toxic pesticides as substitutes for the restricted DDT.

In addition to being a danger to human health, pesticides exact high costs from our environment as pollutants. Economists refer to these pollution costs as part of the "external" costs (Edwards, 1971). While the direct cost of treating crops with pesticides is borne by the farmer, pollution costs are borne by society as a whole. Hence, the grower, in deciding to employ a pesticide for pest control, is concerned mainly with the price of the pesticide and application costs; the external costs are paid by society.

Scientists are concerned that so little is known about the ecological effects of pesticides on the plants and animals making up man's life system. At least an estimated 200,000 species of plants and animals comprise the life system of the United States. Information on the effect of pesticides is available for less than 1% of these species, and at best most of this information is incomplete (HEW, 1969; Pimentel, 1971). This lack of information should be alarming to both the public sector and the government when it is recognized that man's survival depends upon the functioning of his life system. This system provides man with a quality atmosphere; it protects him from deadly solar ultraviolet light (screened out by oxygen and ozone); it functions in degrading pollution wastes; and it plays many roles in the production of man's food and fiber (Allee, et al., 1949; PSAC, 1965).

No one knows *how many* species in the life system can be destroyed before the survival of man himself is endangered. Obviously, some species are more important to man than others. However, any gross tampering with the life system, as is occurring today with the wide release of agricultural and industrial chemicals into the environment, may threaten man's survival.

Pesticides have reduced some populations of beneficial insect parasites, predators, and pollinators in certain regions of our country. This reduction has increased some crop losses (PSAC, 1965; HEW, 1969). For example, when predator populations were inadvertently eliminated on beans and potatoes treated with DDT, chlordane, and other insecticides, outbreaks of mites occurred. At times the densities of these plant pests increased 20-fold above their "natural control" level (Klostermeyer and Rasmussen, 1953). Some pesticides have caused fish kills and sometimes have stopped reproduction in a species, such as lake trout (Burdick, et al., 1964). In addition, several valuable bird species, including eagles, falcons, and pelicans, have declined in part due to pesticides in some habitats in the United States (PSAC, 1965; HEW, 1969; Pimentel, 1971).

Pesticide pollutants are now widespread and occur in the water, soil, air, and most living organisms, including man. In the United States alone, nearly 40,000 pounds of DDT are estimated to be present in a total of nearly 200,000,000 humans (PSAC, 1965). However, no harmful effects are believed to have resulted from this dosage (HEW, 1969).

Even the amount of pesticide measured drifting in the atmosphere is disturbing. Concentrations of DDT, for example, were found to range from below detectable levels to 23 ng/m^3 for rural air samples. In urban communities which had pest control programs, concentrations ranged from below detectable levels to as much as 8,000 ng/m^3 (Tabor, 1965, in Cohen and Pinkerton, 1966).

Pesticides can enter the atmosphere either during application by volatilization and codistillation, or they can be picked up from soil and plants by the wind. Pesticide application by aircraft spraying is especially effective in polluting the environment. Various studies indicate that as little as 25% of the pesticide applied by aircraft reaches crop level; the other 75% drifts away in the atmosphere (Hindin, et al., 1966; Ware, et al., 1970; Buroyne and Akesson, 1971; Akesson, et al., 1971). With 60% of all insecticides used in agriculture being applied by aircraft (USDA, 1971*a*), the problem of polluting the atmosphere and the environment is significant. Drift can be prevented if suitably large spray droplets are used in application with maximum winds of 7 mph. However, they are not as effective as fine droplets against some insect pests. Large droplets are satisfactory though for most herbicides. Some states such as California and Texas have initiated legislation concerning droplet size as well as other factors in an effort to control the drift problem with aircraft applications.

ALTERNATIVE METHODS OF PEST CONTROL

Pesticide use in some crops could and should be reduced. In others, these economic poisons are valuable tools when employed as one part of a crop systems management program. Let us examine some current alternative methods of pest control which might be immediately employed to reduce pesticide use.

One possible alternative to pesticides already mentioned involves increasing the number of crop acres planted to offset pest losses. This would mean reactivating some of the nearly 60 million acres now diverted from crop production. This alternative might be satisfactory for crops such as corn and cotton, but would not work with crops such as apples and peaches.

A second alternative is to plant some major crops in geographic regions where their pests are generally less numerous, thus decreasing use of pesticides. Implementing such a change would be sociologically difficult, but the environmental significance of such a step warrants further consideration. The importance of geographic regions for production is well illustrated by the codling moth pest in apples. In the South, there are 3 complete generations of the pest per year, whereas in the far northern regions there may be only a single generation (Jenne, 1912; Chapman and Lienk, 1971). Obviously, less insecticide is needed in the northern region for control of the codling moth. Also, it should be pointed out that there are varieties of apples which are significantly resistant to the codling moth (Cutright, 1937). Implementing sanitation and other cultural controls would also contribute to reducing this pest (Metcalf, et al., 1962).

Pest problems with vegetables also vary in severity in different climatic regions. For example in the Southeast, 100% of the potato acreage received insecticidal treatments, whereas in the northern plains only 42% received treatments (USDA, 1968). Similar differences occur with fungicides. In the northern plains, 94% of the potato acres was treated with fungicides; in the mountain region only 19% of the potato acres was treated (USDA, 1968). Although other factors are involved, these figures suggest that some regions have fewer pest problems and thus may be more advantageous for culture of a particular crop than other regions.

Another successful alternative is to rotate crops. For many decades crop rotation proved to be an effective and profitable practice. Unfortunately, in the past few decades, pesticides have been substituted for this practice in some crops. In other cases, employing one pesticide may prevent the rotation of a crop. For example, some herbicides may reduce corn rotations with crops of oats, soybeans, and other non-host crops of corn pests because of the hazards of herbicide residues for these susceptible crops (Knake and Slife, 1962; Wisk and Cole, 1965; USDA, 1968; Swain, 1970; and Burnside, et al., 1971). As a result, in some cases there is a tendency to grow corn on corn and this may increase insect, disease, and weed pest problems. For instance, corn rootworm is a pest problem which may follow repeated corn croppings (Tate and Bare, 1946; Hill, et al., 1948; Metcalf, et al., 1962; Ortman and Fitzgerald, 1964; Robinson, 1966). The resulting rootworm problem may require additional insecticide for its control. This contributes to pollution and also increases the overall costs of pest control.

Another long-time, effective control technique for some pests is crop sanitation. Destroying crop remains eliminates a large portion of the corn borer population (Thompson and Parker, 1928). In the 1930s and 40s, fall plowing of corn stubble and stalks was widely used as a control measure for the corn borer; however, this measure was never economically evaluated.

Resistant varieties of crop plants could replace some of the more susceptible varieties. Although only a few insect resistant varieties are presently available, these have been highly effective in reducing crop damage. For example, the Hessian fly, a serious pest of wheat, is well controlled by resistant wheat varieties (Painter, 1951). The effectiveness of this pest control technique is further substantiated by a comparison of the reproduction of chinch bugs on two varieties of sorghum. On one variety (dwarf yellow milo), the bug produced an average of 99.4 offspring, whereas on a highly resistant variety (Kansas orange sorgo), the production of offspring averaged only 0.3 (Dahms, 1948).

Resistant varieties have been used more extensively for control of plant diseases than for insect damage control. Sometimes years of research are required to find resistant factors in plants and then to incorporate these factors into a variety which has all the desirable yield and quality characteristics (Painter, 1951; Van der Plank, 1968). The use of insect resistant plant varieties is usually assumed to be a long-range alternative, but resistant varieties have been developed in 3 to 5 years. Certainly resistant varieties are an alternative which merits immediate and greater attention.

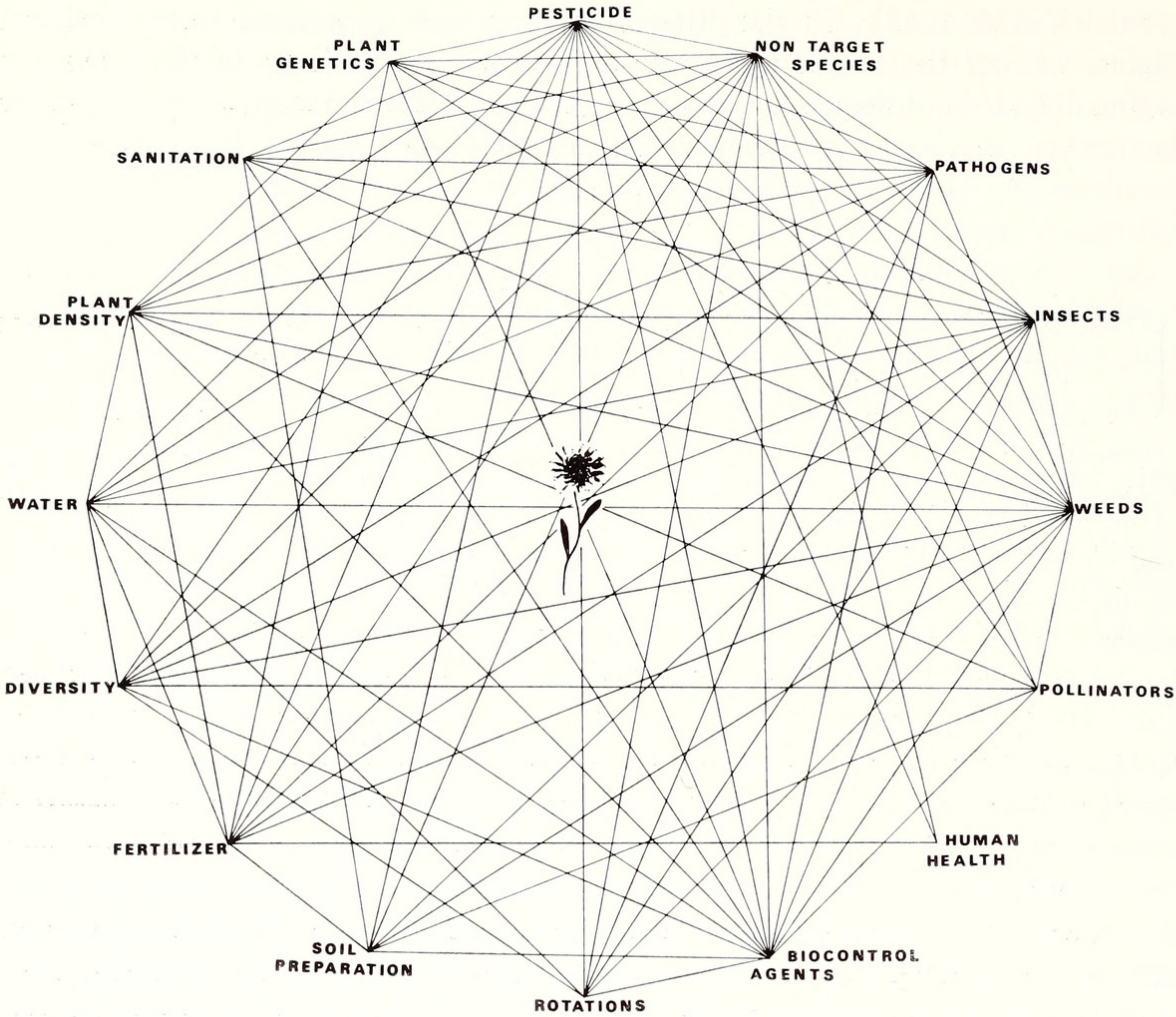

FIG. 3. The inter-relationships of the factors involved in the control of insect, pathogen (crop diseases), and weed pests associated with a particular crop plant.

Other controls which have proven effective for specific pests include such cultural practices as soil preparation, water management, and roguing of diseased hosts.

In addition to those bioenvironmental controls which could be implemented immediately for control of certain pests, new research should be undertaken to develop new bioenvironmental controls. Proven potential exists in other controls such as parasites (including pathogens), predators, attractants (chemical and physical), sterile male, and genetical means (PSAC, 1965).

Insecticide usage, for instance, could be drastically cut if bioenvironmental controls were developed for just a few major crop pests. For example, an estimated 40% of all insecticide applied annually in the United States is employed against only three pests; the cotton boll weevil, the cotton bollworm, and the apple codling moth (ACS, 1969). Development of effective bioenvironmental controls of these three pests would significantly reduce total insecticide use.

Pesticides are valuable pest-management tools and this deserves reemphasis.

The prime difficulty with them lies in man's tendency to completely substitute pesticides for effective bioenvironmental controls. Pesticides should be employed primarily as "stop-gap" or "fire-fighting" tools and sound bioenvironmental controls relied upon as the primary control method (PSAC, 1965).

"SYSTEMS" APPROACH TO PEST CONTROL

Because there is no simple answer or single technique for pest control, there is need for a "systems" approach to this complex problem. This approach would include the application of ecological principles to all aspects of crop culture and pest management and analysis of costs, benefits, and risks of all factors involved in crop production and pest management.

With the systems approach, pest management becomes an integral part of a total crop-culture program including the other crops grown in the region (Watt, 1964; Pimentel, 1970; Shoemaker, 1971). This type of pest control requires an understanding of the basic mechanisms affecting the crop and the interactions of major factors such as the pest itself, crop plant, water, soil, and fertilizers. Included in the systems analysis, in addition to crop-cultural practices, are the effects of economics as well as the maintenance of public health and the system's environmental quality. Then the total costs, benefits, and risks of the factors in the system can be evaluated and used as a basis for making sound decisions about pest control measures.

Figure 3 illustrates some of the complex interrelationships among different factors involved in pest control in an agro-ecosystem. These relationships are even more intricate than they appear. For example, a group of pests, together with all their enemies, also exists at each point where insect, disease (pathogens), and weed pests are pinpointed (Fig. 4).

The tools of systems analysis and computer technology are invaluable aids in dealing with the many interactions in crop systems. Initially, only the major pests need be included in a pest-management program; then as additional information is gathered, a more complete and sophisticated pest-management program could be developed for the crop and the region.

Unfortunately, at present there is no good, practical example of the systems approach being applied to pest control. However, the advantages of this approach can be understood by analyzing the utilization of crop rotation for corn rootworm control and the herbicide, 2,4-D, for corn weeds. To rotate corn with another non-host crop of corn pests has several associated costs and benefits. A cost consideration is the fact that the second crop may not yield the profit per acre of corn. Specialized equipment is needed to plant and harvest both crops. The benefits include reduced costs for insecticide for the rootworm, reduced danger of poisoning to the farmer and his laborers, and also reduced environmental pollution. If a legume were used in the rotation, other benefits might include reductions in associated insect pests, plant pathogens, and weed

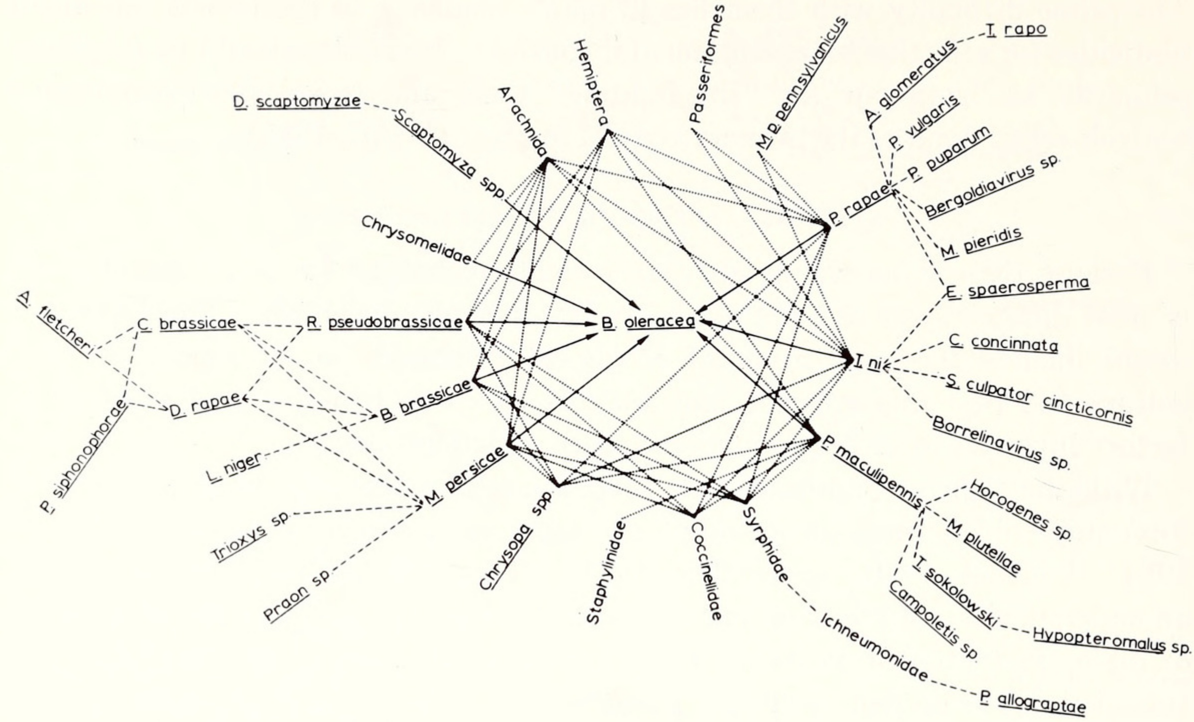

FIG. 4. The relationships between the cole crop-plant (*Brassica oleracea*), the insect pests (————), the parasitic (- - - - -), and predaceous (· · · · ·) enemies of the insect pests (Pimentel, 1961).

pests, plus reduced fertilizer needs for corn. When 2,4-D is used for weed control, the costs include application charges, increased chances of environmental pollution (Pimentel, 1971), and perhaps an increase in insect pests. For example, aphid numbers have been shown to increase several-fold on certain plants exposed to 2,4-D (Maxwell and Harwood, 1960; Adams and Drew, 1969). On the other hand, the benefits of 2,4-D weed control include reduced costs in some instances (Drew and Van Arsdall, 1966; Armstrong, et al., 1968) and more effective control of weeds if conditions are wet. All the factors involved in management of the corn ecosystem could be programmed for a systems analysis to determine the optimal management practices for the total system including the environment surrounding the crop.

The need for a systems approach to pest management and for the development and use of additional bioenvironmental controls is clear. Strong measures for change should be instituted now to halt the increased reliance on pesticides, which, according to USDA figures, has escalated during some years as much as 24% (USDA, 1970*a*).

CHANGES IN PESTICIDE USE

Immediate reductions in pesticide use would be possible by substituting "treat-when-necessary schedules" based on the actual measurements of pest populations for the currently employed "routine spray schedules" which waste

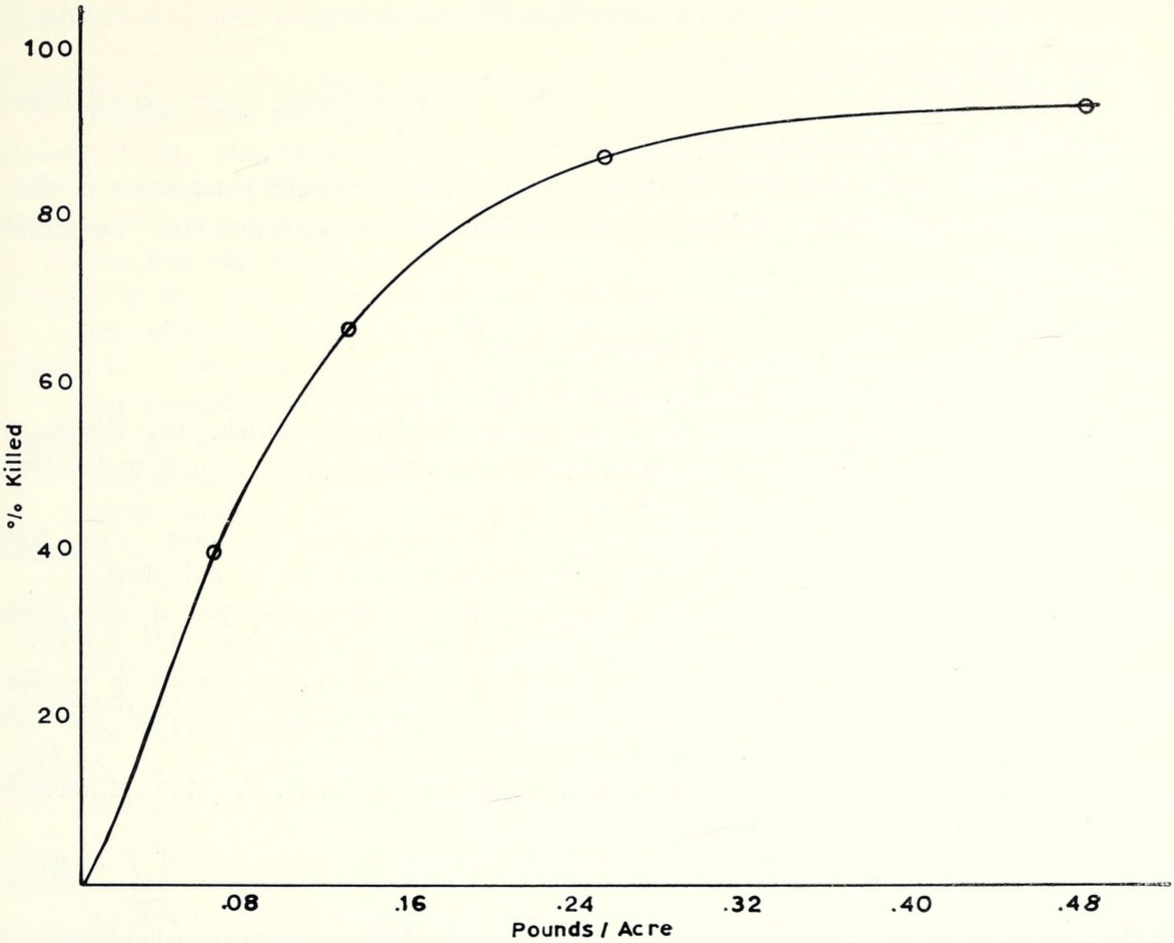

Fig. 5. Amount of dieldrin applied per acre and the percentage kill of boll weevils after 22 hours exposure (Bottger, et al., 1958).

pesticides, contribute to pollution, and increase food costs. Estimates suggest that farmers could reduce insecticide use 35 to 50% with little or no effect on crop production by just "treating-when-necessary" (PSAC, 1965).

A further reduction in pesticide use would also be possible if the current policy favoring 100% pest kills were replaced by lower-level pest kills based on sound economic-threshold densities (Smith, 1969). The increased costs of 100% pest kills can be easily seen in Fig. 5. Note that the top of the "S" curve is flattened; thus increasing the amount of pesticide applied per acre results in smaller and smaller increases in both percentage kills and crop yields. Policies which favor 100% pest kills on crops are wasteful, may be dangerous, and often result in costly "overkills."

In conclusion, pesticide use in the United States could be reduced significantly if:

1. Bioenvironmental pest controls which were replaced with pesticides were again put into full practice wherever possible.
2. Some or all of the 60 million acres currently diverted at a cost of $3 to $4

billion annually were planted to help balance the increased crop loss resulting from a reduction in pesticide use.

3. A "treat-when-necessary" program based on monitoring pest populations were initiated and aircraft spray drift were reduced.
4. The public were educated to be concerned for the safety of their fruits, vegetables, and other produce and attach less importance to "cosmetic appearance."

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