UNIVERSITY OF MISSOURI-COLUMBIA
COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION

A. Max Lennon, Director

Pest Control As A Production Constraint for Grain Crops and Soybeans In the United States to 1990

J. C. Headley

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PEST CONTROL AS A PRODUCTION CONSTRAINT FOR GRAIN CROPS AND SOYBEANS IN THE UNITED STATES TO 1990

J. C. Headley

Increased demand for food is associated with rising per capital income and growing population. Both per capita income and population are expected to increase during the remainder of this century. New policies and technologies will accompany greater demand for food. The overall objective of U.S. agricultural policy is to assure adequate diets to combat malnutrition, to constrain world-wide inflation and to assure farm incomes that will support an economically efficient farm sector.

The objective may be approached either by expanding food producing resources such as farmland and labor or by expanding the amount and array of capital inputs that enhance land and labor productivity such as fertilizer, pesticides, machinery, improved varieties, etc., or some combination.

Since the supply of productive farmland is only slowly expandable and sometimes at great cost, and since agriculture competes unfavorably for labor in a world which is becoming more industrialized, pressure will continue on the development of capital inputs to increase productivity of land and labor. However, due to concerns for the natural environment throughout the world, there is continued pressure to provide technology, especially that of a chemical nature, that will not result in unacceptable consequences for the environment.

In the U.S. and throughout the developed world, both chemical pesticides (insecticides, fungicides, herbicides, rodenticides, miticides) and commercial fertilizer have been carefully examined for their pollution effects on the environment. Most developed countries regulate pesticides to protect the environment. Fertilizer, while not regulated as a polluting substance, is being examined and certain legislation such as P.L. 92-500 may influence fertilizer use directly, through means used to control non-point pollution from agriculture.

The controversy over pesticide use in the U.S. has promoted considerable argument about the contribution pesticides make to agricultural production. One side argues that the loss of pesticide technology would have devastating effects on production and prices; the other side argues that farmers overuse pesticides and that their contribution is overstated. The latter group argues that the effects of a no pesticide strategy for agriculture on production and prices would be minimal.

The purpose of this report is to address the question of whether or to what extent pest control may limit the productive capacity of U.S. agriculture for grain crops and soybeans in the coming decade.

The following sections will deal with

(1) the current state of pesticide use practices for grain crops and soybeans in the U.S.,

(2) an analysis of the impact of pesticides on grain crop and soybean production, location of production, cropping systems, produce prices and return to land,

(3) a review of the outlook for the development of pesticide technology and practices over the coming decade,

(4) possible environmental consequences of the continued use of pesticides, and

(5) some suggested policy strategies to reduce the reliance on chemicals.

Current Pest Control Practices for Grain Crops and Soybeans

The principal grain crops produced in the U.S. are corn, wheat, grain sorghum, rye, oats and barley. While all but grain sorghum are used to some extent directly as human food, large quantities

of corn and oats are also used as feed for meat producing animals.

For the purposes of this report, the grains have been divided into a feed grain group (corn, grain sorghum and oats) and a food grain group (barley, wheat and rye) based on the largest relative use of each, whether for feed or food. Soybeans, classed as oilseed, are seldom fed directly to livestock, but are processed and fed as a meal that is an important protein source. Soybean oil is used for a variety of products including shortening and industrial products.

Pest Control for Feed Grains

Corn

Corn acreage for the period 1967-76 ranged from 65 million to 84 million acres. About 63 percent of this acreage was in the states of Ohio, Indiana, Illinois, Iowa, Minnesota, Missouri and Nebraska. In these states corn was the major grain crop or shared the principal grain crop status with soybeans. States with over 1 million acres of corn were the lake states of Wisconsin and Michigan, plains states of Kansas and South Dakota and southern and eastern states of Kentucky, Georgia, North Carolina, Pennsylvania and New York [12].

The major pest problems in corn production were weeds and insects. High yielding hybrid varieties require early planting to realize their yield potential. This has made the use of pre-emergent herbicides an important practice, since there may be periods of wet weather after planting that preclude cultivation to control early season weeds and grasses. A 1974 U.S.D.A. pesticide use survey (1) indicated that more herbicides were used on corn than on any other crop. Over 80 percent of the corn acreage is chemically treated for weed control. Roughly 45 percent of all herbicides applied are applied to corn. The two largest groups of materials used are the amides and the triazines, comprising about 75 percent of herbicides applied to corn. Amides include such commercial products as "Ramrod" and "Lasso" and are used for pre-emergent control of grasses. Triazines, mainly atrazine, are used as pre-emergent control of broadleaved weeds.

The use of herbicides has increased dramatically. Total use of herbicides, measured in quantity of active ingredients, doubled between 1966 and 1971, and the same increase was true for the amount applied on corn. This represented an annual compounded growth rate of 15 percent. The rate of growth in herbicide use has slowed in recent years, and while reliable data are not available after 1971, it appears that the growth has been between 6 and 7 percent per year. The continued growth has been due to (1) an expansion in corn acreage in response to higher prices and (2) the movement toward reduced tillage which requires more herbicide per acre. Reduced tillage increases herbicide use per acre significantly because herbicides are broadcast rather than banded.

Corn insect problems largely relate to what is referred to as the "soil insect complex." A major portion of insecticides applied to corn are aimed at soil insects--corn rootworm, cutworms, wireworms and grubs. Other major insect pests include corn borers, army worms, ear worms, and chinch bugs.

Between 50 and 60 percent of corn acreage is chemically treated for insects annually and soil insects are the principal target [6, p. 51]. About 90 percent of the materials applied to control soil insects are applied before or at the time of planting. Application methods are (a) broadcast, (b) banding, (c) starter fertilizer and (d) furrow, depending upon the pesticide formulation and the insect target. It has been common to broadcast granular materials for cutworm, wireworm and rootworm control, but the practice is becoming less prevalent. Banding in the row has become the primary method. Post-emergence treatment for soil insects is used on a limited basis sometimes as a spray as with toxaphene or as a granular material combined with cultivation. However, control results have not been as stable as with the pre-emergence treatments.

Because the bulk of materials applied to control corn soil insects is soil incorporated, the potential loss due to water runoff is reduced. Chlorinated hydrocarbon insecticides, such as chlordane-heptachlor, tend to attach to the soil particles and find their way into water courses only if the soil is eroded away. Obviously there is no chance of drift damage to the environment from soil incorporated insecticides as there would

be with the above surface sprays. In some cases
the seed may be treated to control seed-corn
beetles or seed-corn maggots. Foliar sprays are
used for mites, aphids, earworm and corn borer.
Sometimes a foliar treatment may be used to kill
corn rootworm adults, to control larvae the follow-
ing year.

Since 1978, corn insect control has been
accomplished primarily with chemicals. However,
the trend is away from materials that persist in
the environment. Compounds such as aldrin, diel-
drin, chlordane and heptachlor have been subject to
registration cancellations by the U.S. Environmental
Protection Agency (EPA). Aldrin and dieldrin
registrations were cancelled in 1975. Chlordane
has been cancelled and heptachlor registrations for
all agricultural uses will be cancelled by the close
of the 1980 crop year, after a three year phase out
program. By 1981, chemical controls available for
corn insect control will consist primarily of
organophosphate and carbamate compounds and perhaps
some botanical and biological control materials.

Chemical control of corn soil insects since
the cancellation of aldrin and dieldrin and with
the eventual cancellation of chlordane and hepta-
chlor, will give major responsibility to the
organophosphorous and carbamate compounds. There
are no established or new chlorinated hydrocarbon
compounds effective against soil insects. The
impact of this fact is not known since insecticides
applied to control soil insects are considered a
form of insurance. There is no doubt that the
environment will be improved due to less chlorinated
hydro-carbons in the soil.

Cultural and management practices such as
rotations can be used against corn insects.
However, the practice that controls one insect
sometimes encourages others. For example, the
practice of crop rotation to help control rootworms
will promote cutworms and wireworms, if both sets
of insects are likely to be problems. Continuous
corn which tends to control cutworms and wireworms
encourages corn rootworms. Similarly, minimum
tillage will provide conditions favorable for wire-
worms and cutworms, while discouraging some species
of corn rootworms.

Rotations in general have been found to be
effective in reducing damage from about one-third
of the common insect pests of corn, but have little

or no effect on the reamining insects [6, p. 54].
Some control of corn insects can be achieved by
controlling planting date, but the effect is not
uniform. Early planting discourages armyworms,
rootworms, and chinch bugs, but is conducive to
cutworms, wireworms and European corn borer. Early
planting dates can affect yields significantly so
there are economic incentives to plant early
especially if there are other means of controlling
the insect problem that may result.

Biological methods to control corn insects are
in use, but there is no conscious use of other
organisms to control any pest species in corn.
There are, however, known natural enemies of the
corn borers, earworm and armyworm. Hybrid plant
resistance is developed for rootworms and European
corn borers, but not for cutworms and wireworms.
Pheromones, juvenile hormones or pathogens are not
used in any commercial way and, therefore, inte-
grated pest management consists of chemicals, some
cultural practices and plant resistance. This is
not likely to change markedly within the next
decade.

Grain Sorghum

Grain sorghum is a feed grain and silage crop
produced predominantly in the plains states as an
alternative to corn. Grain sorghum is much more
drought resistant than corn and will tolerate dry,
hot windy weather better than corn. It is there-
fore principally produced (in excess of 7,000,000
acres) in Kansas, Nebraska, Oklahoma and Texas.
Texas is the largest producer. The irrigated
southwest and far western states of California,
Colorado, New Mexico and Arizona have acreages of
100-300 thousand acres and Missouri produces grain
sorghum on about 600-700 thousand acres. The U.S.
acreage was relatively stable over the period 1967-
76 at about 13-16 million acres for grain in addi-
tion to about 750,000 acres used for silage. Total
grain sorghum production for grain is about 0.7
billion bushels compared to about 6 billion bushels
of corn [12].

Major insect pests of grain sorghum are fall
armyworms, corn earworm, cutworms, greenbugs and
sorghum midge. Other possible insect pests are
European corn borer, grasshoppers and sorghum
webworms.

Chemical controls for these pests include toxaphene, disulfoton, carbaryl, mevinphos, dimethoate, ethion and malathion. The most used materials are disulfoton, carbaryl and perhaps toxaphene. These are used against the major pests listed above. Special care must be taken with grain sorghum grown for silage, since toxaphene will create unlawful residues in milk and meat, because it is a chlorinated hydrocarbon and is fat soluble. Unlike corn, soil insects are not a problem for grain sorghum with the exception of cutworms.

Grain sorghum accounts for about 4 percent of the insecticides applied to crops in the U.S. and ranks fifth in use among the crops behind cotton, corn, vegetables and peanuts [1]. About 60 percent of the insecticides applied to grain sorghum is used in Oklahoma and Texas. The use is smaller than for corn principally because of the smaller acreage, since the intensity of insecticide use on the average is about the same as corn.

Measures to control insect pests of grain sorghum non-chemically are resistant varieties and date of planting. For example, loose headed varieties are less susceptible to damage from corn earworms and most modern varieties are resistant or tolerant to greenbugs. For cutworms, damage can be reduced by avoiding early planting on soils subject to infestation. Avoiding very late planting can reduce damage due to sorghum midge and sorghum webworms. There do not appear to be any operative biological methods other than resistant varieties.

Weed pests of grain sorghum tend to be the broadleaf weeds rather than the grasses. Grain sorghum is responsible for about 5 percent of total herbicide use on crops [1]. Four chemical herbicides are most often used on grain sorghum. These are 2,4-D, a post-emergent spray for broadleaf weeds; propachlor, known in the trade as "Ramrod" and effective against grasses; atrazine, a pre-emergent, effective against broadleaf weeds.

Regionally, the southern plains states of Oklahoma and Texas are responsible for at least half of the herbicides applied to grain sorghum. About 23 percent of the herbicides are applied in the northern plains states of Kansas, Nebraska and South Dakota. So, roughly three-fourths of the herbicides applied to grain sorghum are applied in the plains states.

Alternatives for weed control include the usual cultivation, rotation with small grain or fallowing.

There are no biological weed or grass controls related to sorghum on the horizon.

Oats

Production of oats has been declining in the U.S. for some time, certainly since 1960. Harvested acreage has slowly declined from about 28 million acres in 1959 to about 12 million in 1976. Average yield has not changed much over the period, therefore, total production has declined. Feed use accounts for 87 percent of the domestic use. Exports are minor [12].

The largest oat producing state is Minnesota. About 60 percent of the oats are produced in Minnesota, Iowa, South Dakota, Wisconsin and North Dakota, in descending order of acreage produced.

Declining oat production has been due first, to a drastic reduction in the horse population since the advent of mechanization and second, to the declining profitability of oats due to shifting demand to other sources of protein such as soybeans. Consequently, oat production all but left the corn belt in favor of corn or soybeans, especially in the southern parts of the corn belt where yields were never very good due to unfavorable climatic conditions.

Insect and weed pests of oats are a relatively minor problem. Occasionally wheat stem sawfly may pose a problem in the northern Great Plains. However, the best method of control for this pest is crop rotation and deep plowing. Weeds are not usually a problem for oats, since they are not intertilled and tend to crowd out early season grasses and broadleaf weeds.

Pest Control for Food Grains

For the purposes of this study, the food grains consist of wheat, barley and rye. Production of these crops tends to be concentrated in the western corn belt, the northern and southern plains, and the mountain and pacific states.

Wheat

Several different market classes of wheat are produced in the U.S. By far the largest acreage of wheat is devoted to hard red winter wheat, followed

by soft red winter, white winter, white club, hard red spring, durum and white spring, in that order. There are over 200 varieties. All market classes with the exception of the spring wheats and Durum are planted in the fall. Small acreages of spring wheat are fall seeded [8, p. 4].

During the period 1967-76, harvested wheat acreage expanded from 58.3 to 70.8 million acres. Production increased from 1.5 to 2.1 billion bushels during the same period [12]. Large acreage increases took place beginning in 1974 encouraged by high prices due to strong foreign demand.

In 1976, the 70.8 million acres was composed of winter wheat, of which 49.5 million acres or 70 percent was hard red winter. The balance consisted of 4.6 million acres of durum wheat and 16.7 million acres of other spring wheat.

Domestic food use currently accounts for about 550 million bushels of wheat, while exports are about one billion bushels. Feed for livestock is a very minor use. Current carryover levels are adequate to cover one year's domestic consumption.

The two largest winter wheat producing states are Kansas and Oklahoma, accounting for 35 percent of the harvested acreage. Other states with over two million harvested acres are Colorado, Montana, Nebraska, Texas and Washington. Illinois, Indiana, Ohio, Missouri and Oregon each harvest between one and two million acres of winter wheat annually.

Durum wheat, used primarily for macaroni products, is produced mostly in North Dakota. Only about 4.5 million acres is grown. Some is produced in the far west states under irrigation.

Conditions for winter wheat production are less favorable as one moves north because of the length and severity of the winter. Therefore, North Dakota, South Dakota and Minnesota produce more spring-sown wheat than winter wheat. Montana produces about two million acres of spring wheat and three million acres of winter wheat. North Dakota produces slightly less than half of the spring wheat of the nation with a harvested acreage of 7.9 million. The spring wheat has various uses ranging from feed to blending of flour to use as a general purpose flour.

Insects that are most often a problem in wheat production are Hessian fly, cereal leaf beetle, grasshoppers, wireworms, wheat stem sawflies, armyworms, cutworms, greenbug, chinch bug, joint

worm and wheat stem maggot. More than 100 species
of insects may be pests of wheat. However, most
are of only local or minor importance [8, p. 42].
      The most important wheat insect pest is
Hessian fly. It occurs in most areas where wheat
is grown. The maggots or larvae feed on the juices
of the stems, weakening them and causing them to
break when the heads become heavy before harvest.
      The chemical control of Hessian fly consists
of application of disulfoton or phorate at plant-
ing time in the row. Cultural methods and resis-
tant varieties are very effective. Crop rotation
and field sanitation are the chief cultural methods
along with delaying planting of fall seeded wheat
to avoid the fall brood of flies. Agricultural
extension services publicize the "fly free" dates
for planting, which vary from about 12 September
in the north (Minnesota, Wisconsin) to 27 October
in the south (Georgia). Illustrative dates are
shown in Figure 1. The dates change from year to
year depending upon weather.
      Much research has been done on resistant
varieties. A large number of resistant varieties
are available and being used. Since there are many
biotypes of Hessian fly, a variety that is resis-
tant in one locality may not be so in another
locality.
      Cereal leaf beetle is an important pest of
wheat in the upper midwestern states. The larvae
and adults are leaf feeders and weaken plants
causing death and yield reductions. Several chemi-
cals are effective in controlling the pest includ-
ing seed treatment. Resistance has been found in
wheat, but the remaining problem is incorporating
this resistance into adapted varieties for commer-
cial use. Progress is being made [8].
      Occasionally, grasshoppers cause severe damage
to wheat. Chemical treatments of carbaryl, mala-
thion or toxaphene are the most effective controls.
Biological controls are not available for grass-
hopper control.
      Wheat stem sawflies cause major damage to
wheat in the western part of the northern plains.
It is an indigenous pest that lives among the wild
prairie grasses of the region. Certain cultural
practices such as strip cropping to guard against
erosion and retain moisture have aided sawfly
populations. Resistant varieties are the most
practical control method. Parasites naturally help
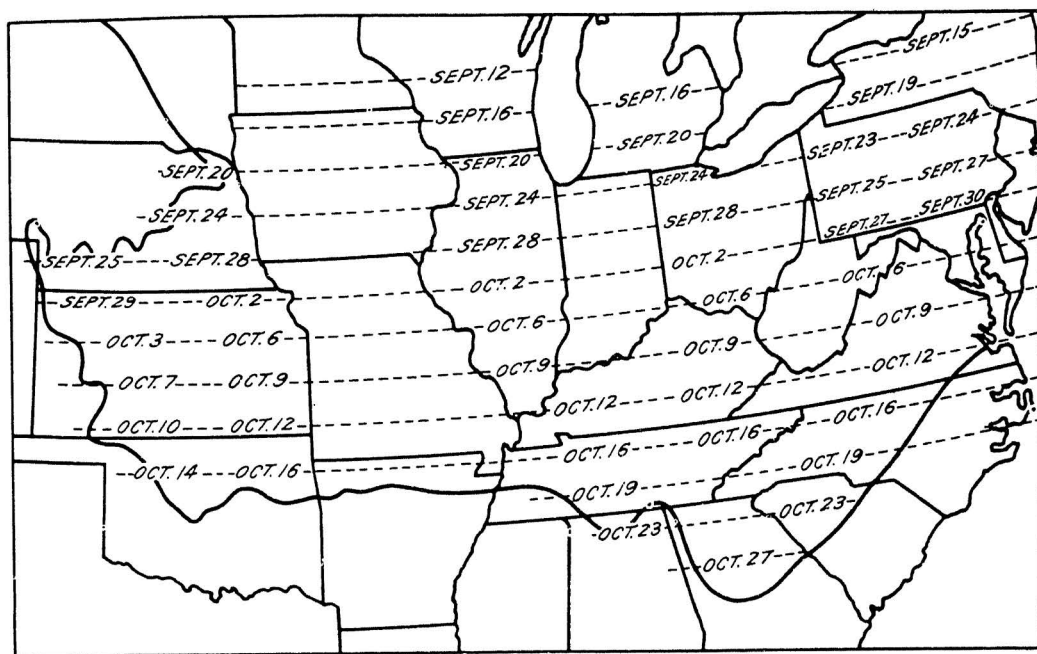
Figure 1.   "Fly Free" Dates for Planting Wheat, U.S. (8)

to control the insect as do cultural practices that promote vigorous growth.

Wireworms attack the seed as soon as it is planted and also feed on roots and crowns. Control includes using plenty of viable seed and providing conditions that promote rapid germination. Occasionally the seed may be treated.

Armyworms are occasional pests of winter wheat especially in the east central and middle Atlantic states. Chemical controls consist of parathion, toxaphene or trichlorfon sprays. Fall armyworms can be treated similarly.

Cutworms may be a problem in wheat regions. Cultivation of stubblefields to kill vegetation just prior to seeding will tend to control this pest. Toxaphene sprays or carbaryl baits also can be used.

Chinch bugs can be a pest when conditions are right. They are most damaging to spring wheat. Good thorough tillage, high fertility and seeding at the proper time will help to reduce damage. Although seldom done, chemicals can be used.

In the soft wheat regions of the east and south, wheat jointworms are one of the most consistently injurious. Early harvest and immediate plowing under of the crop residues give some control [8].

The southern plains sometimes has severe damage due to greenbugs. Parasitic wasps and lady beetles help to control populations. The use of good cropping practices and strong vigorous stands are cultural methods of control. Dimethoate or parathion can be used as chemical controls although these chemicals will also kill the beneficial insects if any are present.

Chemical control of insect pests of wheat is not nearly as important as cultural methods and resistant varieties. Wheat accounts for only 1 percent of chemical insecticides applied to crops [1]. Only hay and pasture use less total insecticides than wheat.

Weeds are perhaps the most serious pests of wheat. Since the major wheat production regions are in areas of relatively low rainfall, the competition for moisture by weeds can reduce yields, affect quality and provide hosts for insects and diseases. They also compete for fertility.

The most serious weed pests of wheat are perennials. Tillage practices and rotations help, but chemicals may be required to make wheat

production economical in certain areas. This class of pest includes garlic, field bindweed, Canada thistle and quackgrass.

Certain annual weeds such as cocklebur, smartweed and pigweed can cause problems, however, they are usually easier to control than perennial weeds. Chemical herbicides such as 2,4-D are effective against these weeds if tillage practices and rotations fail.

U.S.D.A. surveys [1] indicate that the phenoxy herbicides are used most to control weeds in wheat. The most used compound is 2,4-D followed by MCPA. Weed control in wheat represents the second largest use of 2,4-D (corn is first) and represents about 25 percent of the use for all crops. Wheat probably accounts for about one third of the MCPA applied to crops. However, in terms of total herbicide use, wheat accounts for only about 5 percent of the use on crops. If wheat is underseeded with legumes, this precludes the use of herbicides since the legumes will be killed also.

Wheat diseases such as rust and smut are common and can have an effect on yields. The best controls for diseases are cultural practices, seed treatment and the use of pure seed that is not infected.

Barley

Barley production is largely concentrated in the northern plains, Montana, Idaho and California. North Dakota is the leading producer with about two million acres, roughly one third as large as the North Dakota wheat acreage. The inclusion of Montana and California accounts for half of the barley acreage. The total acreage nationally has been declining since about 1960, while average yields have increased somewhat [12]. Feed uses have declined, while uses for food and alcohol have increased over time, no doubt due to increasing beer production. About half of the crop is used for feed and half for food and other uses.

The pests of barley are similar to those for wheat and the controls are also similar. Thrips are a major insect species which can be controlled with parathion sprays, usually aerially applied. Barley differs from wheat in that Hessian Fly is not a problem. Barley does not present the most serious pest control problems in agriculture.

Rye

        Rye can be considered as a minor crop in the
U.S. Harvested acreage has declined since 1960 and
is currently at about 800 thousand acres. Although
up to three million acres may be planted annually,
most of it is pastured [12]. Yields have been
relatively unchanged for the last decade. North
Dakota, Georgia, South Dakota and Minnesota are
the leading producing states accounting for half of
the production.
        Rye is not a strong competitor for the use of
farm resources compared to wheat or corn, a fact
that has contributed to its declining production.
Export demand has been very volatile. While about
25 percent of the production is used directly for
food, the bulk of the production domestically is
used for feed. Historically, however, it has been
considered as a food grain.
        Pest problems in rye are very much like those
of the other small grains, although Hessian Fly is
not a problem in rye. Rye, due to its minor role
in feed and food supply, is not a major source of
pest control problems for agriculture.

Pest Control for Soybeans

        In recent years the acreage of soybeans has
increased. This has been due to (1) poor economic
conditions for cotton production in the traditional
cotton areas of the south, causing a switch to
soybeans and (2) export demand leading to dramatic
price increases causing soybeans to displace some
corn acreage as well as small grains. During the
decade 1967-76 soybean acreage increased by about
10 million acres to 50 million.
        The principal producing states (over four
million acres) are Illinois, Iowa, Missouri and
Arkansas. Other states with significant acreage
(two-four million) are: Indiana, Louisiana,
Minnesota, Mississippi and Ohio [12]. Because of
the short growing season relative to corn, soybeans
can be grown as a double crop following winter
wheat in parts of the Corn Belt or it can be grown
in rotation followed by winter wheat.
        Weeds and grasses are perhaps the major pest
problems of soybean production. Weeds are controll-
ed by tillage, cultivation and herbicides, although
the emphasis on tillage and cultivation has

diminished over the last ten years. Cultural practices are still important, however, especially for weed control early in the season.

Herbicides are available for use before planting as pre-emergence and post-emergence treatments. It is estimated by the U.S.D.A. that in excess of 80 percent of soybean acreage is treated with herbicides in some form [2].

Measured in pounds of active ingredients, the three groups of herbicides most used are: (1) the amides, which include propachlor and alanap; (2) the benzoics, which is amiben; and (3) others, including trifluralin, nitralin and fluorodifen [1]. Soybean applications account for about 16 percent of all herbicides used in agriculture. The majority of these are applied in the Corn Belt.

There are several materials from which to choose. The pre-plant materials tend to be more effective against grasses. The pre-emergent compounds work against most of the broadleaf and grassy species of weeds and must be applied before the weed seed germinates. Post-emergent controls are used much less extensively than the pre-plant and pre-emergence materials, although there may be some new material that will become more widely used in the future [6]. It has been demonstrated at the University of Illinois that herbicides increased soybean yields by about 20 percent on the average, based on a ten year experiment [4]. Herbicides did not reduce the variation in yields as measured by the coefficient of variation. Herbicides have made a significant economic impact on soybean production.

Soybean insect pests do their damage as larvae feeding on the leaves or pods. Among these are the Mexican bean beetle, green stink bug, green cloverworm and bean leaf beetle. Wireworms can also damage soybeans by attacking the seed in the soil prior to emergence. While soybean treatment for insects is relatively small compared to corn, high soybean prices have encouraged growers to be sensitive to insect damage, and treatment has increased more than the increased acreage alone would justify. In addition, as soybeans have become more prevalent in the south, insect problems there are enhanced by climatic factors not found in the Corn Belt.

Research has demonstrated that soybeans can tolerate considerable defoliation at early growth stages with no perceptible or little effect on yield [6, p. 65]. Furthermore, some rather good

guides to the amounts of defoliation that constitute
damage and the numbers of larvae necessary to
inflict damage are available. Therefore, farmers
can, if they wish, make careful decisions about
effective use of insecticides to control leaf
feeders. Such decisions will tend to optimize
income and minimize pesticide applications.

The array of insecticides used on soybeans
include toxaphene (a Chlorinated hydrocarbon),
methyl parathion (an organophosphate) and carbaryl
(a carbamate) [1]. Two of these materials, toxa-
phene and carbaryl, are being examined carefully
by EPA concerning their re-registration, so they
might not be available after 1980. Methyl para-
thion is very acutely toxic to warm-blooded ani-
mals and must be handled very carefully, preferably
by a professional. Soybean use of insecticides
accounts for about 3 percent of all insecticides
used in agriculture. This is small relative to
corn and cotton.

A non-chemical control available for soybean
insects is Bacillus thuringiensis used as a spray
against lepidopterous insects. Plant resistance,
pathogens, parasites and predators appear to work
in research modes, but their widespread use has
yet to be achieved.

Control Techniques and the Future of Pest Control for Grain and Soybeans

Two forces are at work on pest control in
agriculture with opposite effects. One force is
the concern for too much environmental pollution
resulting in close scrutiny of pesticides. This
force will tend to limit the array of chemicals
available. The other force is the continual con-
cern for the nourishment of the ever-growing
domestic and foreign population over the next 20
to 25 years and even longer into the future. This
force tends to support the demand for pest control
in general and chemical control in particular,
since chemicals are relatively easy to export and
are well developed.

As the conflicting forces of environmental
quality and need for food continue, a question can
be raised relative to the influence of the environ-
mental concerns on the ability of domestic agricul-
ture to produce. This question is raised despite
the conclusions of some that U.S. agriculture's

capacity to produce will be unchallenged by 1985
[13]. An attempt is made in this section to
examine the future of pest control to about 1990
and examine its possible influence on agriculture
and the environment.

Forecasting Pest Control Methods

This study examined some of the grain and
soybeans pest control options in the next decade or
so and analyzed the economic impact of those most
likely to be followed at least up to 1990.

Entomologists, weed scientists and plant
pathologists from across the nation were surveyed
to determine their judgment of the options avail-
able. In addition, assessments by the National
Academy of Science [6] and the Midwest Research
Institute [5] were used to project the future of
pest control for grain crops and soybeans.

Thirty-nine agricultural experts involved in
research and extension work in pest control respond-
ed to the survey. It was designed to

(1) assess the expected future importance of
various control techniques,

(2) to assess the impact of new practices such
as no tillage on pest control and other resources,
and

(3) to estimate the impact of pesticide techno-
logy on yields and crop production resources.

Table 1 presents a summary of the survey
respondents' predictions of probable use to be made
of various control methods over the next 15 years,
and the trends in use. The table shows that the
agricultural research and extension people surveyed
believed that chemicals and resistant varieties will
continue as the major pest control methods. Insec-
ticide use is expected to decrease as bacteria,
viruses and resistant varieties increase. However,
even with these expected increases, bacteria are
expected to remain in a minor role and viruses will
probably be relatively insignificant for grain crops.

Selecting the Options

The findings are in agreement with those of
other studies. Lawless and von Rümker [5, p. 319]
concluded that the chemical pesticide market will
hold to present levels or increase through 1985 and
perhaps to 2000. They cited increasing cropland use
and increasing world food demand as the principle

reasons. They also cited pesticide regulation and pest resistance as minor reasons for increases in the quantities of pesticides used.

In assessing the future use of biological pest control methods, Lawless and von Rümker concluded that substantial technical, economic and social limitations stand in the way of large-scale adoption of biological and related pest control technologies including phermones and hormones, the so-called third generation insecticides [5, p. 321]. Technical problems such as shelf life and transportation will probably keep biological methods from the large markets represented by grain crops and soybeans for at least the next 10-15 years. The report for the National Academy of Sciences by the Kennedy Committee came to the same conclusion [6, Ch. 11].

Based on the results reported above, it appears that the principle pest control strategies of the next 10-15 years are:

(1) Continue liberal use of chemicals with a minimum of cultural, mechanical and biological control methods to achieve a minimal form of integrated control

(2) Make changes in crops grown and their production locations to minimize the ecological advantage of pests; then supplement the program with chemicals, available biological controls, and cultural methods such as no-till, or

(3) Ban pesticides and adjust cropping systems and cultural practices to pest control with no chemicals. These strategies or some form of them will be examined in the empirical analysis to follow.

Empirical Analysis of Pest Control

Options that appeared feasible for pest control on grain crops and soybeans were selected from the previous section. Following this, a model for U.S. agriculture developed by Taylor [11] was used to assess the impacts of various possibilities.

The model was a national linear programming-spatial equilibrium model that maximized the consumers' surplus (a measure of consumer economic welfare) plus the producers' surplus (a measure of economic rent to producer assets). An explanatory note on consumers' and producers' surpluses is found in the appendix. To accomplish the maximization, the model chooses the crops for each of several

producing regions and allocates resources among the
crops so as to achieve a competitive market equili-
brium (the quantity supplied equals the quantity
demanded) while at the same time locating production
to minimize the transportation costs from the
production location to the consumption location.
The model has been used previously to analyze policy
alternatives related to restricting nitrogen ferti-
lizer, hail suppression, boll weevil control and
soil conservation [10].

Model Dimensions and Data

     To implement the model, the nation was divided
into 115 producing regions corresponding roughly to
the sub-areas defined for the Firm Enterprise Data
System (FEDS) used as a basis for budgets by the
Economics, Statistics and Cooperative Service (ESCS)
of the U.S. Department of Agriculture. In some
cases, sub-areas were combined to form a producing
region. Budgets for crop activities were developed
for each producing region to reflect the differences
in yields and costs between regions.
     In addition, the nation was divided into 21
consuming regions each of which consisted of a state
or states. These consuming regions formed the basis
for computing transportation costs for products as
supply was equated to demand. Each of the 21 con-
suming regions contained a subset of the 115
producing regions with a producing region belonging
to one and only one producing region. In certain
eastern and far western states, areas were elimi-
nated altogether because there was little or no
food or feed grain production. A map of the 21
consuming regions is presented in Figure 2. A map
showing the producing regions overlaid by the con-
suming regions is found in Appendix Figure 1.
     Production activities included were corn, wheat,
oats, barley, grain sorghum, rye, soybeans and
cotton. Cotton was included since it is a strong
alternative to grain and soybeans in certain areas
of the south, southwest and far west.
     In total, the model contained 524 different
activities reflecting regional differences in crops
and cultural practices such as irrigation. Acreage
flexibility constraints were placed on the model to
prevent the model from allocating more or less than
a certain percentage of land to a crop in a produc-
ing region. The constraints were first set at 75
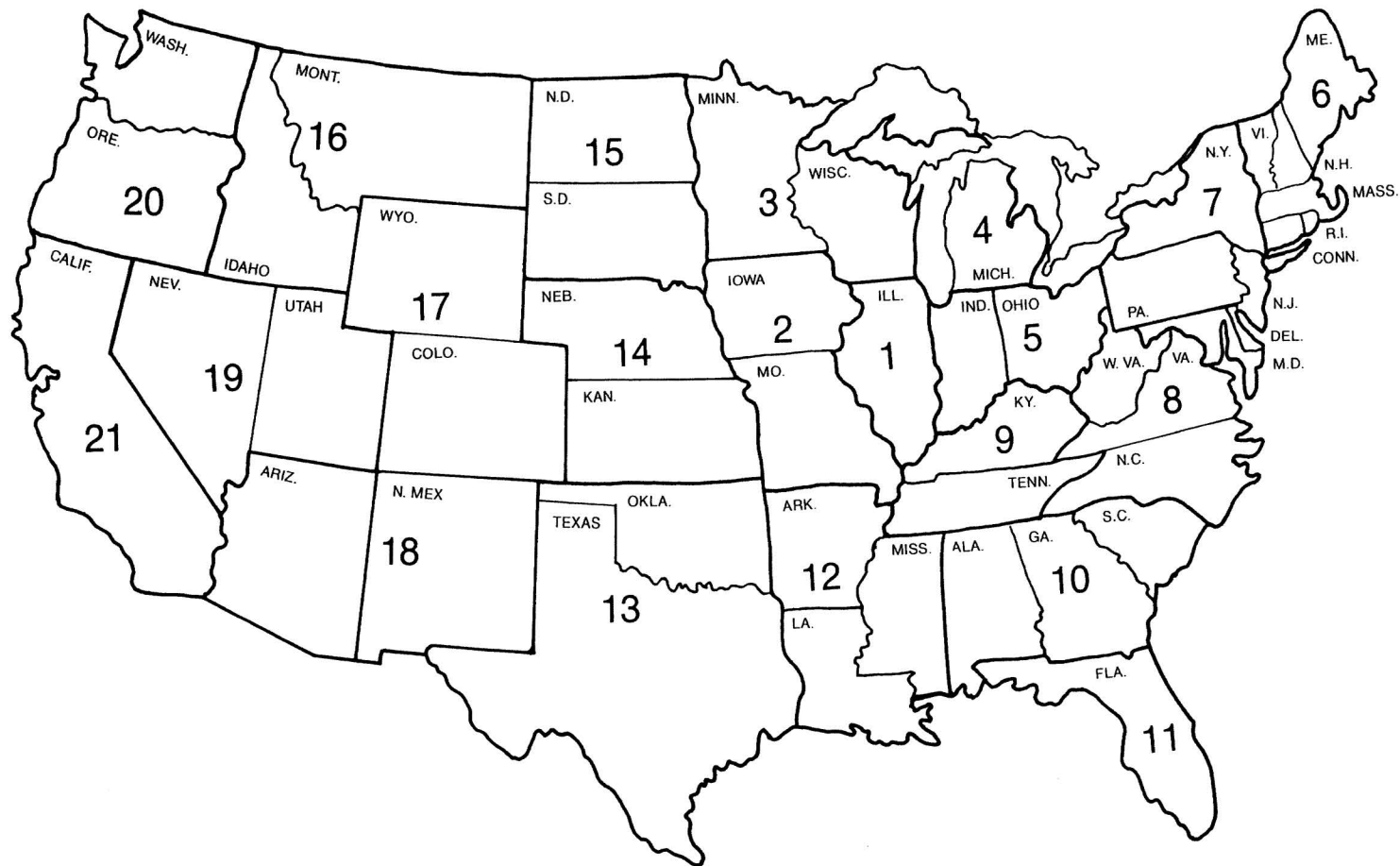
Figure 2. Consuming regions for National Linear Programming-Spatial Equilibrium Model. U.S. 1975.

and 125 percent of the 1975 actual acreages in the producing regions and then certain scenarios were evaluated with the constraints set at 50 and 150 percent of the 1975 actual acreages. In this manner upper and lower bounds were placed on the crops produced and unrealistic solutions were prevented.

Equilibrium in consumption was achieved through the use of 21 consuming regions. There were transportation activities for rail and barge alternatives for each of three product groups, namely: feed grains (corn, grain sorghum and oats), food grains (wheat, barley and rye), and oilseeds (soybeans and cotton). The consuming regions followed state boundaries. Homogeneity of crop production capability was the basis for definition of these regions. Since the surpluses which were maximized were net of transportation costs, the transportation costs were minimized in each solution.

Basic data on yields and costs of production were obtained from U.S.D.A. crop budgets for 1975. These data were specific to producing regions for each crop under various production practices such as irrigation, fallowing, and the pest control methods used in 1975. Data on nitrogen, phosphorus and potassium fertilizer elements were included for each crop activity to be accounted by the model along with insecticide and herbicide expenditures.

Four different pest control scenarios were examined and a solution for the model was obtained for each and compared to the 1975 benchmark solution. The benchmark solution was obtained by solving the model to obtain acreages, production and prices with no restrictions on pesticide use.

The four scenarios are identified and defined as follows:

Scenario 1 - No chemical pesticides used on grain crops or soybeans using yield reduction coefficients based on a survey of agricultural experts (Table 2).

Scenario 2 - No chemical pesticides used on grain crops, soybeans or cotton using yield reduction coefficients based on a survey of agricultural experts with cotton yield reduction coefficients

supplied by C. R. Taylor of Texas A & M resulting from boll weevil control research.

Scenario 3 - No chemical pesticides used on grain crops, soybeans or cotton using yield coefficients supplied by C. R. Taylor for all crops (Table 3).

Scenario 4 - No tillage for grain crops or soybeans using coefficients for expected adoption, yield, pesticide use and other resource needs based on a survey of agricultural experts (Table 4).

The coefficients used in Scenario 3 provided yield reduction coefficients that were in general less than those estimated by the survey of experts. All of the yield impact coefficients are arrayed in Tables 2 and 3.

Data for measuring the impact of "no-till" on yield, pesticide use and cultivation costs are given in Table 4. The numbers in the table are the modal or most typical response from 39 agricultural research and extension workers in response to the statement:

Assuming that the use of minimum tillage increases to include the maximum possible acreage in the state (given presently available technology), the following responses might be expected.

The details shown in Table 4 were then listed with blanks to be checked or filled.

The production coefficients in the affected activities were adjusted for each alternative solution considering the data collected. That is, variable costs[1] were changed to reflect changes in pesticide costs and tillage costs and yield coefficients were changed to reflect the degree of pest damage. It was assumed that quality of output was constant over each alternative.

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[1] The model maximized the return above all costs except return to land and overhead. In the FEDS budgets, items for variable costs, ownership costs such as machinery depreciation and management charge were included in costs. Variable costs included items such as seed, fertilizer, pesticides, fuel and labor.

Discussion of the model here is very general in the interest of space. A detailed description of the basic model can be found in Taylor et al. [11].

Results of Model Solutions

After computation, the model solutions were summarized. With the exception of the results showing changes in the surpluses, grain and oilseed prices and the measurements of land rent, the results are reported by consuming region. For the crop acreages, the benchmark and the pesticide use scenario solutions were compared to the actual acreages in those regions in 1975. The relevant comparison for this analysis in each case, however, is the comparison of the pesticide use scenario with the benchmark solution.

The results of the model solutions showing acreages and production by consuming region for feed grains, food grains and the oilseed crops, soybeans and cotton are found in the Appendix. Summaries of the results in percentages appear in tables incorporated in the body of the report. Blank cells in these tables indicate that no data were available.

Pesticide Prohibition with Flexibility
Constraints at 75-125 Percent

Prohibiting the use of pesticides under the prescribed constraints conditions resulted in solutions that indicated an increase in acreage of the feed grains (corn, grain sorghum and oats) by about 4 to 6 percent as shown in Table 5. Total production of these grains, measured in corn equivalents, was reduced by from 12 to 27 percent as shown in Table 5. Increases in acreage were the most pronounced in Consuming Regions: 14 (Kansas and Nebraska), 15 (North and South Dakota), 10 (Alabama, Georgia and South Carolina), 11 (Florida), 17 (Wyoming and Colorado) and 8 (West Virginia, Virginia and North Carolina). The Regions 1, 2, 3 and 5, generally considered to be the Corn Belt, did not indicate much change in feed grain acreage as a result of banning pesticides on grain crops, soybeans and cotton.

When pesticides were banned on grain crops and soybeans, but not on cotton, the results showed

little change in total acreages of food grains
(Scenario 1, Table 6) compared to the situation
where pesticides were also banned on cotton. A
similar result was obtained for feed grains (Table
5). Banning pesticides on grain crops and soybeans
alone had little effect on cotton acreage. However,
when the ban was extended to cotton, the cotton
acreage increased by almost one third compared to
the benchmark (Table 8).

The response of soybean acreage to prohibiting
the use of pesticides varied depending upon which
of the "no pesticide" scenarios was used (Table 7).
If Scenario 3 is relevant, total acreage would be
reduced by about 1.5 million acres or 3 percent.
Acreages in Iowa and Missouri (Region 2) and
Michigan (Region 4) accounted for most of the acre-
age reduction under this scenario. The results
seem to indicate that feed grain acreage, primarily
corn, expanded to replace soybeans disadvantaged by
the lack of herbicides. Compare Tables 5 and 7.
Wheat and barley acreages also tended to offset the
reduced soybean acreage (Table 6).

National soybean acreage was reduced about
1 percent when cotton pesticides were included in
the prohibition (Scenario 2). When only grain crops
and soybeans usage was prohibited, total soybean
acreage rose about 3 percent (Scenario 1). Acreage
in Region 12 (Arkansas, Mississippi and Louisiana)
rose by almost 2 million acres (24%) under this
scenario, however, the acreage in Region 2 (Iowa
and Missouri) declined by almost 1 million acres
(9%) for the reasons given above. The increases in
soybean acreages were undoubtedly due to the
increased prices that resulted from lowered yields
and because soybeans are a better alternative cash
crop than corn in Arkansas, Mississippi and Louisi-
ana as well as in the bulk of the south and south-
east.

When the prohibition of pesticides was extended
to cotton, the acreage also increased due to
lowered production and higher prices (Table 8). In
general, the prohibition of pesticide use on grains,
soybeans and cotton increased acreages of cotton,
decreased soybeans and reduced oilmeal production
(Table 7 and 8).

The effects of the prohibition on production
of food grains is shown in Table 5, for feed grains
in Table 6 and for oilmeal in Table 7. Production
for all product groups was reduced. For the

scenarios that used the coefficients derived from the survey of research and extension workers, namely Scenarios 1 and 2, production of feed grains and oilmeal was reduced by 26 and 29 percent respectively compared to that benchmark. Food grains were reduced somewhat less (about 18 percent) suggesting a less important role for pesticides in food grain production than for feed grains or soybeans.

The acreage and production impacts were somewhat less for Scenario 3 than for Scenarios 1 and 2. This alternative used coefficients for yield effects and tillage costs based on various research studies as given in Table 3. These coefficients implied less dramatic yield reductions due to prohibiting pesticides than was the case for those obtained from the research and extension workers. As a consequence, the solution based on this alternative called for a 13 percent reduction in feed grain production (Table 5), a 3 percent reduction in food grains (Table 6) and about 21 percent reduction in oilmeal output (Table 7). The impact on oilmeal production derives from the importance of herbicides in soybean production. Acreages for food and feed grains did not increase as much as with the other scenarios and soybean acreage declined.

Farmer expenditures for pesticides and fertilizer use were computed for the solutions. Since the prohibition of pesticides resulted in larger acreages, fertilizer use increased (Tables 9 and 10). Naturally the expenses for insecticides and herbicides were zero for Scenarios 1, 2 and 3 since all pesticides were prohibited. Insecticide and herbicide expenditures for Scenario 4, the no-till scenario, were computed as a percent of the benchmark solution and are shown in Table 9. This scenario resulted in 4 percent increase in insecticide expenditures and a 3 percent increase in herbicide expenditures. The increase was not more dramatic because of the assumptions about adoption rates for no-till (see Table 4).

Pesticide Prohibition with Flexibility Constraints at 50-150 Percent

Selected scenarios were examined after changing the acreage flexibility constraints to allow more latitude for acreages to shift between regions.

Scenarios 3 and 1 were examined again to see the effect of more regional flexibility in acreages.

The result was that the acreage of feed grains increased more absolutely and percentagewise with the pesticide prohibitions when the constraints were relaxed, and the feed grain production was reduced less (Table 11). This resulted from more shifting between regions, and production could be moved to regions where marginal costs were less.

In Table 11 one can see that Scenario 1 for example, provided a 21 percent reduction in feed grain output relative to benchmark when flexibility constraints were set at 50-150 percent compared to a reduction of 26.6 percent with the flexibility constraints set at 75-125 percent (Table 5). The changing of the flexibility constraints made little difference in the relative level of food grain production. These results can be seen by comparing Tables 6 and 11. The stability of food grain production is probably due to the fact that (a) pesticides are not as important for food grain production as for feed grains and (b) food grains can be grown profitably throughout a wider geographic area than can the feed grains. For instance, in Table 11, the acreage of food grains in Region 4 (Michigan) increased by about two and a half times as a result of the ban on pesticides. By contrast, the acreage of feed grains increased only by about 9 percent in the same region (Table 11).

In the case of soybeans, the impact of changing flexibility constraints on acreage under different pesticide prohibition scenarios was minimal. The change in the constraints reduced the total benchmark acreage by less than 2 percent. Regional distributions of acreages were changed markedly in certain instances. For example, the loosening of the constraints decreased the benchmark acreage in Region 1 (Illinois) and increased it by 35 percent in Region 2 (Missouri and Iowa) and increased the acreage in Region 3 (Minnesota and Wisconsin) by 72 percent.

The banning of pesticides with the 50-150 percent flexibility constraints did not change total soybean acreage significantly; only by 3.5 percent or less. Banning pesticides resulted in reductions in oilmeal production by about the same amount, 25 percent, under the looser acreage constraints as under the tighter constraints (see Tables 7 and 12).

Effects of Pesticide Prohibition on Product Prices and Economic Surpluses

Table 13 shows the prices generated by the model for the various scenarios with the alternative flexibility constraints. Two scenarios led to much higher prices relative to the benchmark model due to the reductions in output noted earlier. One of those prohibited pesticide use on grains and soybeans. The other prohibited pesticides on grains, soybeans and cotton using the coefficients based on the survey of extension and research workers. Feed grain prices and oilmeal prices increased about three fold under the tight flexibility constraints.[2] Food grain prices were increased least due to smaller relative reductions in output noted above. The use of Scenario 3 which assumed smaller yield impacts gave the expected result--food grain prices changed little from the benchmark and price increases for feed grains and oilmeal for Scenario 3 were roughly one-third of those for Scenarios 1 and 2 where yields were assumed to be reduced more dramatically.

Prices generated by the model with the 50-150 percent acreage flexibility constraints, as shown in Table 13, were changed very little from the benchmark with tighter constraints. The prices generated for Scenarios 1 and 3 were only slightly higher for food grains compared to the 75-125 percent acreage flexibility constraints due to a slightly lower production. Feed grain prices for Scenario 1 were $4.43 per bushel of corn equivalent compared to $6.84 per bushel with the tighter constraints due to a smaller relative reduction in production of feed grains. Oilmeal prices were unaffected by the change in flexibility constraints.

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[2] These feed grain prices appear too high based on usual demand elasticities. However, the demand function in the model was a horizontal summation of the domestic and export demand functions resulting in a kink in the total demand function. The reduction in feed grain output resulting from the model forced the quantity-price relation on the very inelastic domestic demand curve resulting in the large price increases for the two scenarios in question. For a discussion of the demand relations assumed see Taylor et al. [11, p. 15].

In Table 14, one can see the effect of the pesticide prohibition alternatives on economic welfare as measured by the surpluses. These results are for the 75-125 percent flexibility constraints only. The results for the 50-150 percent constraints would be similar to those in Table 14 except for the effect of the lower feed grain prices when pesticides are prohibited. The results show consumers worse off with reduced consumer surpluses due to higher prices for less food. Producers are shown to be better off with increased producer surpluses due to product price increases that exceeded increases in variable costs. Landowners are shown to benefit by increased land rents, which constitute the change in producers' surplus. This increase in economic rent would, should it come to pass, likely lead to higher land prices.

In summary, this analysis suggests that in the absence of control alternatives to chemical pesticides, cropping patterns would not change markedly. However, without the pest control provided by pesticides, grain and soybean production would fall and prices, farm income and land values would rise. The segment of consumer welfare measured by the market values for food would be diminished markedly unless consumer income increased by comparable amounts.

The No-Till Alternative

The no-tillage scenario was evaluated involving only corn, soybeans and grain sorghum. The expected adoption rates and yield and cultivation coefficients are shown in Table 4, derived from the survey of research and extension workers.

According to the model solution based on the expected adoption rates, the no-till alternative had little effect on either acreages or production (Tables 5, 6, and 7) with the exception of oilmeal. The model coefficients assumed yield reductions of from 5 to 10 percent for soybeans produced with no-till resulting in reduced oilmeal output.

The principal difference between the no-till alternative and the benchmark solution was in herbicide and insecticide expenditures by farmers. Insecticide expenditures were increased by about 4 percent and herbicide expenditures were increased by about 3 percent. The no-till alternative did not result in any significant change in cropping patterns.

In Table 11 one can see that the no-till alternative made no significant differences in product prices since cropping patterns were not altered. From Table 14 one can see that no-till influenced the welfare measure very little also.

The no-till alternative does not reduce pesticide use so no particular advantage can be listed in that respect. However, soil erosion would likely be reduced and that would generally benefit the environment. To the extent that soil erosion is reduced, it could reduce the pesticides found in bodies of water and water courses and have a beneficial effect on the distribution of pesticide pollution. The magnitude of this impact was not estimated.

Policy Implications and Environmental Consequences: Some Conclusions

This study examined the outlook for pest control in agriculture for the next 10-15 years, up to the 1990s. After examining the likely development of technology, the conclusion was that while there are alternatives to chemicals, none of the new alternatives, such as the "third generation" compounds, are likely to be of major importance in this time dimension. The review of the pest control situation for grain crops and soybeans revealed extensive use of cultural control methods and certain biological controls such as resistant varieties. Therefore, pest control in the above crops for the balance of the century will probably be limited to the use of chemicals.

The empirical planning analysis in this study demonstrated in a crude way the importance of pest control in maintaining production, holding down product prices and land prices. Land prices are currently under rather severe inflationary pressure. The study demonstrated that feed grain and oilmeal prices and production are the most sensitive to the presence of effective pest control as agriculture is currently organized.[3]

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[3]One should remember, however, that the data documenting the production impact of pesticides on an aggregate basis was an extreme approximation and involved considerable "judgment" estimation. Therefore, the results should be treated accordingly.

Over the last 10 years regulatory action by the Environmental Protection Agency has had an impact on the kind, amount and way that pesticides are used. Many of the environmentally undesirable chlorinated hydrocarbon registrations have been cancelled. The use of certain compounds have been restricted to certified applicators which will, it is hoped, result in a reduction of flagrant environmental insults. The problems of pest resistance, secondary pests and resurgence remain.

Environmental concerns with pesticide use remain. They are hazardous to applicators and field workers, although the latter is no problem for the crops considered here. Concern for destruction of beneficial organisms as well as wildlife and aquatic species is evident. The unfortunate fact is that the extent or value of these effects is not adequately documented. These issues need continued research.

The question of what can be done, given the state of affairs as presented by this study, to minimize the damage to the environment resulting from the use of chemical pesticides constrained by some level of agricultural production still remains. It seems that the best way to accomplish this objective is to eliminate all but those pesticide applications that are absolutely required to meet production demands.

Since the conclusion of this study is that over the next 10-15 years U.S. agriculture will be dependent in a major way on chemical pesticides for pest control in grain crops and soybeans, the policy alternatives seem limited to those that will eliminate unnecessary pesticide applications. Generally there are two ways to accomplish this. First, if management resources were available, farmers could make better decisions concerning the amount and timing of pesticide applications and selection of resistant varieties where appropriate. One example of this approach has been subsidized insect scouting programs in cotton. Second, since one important motivation to use pesticides is to reduce risk and since this looms ever more important as farmers are obligated for larger cash expenses in producing a crop, some method of risk pooling should reduce the use of pesticides for insurance purposes.

Considering the first alternative, there may be some possibilities for grain crops and soybeans where above-ground insects are involved. Insect

scouts might be useful in controlling armyworms,
grasshoppers or greenbugs for example. They would
be less useful where the corn soil insect complex
is involved, because soil insect problems are so
difficult to forecast. Scouting would not be of
help in dealing with weed problems.

Where above-ground insects are involved on
grain crops and soybeans, seldom are these crops
treated on a schedule as is the case with cotton or
horticultural crops. Therefore, farmers should act
as scouts and the better farmers are doing so.
Whether they treat unnecessarily depends on how
accurately farmers are able to identify the pests
as well as how well they understand what consti-
tutes damage. Most extension pest management
programs to educate farmers in insect identifica-
tion and economic thresholds would help to improve
performance in this area.

In the second alternative, socially subsidized
insurance might reduce pesticide applications that
are made "just in case." By farmers and society
sharing the costs through an insurance program
operated by the Agricultural Stabilization and
Conservation Service of the U.S. Department of
Agriculture, the risks of unforeseen attacks by
insects and diseases could be pooled [3]. Such a
program might be especially useful in dealing with
corn soil insects such as cutworms and rootworms.
The insecticides are applied either pre-plant or
at planting time before it is known with much
certainty whether there is a real threat. Farmers
should be willing to pay insurance premiums at
least equal to the cost of insecticide treatments
if assured of indemnity of losses should the pests
materialize.

In the case of weeds, claim adjustment would
be difficult, if not impossible, to administer. An
insurance program would also likely involve more
reporting on crop acres and practices than many
farmers would want to do--an obvious drawback given
the current farmer attitude toward regulation and
government interference. While there are some
real questions about the feasibility of an insurance
program to cover risks from pests, it has not
received the attention it deserves.

Table 1. Estimated Importance of Pest Control Methods for
Grain Crops and Soybeans, U.S. Agriculture
1978-1992

Pest Control Technique	Probable Use Over Next 15 Years	Trend in Use[1]
Chemical Poisons		
Insecticides	major	−
Herbicides	major	+
Mechanical Methods	minor	−
Biological Methods		
Parasites and Predators[2]	minor	0
Bacteria	minor	+
Viruses	not significant	+
Phermones	not significant	0
Resistant Varieties	major	+
Pest Genetics	minor	−
Cultural Methods		
Crop Rotations	minor	−
Trap Crops	minor	0

Source: A summary of responses from 39 U.S. agricultural
extension and research workers, 1977.

[1] "+", "-", or "0" means a trend that is increasing,
decreasing or unchanged, respectively.

[2] Parasites and predators refers to the application
of parasites and predators. Naturally occurring parasites
and predators have been and will continue to be important
in insect control.

Table 2.   Estimates of Percent Yield Impact on Average Yield,
           Level of Cultivation and Replant from Banning
           Chemical Pesticides, from Survey of Agricultural
           Scientists and Extension Workers, U.S., 1976

REGION	CROP	YIELD	CULTIVATION	REPLANT
Northeast and	Soybeans	-15	+15	0
Appalachia	Corn	- 5	+20	+10
	Grain			
	Sorghum	- 5	+20	0
	Wheat	- 5	+10	0
Southeast	Soybeans	-45	+100	+15
and Delta	Corn	-25	+75	+20
	Grain			
	Sorghum	-25	+75	+50
	Wheat	-35	0	0
Corn Belt and	Soybeans	-25	+100	0
Lake States	Corn	-30	+100	+25
	Grain			
	Sorghum	-15	+100	+25
	Wheat	-15	+10	+10
Northern	Soybeans	-25	+100	+10
Plains	Corn	-45	+80	+50
	Grain			
	Sorghum	-40	+80	+50
	Wheat	-25	0	+15
Southern	Soybeans	-40	+200	+ 5
Plains	Corn	-30	+150	+20
	Grain			
	Sorghum	-25	+150	+10
	Wheat	-15	0	0
Pacific and	Soybeans	-45	+40	+30
Mountain	Corn	-45	+50	+30
	Grain			
	Sorghum	No Data		
	Wheat	-45	+ 5	+20

Source: Survey responses from 39 Agricultural Research
          and Extension Workers

Table 3.   Estimates of Percent Yield Impact on Treated Acres
of Banning the Use of Herbicides and Insecticides
on Selected Grain Crops, by Region U.S., 1976.

Region	Crop	Pesticide Type	Yield Impact	% Acreage Treated (e)
Northeast	Corn (a)	Herbicide	−20.0	86
	Corn (b)	Insecticide	−0.18	9
	Soybeans (a)	Herbicide	−22.0	52
	Grain Sorghum (c)	Herbicide	−25.0	14
Appalachian	Corn (a)	Herbicide	−20.0	73
	Corn (b)	Insecticide	−0.90	9
	Soybeans (a)	Herbicide	−22.0	55
	Grain Sorghum (c)	Herbicide	−25.0	50
	Grain Sorghum (d)	Insecticide	−0.50	12
	Wheat (c)	Herbicide	−3.0	1
Southeast	Corn (a)	Herbicide	−20.0	32
	Corn (b)	Insecticide	−0.27	1
	Soybeans (a)	Herbicide	−45.0	45
	Grain Sorghum (c)	Herbicide	−25.0	13
	Grain Sorghum (d)	Insecticide	− 2.0	79
	Wheat (c)	Herbicide	− 3.0	4
Delta	Corn (a)	Herbicide	−20.0	59
	Corn (b)	Insecticide	− 0.9	4
	Soybeans (a)	Herbicide	−45.0	63
	Grain Sorghum (c)	Herbicide	−25.0	54
	Grain Sorghum (d)	Insecticide	−2.00	36
Corn Belt	Corn (a)	Herbicide	−20.0	87
	Corn (b)	Insecticide	− 4.3	45
	Soybeans (a)	Herbicide	−22.0	77
	Grain Sorghum (c)	Herbicide	−25.0	58
	Grain Sorghum (d)	Insecticide	− 3.0	24
	Wheat (c)	Herbicide	−10.0	71
Lake States	Corn (a)	Herbicide	−20.0	92
	Corn (b)	Insecticide	− 1.7	25
	Soybeans (a)	Herbicide	−22.0	71

Table 3 (continued)

Region	Crop	Pesticide Type	Yield Impact	% Acreage Treated (e)
Northern Plains	Corn (a)	Herbicide	-20.0	70
	Corn (b)	Insecticide	- 3.2	43
	Soybeans (a)	Herbicide	-22.0	56
	Grain Sorghum (c)	Herbicide	-25.0	59
	Grain Sorghum (d)	Insecticide	- 3.0	37
	Wheat (c)	Herbicide	-12.0	48
Southern Plains	Corn (a)	Herbicides	-20.0	12
	Corn (b)	Insecticide	-0.05	6
	Soybeans (a)	Herbicide	-22.0	39
	Grain Sorghum (c)	Herbicide	-25.0	39
	Grain Sorghum (d)	Insecticide	- 5.0	42
	Wheat (c)	Herbicide	- 5.0	3
Mountain	Corn (a)	Herbicide	-20.0	48
	Corn (b)	Insecticide	- 2.8	39
	Grain Sorghum (c)	Herbicide	-25.0	24
	Grain Sorghum (d)	Insecticide	- 2.0	40
	Wheat (c)	Herbicide	-10.0	68
Pacific	Corn (a)	Herbicide	-20.0	34
	Corn (b)	Insecticide	- 2.7	19
	Grain Sorghum (c)	Herbicide	-25.0	11
	Grain Sorghum (d)	Insecticide	- 1.0	79
	Wheat (c)	Herbicide	-10.0	67

(a) Source: Fred Slife [9]
(b) Source: Pimentel and Shoemaker [7]
(c) Source: Morris Merkle, telephone conversation with
             C. R. Taylor
(d) Source: George Teetes, telephone conversation with
             C. R. Taylor
(e) Source: Paul Andrilenas [1]

Table 4. Estimated Maximum Adoption of the Practice of "No-till" and Its Effect on Yield, Pesticide Use and Cost of Cultivation, by Production Regions, Based on a Survey of Agricultural Research and Extension Workers, U.S.

Region	Crop	Percent Acreage Affected	Percent Change				
			Herbicides	Insecticides	Fungicides	Cultivation Costs	Yield
Northeast and Appalachian	Soybeans	90	+50	+40	+10	-50	- 5
	Corn	95	+65	+50	+10	-50	- 2
	Grain Sorghum	90	+70	+10	+ 2	-50	- 2
Southeast and Delta	Soybeans	10	+25	+50	--*	-50	- 5
	Corn	20	+10	+ 5	--	-50	-10
	Grain Sorghum	4	+10	+25	--	-50	-10
Corn Belt and Lake States	Soybeans	15	+10	+ 2	+ 5	-50	- 5
	Corn	25	+15	+10	+ 5	-50	- 5
	Grain Sorghum	15	+10	+10	--	-50	- 5
Northern Plains	Soybeans	20	+ 5	+10	--	-50	-10
	Corn	15	+ 5	+10	--	-50	- 5
	Grain Sorghum	20	+10	+15	--	-50	- 5
Southern Plains	Soybeans	40	+25	0	--	-50	-10
	Corn	5	+ 5	+ 5	--	-50	- 5
	Grain Sorghum	35	+40	0	--	-50	- 5
Pacific and Mountain	Soybeans	75	+25	+20	--	-50	0
	Corn	40	+15	0	--	-50	- 5
	Grain Sorghum	--	--	--	--	--	--

* Blank cells indicate no data.

Table 5. Indices of Acreage and Production of Feed Grains, by Consuming Region for Pesticide Use Scenarios, Benchmark Solution = 100, 1975, U.S.*

Consuming Region	1975 Actual	Benchmark Model	Scenario**			
			1	2	3	4
1 Acreage	84	100	100	100	100	100
Production	--***	100	70	70	81	99
2 Acreage	91	100	105	105	105	100
Production	--	100	74	74	85	99
3 Acreage	98	100	103	103	103	101
Production	--	100	74	74	85	99
4 Acreage	86	100	105	105	105	100
Production	--	100	73	73	84	99
5 Acreage	83	100	101	101	100	100
Production	--	100	71	71	81	99
6 Acreage	--	---	---	---	---	---
Production	--	---	---	---	---	---
7 Acreage	96	100	103	103	103	100
Production	--	100	97	97	86	98
8 Acreage	103	100	127	127	126	91
Production	---	100	116	116	104	89
9 Acreage	85	100	100	100	100	89
Production	--	100	95	95	86	89
10 Acreage	114	100	135	133	133	100
Production	----	100	99	98	122	98
11 Acreage	133	100	133	133	117	100
Production	---	100	100	100		100
12 Acreage	81	100	100	100	100	100
Production	--	100	76	76	178	100
13 Acreage	95	100	102	93	93	100
Production	--	100	61	57	89	102
14 Acreage	105	100	109	109	109	103
Production	--	100	63	63	93	103
15 Acreage	100	100	115	115	115	101
Production	---	100	90	90	105	100
16 Acreage	---	---	---	---	---	---
Production	---	---	---	---	---	---

Table 5 (continued)

17 Acreage	110	100	120	120	120	92
Production	---	100	65	65	95	89
18 Acreage	89	100	109	100	100	100
Production	--	100	112	100	92	100
19 Acreage	--	---	---	---	---	---
Production	--	---	---	---	---	---
20 Acreage	--	---	---	---	---	---
Production	--	---	---	---	---	---
21 Acreage	101	100	123	114	100	100
Production	---	100	85	76	91	97
Total Acreage	94	100	106	105	104	100
Total Production	--	100	73	73	88	99

*   Flexibility constraints set at 75-125% of actual 1975 acres.

**   Scenarios are defined as follows:

     1.   No pesticides on grain crops or soybeans with yield coefficients based on a survey of agricultural experts.

     2.   No pesticides on grain crops, soybeans or cotton with yield coefficients based on a survey of agricultural experts.

     3.   No pesticides on grain crops, soybeans or cotton with yield coefficients provided by C.R. Taylor.

     4.   No tillage operation with yield coefficients based on survey of agricultural experts.

*** Blank cells indicate no data.

Table 6.   Indices of Acreage and Production of Food Grains by Consuming
            Region for Pesticide Use Scenarios, Benchmark Solution = 100,
            1975, U.S.*

Consuming Region	1975 Actual	Benchmark	Scenario** 1	2	3	4
1 Acreage	133	100	100	100	100	100
Production	---***	100	93	84	84	100
2 Acreage	133	100	100	100	100	100
Production	---	100	93	86	86	100
3 Acreage	133	100	118	118	86	100
Production	---	100	94	102	102	100
4 Acreage	133	100	148	148	129	100
Production	---	100	118	125	125	100
5 Acreage	133	100	100	100	100	100
Production	---	100	93	85	85	100
6 Acreage	---	---	---	---	---	---
Production	---	---	---	---	---	---
7 Acreage	133	100	100	100	100	100
Production	---	100	129	94	94	100
8 Acreage	133	100	100	100	100	100
Production	---	100	101	100	100	100
9 Acreage	133	100	100	100	100	100
Production	---	100	99	90	90	100
10 Acreage	133	100	100	100	100	100
Production	---	100	101	63	75	100
11 Acreage	---	---	---	---	---	---
Production	---	---	---	---	---	---
12 Acreage	87	100	66	66	100	82
Production	---	100	101	42	42	84
13 Acreage	115	100	105	99	98	100
Production	---	100	98	82	83	100
14 Acreage	102	100	104	104	104	100
Production	---	100	97	78	78	100
15 Acreage	123	100	117	117	104	100
Production	---	100	99	86	86	100
16 Acreage	103	100	102	101	100	100
Production	---	100	95	75	75	100

Table 6 (continued)

17 Acreage	108	100	100	100	100	101
Production	---	100	93	56	56	100
18 Acreage	133	100	100	107	100	100
Production	---	100	99	92	92	100
19 Acreage	---	---	---	---	---	---
Production	---	---	---	---	---	---
20 Acreage	99	100	100	100	100	100
Production	---	100	95	66	66	100
21 Acreage	119	100	99	98	99	100
Production	---	100	98	91	90	100
Total Acreage	113	100	106	104	102	100
Total Production	---	100	97	81	80	100

*   Flexibility constraints set at 75-125% of 1975 actual acreages.

** Scenarios are defined as follows:

    1.   No pesticides on grain crops or soybeans with yield coefficients based on a survey of agricultural experts.

    2.   No pesticides on grain crops, soybeans or cotton with yield coefficients based on a survey of agricultural experts.

    3.   No pesticides on grain crops, soybeans or cotton with yield coefficients provided by C.R. Taylor.

    4.   No tillage operation with yield coefficients based on survey of agricultural experts.

*** Blank cells indicate no data.

Table 7.   Indices of Soybean Acreage and Oilmeal Production by Consuming
           Region for Pesticide Use Scenarios, Benchmark Solution = 100,
           1975, U.S.*

Consuming Region	1975 Actual	Benchmark	Scenario** 1	2	3	4
1 Acreage	125	100	100	100	100	100
Production	---****	100	75	75	83	99
2 Acreage	113	100	91	89	89	100
Production	---	100	69	68	71	99
3 Acreage	133	100	100	100	100	100
Production	---	100	75	75	84	99
4 Acreage	104	100	77	77	77	100
Production	---	100	58	58	66	99
5 Acreage	122	100	97	97	100	100
Production	---	100	73	73	83	99
6 Acreage	---	---	---	---	---	---
Production	---	---	---	---	---	---
7 Acreage	133	100	100	100	100	100
Production	---	100	84	84	89	96
8 Acreage	133	100	111	109	109	100
Production	---	100	94	93	96	96
9 Acreage	123	100	115	107	107	92
Production	---	100	98	91	94	89
10 Acreage	133	100	121	113	103	103
Production	---	100	68	64	83	102
11 Acreage	---	---	---	---	---	---
Production	---	---	---	---	---	---
12 Acreage	126	100	124	111	99	103
Production	---	100	70	65	74	102
13 Acreage	109	100	118	106	106	89
Production	---	100	90	91	98	97
14 Acreage	95	100	95	95	95	100
Production	---	100	72	72	84	98
15 Acreage	80	100	100	100	100	100
Production	---	100	75	75	88	98
16 Acreage	---	---	---	---	---	---
Production	---	---	---	---	---	---

Table 7 (continued)

17 Acreage	---	---	---	---	---	---
Production	---	---	---	---	---	---
18 Acreage	---	---	---	---	---	---
Production***	---	100	127	96	96	100
19 Acreage	---	---	---	---	---	---
Production	---	---	---	---	---	---
20 Acreage	---	---	---	---	---	---
Production	---	---	---	---	---	---
21 Acreage	---	---	---	---	---	---
Production	---	100	97	79	79	100
Total Acreage	119	100	103	99	97	100
Total Production	---	100	73	71	79	99

*   Flexibility constraints set at 75-125% of 1975 actual acreage. Oilmeal production includes soybean meal and cottonseed meal.

**   Scenarios are defined as follows:

1. No pesticides on grain crops or soybeans with yield coefficeints based on survey of agricultural experts.

2. No pesticides on grain crops, soybeans or cotton with yield coefficients based on survey of agricultural experts.

3. No pesticides on grain crops, soybeans or cotton with yield coefficients provided by C.R. Taylor.

4. No tillage operation with yield coefficients based on survey of agricultural experts.

*** There was oilmeal production here with no soybean acreage, due to cottonseed production.

**** Blank cells indicate no data.

Table 8.   Indices of Cotton Acreage by Consuming Regions for Pesticide
            Use Scenarios, Benchmark Solution = 100, 1975, U.S.*

Consuming Region	1975 Actual	Benchmark	Scenario**			
			1	2	3	4
1	---***	---	---	---	---	---
2	100	100	100	167	167	100
3	---	---	---	---	---	---
4	---	---	---	---	---	---
5	---	---	---	---	---	---
6	---	---	---	---	---	---
7	---	---	---	---	---	---
8	98	100	100	133	147	100
9	99	100	100	162	162	100
10	100	100	100	144	145	100
11	---	---	---	---	---	---
12	99	100	110	162	160	100
13	84	100	89	121	122	100
14	---	---	---	---	---	---
15	---	---	---	---	---	---
16	---	---	---	---	---	---
17	---	---	---	---	---	---
18	101	100	124	136	136	100
19	---	---	---	---	---	---
20	---	---	---	---	---	---
21	81	100	97	101	101	100
Total	89	100	96	132	131	100

*   Flexibility constraints set on grain crops and soybeans at 75-125% of
     1975 actual acreages.

**   Scenarios are defined as follows:

   1. No pesticides on grain crops or soybeans with yield coefficients
       based on survey of agricultural experts.

   2. No pesticides on grain crops, soybeans or cotton with yield
       coefficients based on survey of agricultural experts.

   3. No pesticides on grain crops, soybeans or cotton with yield
       coefficients supplied by C.R. Taylor.

   4. No tillage operation with yield coefficients based on survey
       of agricultural experts.

*** Blank cells indicate no data.

Table 9. Pesticide Expenditures as Percent of Benchmark
Model by Consuming Region for Scenario 4, 1975, U.S.*

Consuming Region	Insecticide Expenditures % of Benchmark	Herbicide Expenditure % of Benchmark
1	104	103
2	103	104
3	100	105
4	100	101
5	100	103
6	---**	---
7	150	0
8	119	14
9	100	104
10	103	95
11	---	3800
12	100	103
13	105	106
14	111	104
15	100	100
16	100	100
17	100	100
18	100	100
19	---	---
20	100	100
21	100	103
Total	104	103

* Scenario 4 involved no tillage on a portion of grain crops
and soybean acreage(s) according to estimates from a survey
of agricultural experts. (Table 4)

** Blank cells indicate no data.

Table 10.   Fertilizer Use as Percent of Benchmark by Consuming Regions for Pesticide Use Scenarios, 1975, U.S.*

Consuming Region	Scenario** 1			2			3			4		
	N	P	K	N	P	K	N	P	K	N	P	K
1	100	100	100	100	100	100	100	100	100	100	100	100
2	105	104	103	106	104	105	106	104	105	100	100	100
3	104	104	102	104	104	102	100	101	101	100	100	100
4	105	106	107	105	106	107	103	104	104	100	100	100
5	100	101	100	100	101	100	100	100	100	100	100	100
6	---	---	---***	---	---	---	---	---	---	---	---	---
7	102	102	102	101	102	102	101	102	102	100	100	100
8	128	115	118	128	115	118	128	115	118	91	94	94
9	101	104	104	106	107	107	106	107	107	90	92	92
10	129	124	124	132	125	126	131	120	120	100	101	101
11	136	133	133	136	133	133	118	89	115	100	100	100
12	98	116	116	132	129	128	138	121	121	96	100	100
13	103	107	109	99	103	104	99	102	101	101	101	100
14	108	112	109	108	112	109	108	112	109	103	104	104
15	119	101	115	119	101	115	109	108	106	100	100	100
16	102	101	100	102	101	100	100	101	100	100	100	100
17	104	114	100	104	114	100	104	114	95	91	93	100
18	114	104	100	112	108	150	112	108	125	100	50	100
19	---	---	---	---	---	---	---	---	---	---	---	---
20	100	105	100	100	105	100	100	103	115	100	100	100
21	101	98	100	101	100	100	100	100	104	100	100	100
Total	106	106	104	106	106	106	105	105	105	100	100	100

*   Flexibility constraints set at 75-125% of actual 1975 acreages.

** Scenarios are defined as follows:

1. No pesticides on grain crops or soybeans with yield coefficients based on survey of agricultural experts.

2. No pesticides on grain crops, soybeans or cotton with yield coefficients based on a survey of agricultural experts.

3. No pesticides on grain crops, soybeans or cotton with yield coefficients supplied by C.R. Taylor.

4. No tillage operations with yield coefficients based on survey of agricultural experts.

*** Blank cells indicate no data.

Table 11.   Feed Grain and Food Grain Acreage and Production
as a Percent of the Benchmark for Pesticide Use
Scenarios, by Consuming Region, U.S., 1975*

Consuming Region	Feed Grains Scenario** 1	Feed Grains Scenario** 3	Food Grains Scenario** 1	Food Grains Scenario** 3
1 Acreage	100	100	100	100
Production	70	81	85	93
2 Acreage	109	105	100	100
Production	79	87	85	93
3 Acreage	105	105	154	111
Production	74	85	136	105
4 Acreage	109	109	244	244
Production	74	85	201	220
5 Acreage	100	100	100	100
Production	83	81	85	93
6 Acreage	---***	---	---	---
Production	---	---	---	---
7 Acreage	104	104	100	100
Production	97	86	97	100
8 Acreage	192	143	100	100
Production	170	119	95	100
9 Acreage	123	143	100	100
Production	112	96	95	100
10 Acreage	189	165	154	100
Production	136	147	98	100
11 Acreage	200	100	---	---
Production	148	94	---	---
12 Acreage	100	100	100	117
Production	75	87	65	113
13 Acreage	108	104	111	94
Production	69	106	86	94
14 Acreage	115	115	95	95
Production	65	99	71	89
15 Acreage	126	124	116	108
Production	98	112	85	101
16 Acreage	---	---	102	101
Production	---	---	77	94

Table 11 (continued)

17 Acreage	234	217	95	95
Production	132	178	53	88
18 Acreage	116	100	122	100
Production	123	93	98	99
19 Acreage	---	---	---	---
Production	---	---	---	---
20 Acreage	---	---	100	100
Production	---	---	67	95
21 Acreage	123	122	107	98
Production	84	115	96	90
Total Acreage	111	108	107	101
Total Production	79	89	81	96

*   Flexibility constraints set at 50-150% of actual 1975 acres.

**   Scenarios are defined as follows:

   1. No pesticides used on grain crops or soybeans with yield coefficients based on a survey of agricultural experts.

   3. No pesticides used on grain crops, soybeans or cotton with yield coefficients supplied by C.R. Taylor.

*** Blank cells indicate no data.

Table 12. Acreage of Soybeans and Production of Oilmeal
as a Percent of the Benchmark for Pesticide
Use Scenarios, by Consuming Region, U.S., 1975*

Consuming Region	Scenario** 1	Scenario** 3
1 Acreage	100	100
Production	75	83
2 Acreage	90	94
Production	70	74
3 Acreage	100	100
Production	75	84
4 Acreage	54	54
Production	40	45
5 Acreage	100	100
Production	75	83
6 Acreage	---***	---
Production	---	---
7 Acreage	130	100
Production	110	88
8 Acreage	133	201
Production	112	170
9 Acreage	110	104
Production	94	100
10 Acreage	121	118
Production	67	93
11 Acreage	---	---
Production	---	---
12 Acreage	140	98
Production	85	81
13 Acreage	181	113
Production	90	100
14 Acreage	103	100
Production	78	88
15 Acreage	100	100
Production	75	88
16 Acreage	---	---
Production	---	---

Table 12 (continued)

17 Acreage	---	---
Production	---	---
18 Acreage	---	---
Production	96	76
19 Acreage	---	---
Production	---	---
20 Acreage	---	---
Production	---	---
21 Acreage	---	---
Production	95	80
Total Acreage	103	99
Total Production	75	82

*   Flexibility constraints set at 50-150% of actual
    1975 acres.

**   Scenarios are defined as follows:

   1.   No pesticides used on grain crops or soybeans with
         yield coefficients based on a survey of agricultural
         experts.

   3.   No pesticides used on grain crops, soybeans, or
         cotton with yield coefficients supplied by
         C.R. Taylor.

*** Blank cells indicate no data.

Table 13. Prices for Feed Grains, Food Grains, Oilmeal and Cotton Lint Generated for Pesticide Use Scenarios, Acreage Flexibility Constraints, 1975 Benchmark, U.S.*

Flexibility ** Constraints	Commodity	Benchmark Model	Scenario 1 No Pesticides on Grain Crops*** or Soybeans	Scenario 2 No Pesticides on Grain Crops, Soybeans or*** Cotton (1)	Scenario 3 No Pesticides on Grain Crops, Soybeans or**** Cotton (2)	Scenario 4 No-Till ***
75-125%	Food Grains ($/Bu)	2.60	4.14	4.21	2.79	2.60
50-150%	Food Grains ($/Bu)	2.77	4.46	----*****	3.04	----
75-125%	Feed Grains ($/Bu)	2.24	6.84	6.84	3.41	2.29
50-150%	Feed Grains ($/Bu)	2.10	4.43	----	2.88	----
75-125%	Oilmeal ($/lb)	0.07	0.19	0.23	0.11	0.07
50-150%	Oilmeal ($/lb)	0.076	0.187	----	0.115	0.38
75-125%	Cotton Lint ($/lb)	0.38	0.38	1.03	0.80	0.38
50-150%	Cotton Lint ($/lb)	----	----	----	0.63	----

* Prices for food grains, feed grains and oilmeal are on the basis of wheat, corn, and soybean meal equivalents respectively in terms of weight. For example the price of oats was 32/56 of corn and the price of barley was 48/60 of wheat. Soybean production and cottonseed production was expressed in oilmeal equivalents. A bushel of soybeans yielded 46.8 lbs. of meal and a pound of cottonseed yielded 0.48 lbs. of meal equivalent to soybean meal. These could then be summed and multiplied by the price for soybean meal.

** Flexibility constraints represent upper and lower bounds on crop acreages relative to the actual acreage in 1975
*** Yield coefficients based on survey of agricultural experts
**** Yield coefficients provided by C. R. Taylor
*****Blank cells indicate that the model was solved for Scenarios 2 and 4 with the 50-150 per cent flexibility constraints

Table 14. Changes in Consumers' and Producers' Surplus and Levels of Land Rent for Alternative Pesticide Use Scenarios for Grain Crops, Soybeans and Cotton, 1975 Benchmark, U.S.*

Item	Benchmark Model	Scenario 1 No Pesticides on Grain Crops or Soybeans**	Scenario 2 No Pesticides on Grain Crops Soybeans or Cotton (1)**	Scenario 3 No Pesticdes on Grain Crops, Soybeans or Cotton (2)***	Scenario 4 No-Till.**
Change in Consumers' Surplus (10^6)	0	-38,413	-43,815	-12,595	-358
Change in Producers' Surplus (10^6)	0	27,747	28,652	6,733	150
Change in Sum of Consumers' and Producers' Surplus (10^6)	0	-10,666	-15,163	- 5,862	-208
Irrigated Land Rent (10^6)	385	1,736	2,474	1,393	396
Total Land Rent (10^6)	5,723	32,120	32,286	11,449	5,862

* Flexibility constraints set at 75-125% of 1975 actual acreage
** Yield coefficients based on survey of agricultural experts
*** Yield coefficients provided by C.R. Taylor

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APPENDIX

Consumers' and Producers' Surplus

In applied welfare economics, a common measure of the economic welfare of consumers is called the consumers' surplus. It is defined as the area under the demand curve less the amount that consumers paid for the quantity purchased. This is shown as the area designated by the letter A in the graph below.
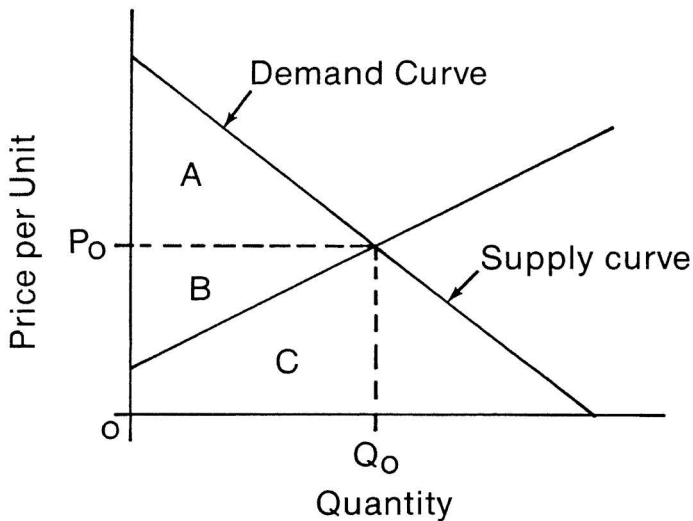
At the market clearing price of P_0, the quantity Q_0 is demanded and supplied. If the demand curve expresses the incremental value placed on the good by consumers and if that incremental value is equal to the incremental utility or satisfaction derived from the good, then the area under the demand curve from $0-Q_0$ is a measure of the total social satisfaction obtained from consuming Q_0. This is the area $A+B+C$.

The price that arises where Q_0 is supplied and demanded is P_0. Consumers spend P_0 x Q_0 dollars for the good. This is the area B+C. Therefore, the total satisfaction obtained less the value of satisfaction paid is given by A+B+C - (B+C) = A. This is a satisfaction surplus for the consumers, because they would have been willing to pay the entire amount A+B+C. The area A can then be taken as a measure of consumer economic welfare.

For producers, the supply curve is the incremental cost function and tells the cost of supplying an additional increment of production. The area under the supply function from 0 - Q_0 is a measure of the social cost of producing Q_0. This is the area C in the graph. When supply is equated with demand at price P_0, producers receive income of P_0 x Q_0 which equals the area B+C. But producer total costs are the area C, so (B+C) - C = B which is called a producer surplus. It is called a surplus because it is a return over and above what producers would have needed to produce the quantity Q_0. As such, it is a return to immobile resources such as land beyond what is needed to keep these resources in production, and is called economic rent.

In this study the linear programming model was designed to maximize the consumers' plus producers' surplus. That is, the model maximized the are A+B in the graph as it relates to the production of grain crops and soybeans.
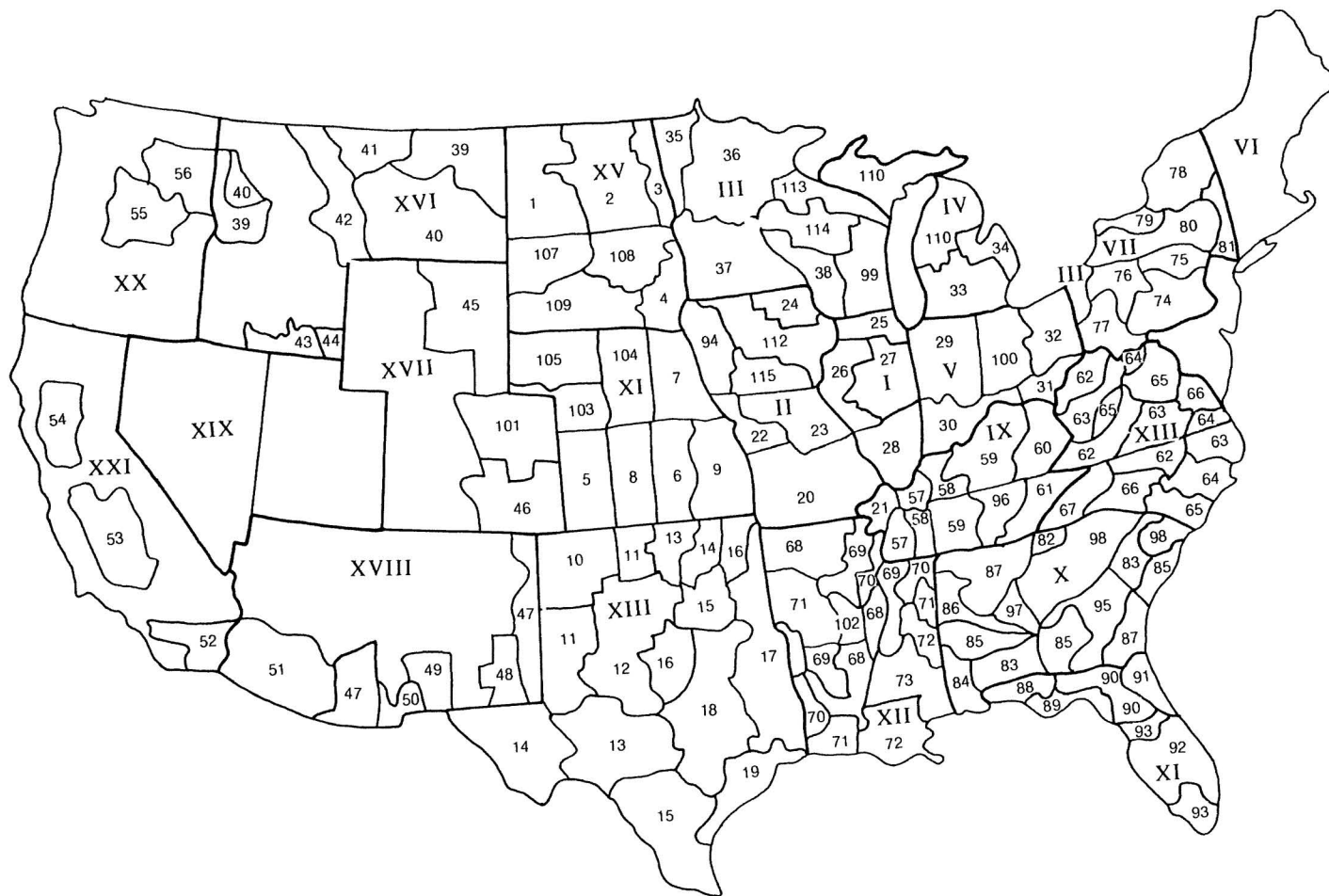
Appendix Figure 1: Map of 115 Producing Regions and 21 Consuming Regions for National Linear Programming - Spatial Equilibrium Model. U.S. 1975.

Appendix Table 1. Acreage of Corn, Grain Sorghum and Oats by Consuming Region for Pesticide Use Scenarios, 1975 Benchmark, U.S.*

Consuming Region	1975 Actual (1000 AC.)	Benchmark Model (1000 AC.)	Scenario 1 No Pesticides on Grain or Soybeans** (1000 AC.)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1)** (1000 AC.)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (1000 AC.)	Scenario 4 No-Till.** (1000 AC.)
1	11,300	13,375	13,375	13,375	13,375.0	13,375
2	17,856	19,578	20,535	20,535	20,522.6	19,577
3	11,890	12,174	12,487	12,487	12,486.8	12,283
4	2,218	2,569	2,695	2,695	2,694.4	2,569
5	9,963	11,997	12,176	12,176	11,996.8	11,997
6	0	0	0	0	0	0
7	2,334	2,438	2,500	2,500	2,499.8	2,439
8	2,088	2,036	2,581	2,581	2,571.7	1,850
9	1,719	2,031	2,031	2,031	2,030.5	1,815
10	2,721	2,386	3,235	3,184	3,182.4	2,386
11	371	278	370	370	324.0	278
12	363	448	448	448	447.8	448
13	8,840	9,263	9,441	8,599	8,580.7	9,263
14	13,486	12,807	14,017	14,017	13,933.7	13,205
15	6,636	6,603	7,609	7,609	7,608.5	6,638
16	0	0	0	0	0	0
17	720	652	782	782	781.8	601
18	331	372	407	372	372.0	372
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	343	341	420	388	341.6	341
Total	93,178	99,348	105,109	104,146	103,750.1	99,437

*   Flexibility constraints set at 75-125%
** Yield coefficients based on survey of agricultural experts
*** Yield coefficients provided by C.R. Taylor

Appendix Table 2. Acreages of Wheat, Barley and Rye by Consuming Region for Pesticide Use Scenarios, 1975 Benchmark, U.S.*

Consuming Region	1975 Actual (1000 AC.)	Benchmark Model (1000 AC.)	Scenario 1 No Pesticides on Grains or Soybeans ** (1000 AC.)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1) ** (1000 AC.)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (1000 AC.)	Scenario 4 No-Till ** (1000 AC.)
1	1,802	1,351	1,351	1,351	1,351.2	1,351
2	1,687	1,265	1,265	1,265	1,264.8	1,265
3	3,845	2,883	3,400	3,400	2,465.1	2,884
4	985	739	1,094	1,094	949.8	739
5	3,287	2,465	2,465	2,465	2,465.1	2,465
6	0	0	0	0	0	0
7	615	461	462	462	461.3	462
8	408	306	306	306	305.8	306
9	412	309	309	309	309	309
10	434	326	326	362	326.2	326
11	0	0	0	0	0	0
12	594	679	446	446	679.1	555
13	16,558	14,339	15,047	14,194	14,007.8	14,354
14	15,807	15,438	15,989	15,989	16,030.2	15,470
15	16,146	13,133	15,332	15,332	13,701.4	13,134
16	7,349	7,158	7,268	7,245	7,174.4	7,158
17	2,501	2,310	2,310	2,310	2,310.2	2,336
18	773	580	579	621	579.5	579
19	0	0	0	0	0	0
20	4,248	4,274	4,274	4,274	4,274.1	4,274
21	1,419	1,193	1,185	1,173	1,180.4	1,193
Total	78,869	69,209	73,408	72,598	70,253.7	69,160

*Flexibility constraints set at 75-125%
**Yield coefficients based on survey of agricultural experts
***Yield coefficients provided by C. R. Taylor

Appendix Table 3. Soybean Acreage for Pesticide Scenarios, 1975 Benchmark, U.S.*

Consuming Region	1975 Actual (1000 AC.)	Benchmark Model (1000 AC.)	Scenario 1 No Pesticides on Grain Crops or Soybeans** (1000 AC.)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1)** (1000 AC.)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (1000 AC.)	Scenario 4 No-Till.** (1000 AC.)
1	8,250	6,625	6,625	6,625	6,624.8	6,625
2	11,550	10,250	9,291	9,144	9,156.1	10,250
3	608	456	456	456	455.8	456
4	3,480	3,353	2,610	2,610	2,610.0	3,353
5	6,770	5,557	5,377	5,377	5,557.1	5,557
6	0	0	0	0	0	0
7	53	40	40	40	39.9	40
8	2,300	1,725	1,910	1,888	1,887.9	1,725
9	3,186	2,588	2,977	2,774	2,773.9	2,390
10	4,380	3,285	3,993	3,729	3,387.6	3,378
11	0	0	0	0	0	0
12	10,344	8,232	10,207	9,175	8,136.1	8,466
13	551	503	596	533	533.2	448
14	2,233	2,344	2,238	2,238	2,237.7	2,344
15	320	400	400	400	400.0	400
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	0	0	0	0	0	0
19	0	0	0	0	0	0
20	0	0	0	0	0	0
21	0	0	0	0	0	0
Total	54,025	45,358	46,720	44,989	43,800.1	45,472

*Flexibility constraints set at 75-125%
**Yield coefficients based on survey of agricultural experts
***Yield coefficients provided by C.R. Taylor

Appendix Table 4.   Acreage of Cotton by Consuming Region for Pesticide Use Scenarios, 1975 Benchmark, U.S.*

Consuming Region	1975 Actual (1000 AC.)	Benchmark Model (1000 AC.)	Scenario 1 No Pesticides on Grain Crops or Soybeans** (1000 AC.)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1)** (1000 AC.)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (1000 AC.)	Scenario 4 No-Till.** (1000 AC.)
1	0	0	0	0	0	0
2	220	221	221	369	368.5	221
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
6	0	0	0	0	0	0
7	0	0	0	0	0	0
8	65	66	66	88	97.1	66
9	324	326	326	529	528.6	326
10	619	622	622	901	902.4	622
11	0	0	0	0	0	0
12	1,957	1,967	2,155	3,188	3,157.3	1,967
13	4,571	5,451	4,859	6,620	6,634.8	5,451
14	0	0	0	0	0	0
15	0	0	0	0	0	0
16	0	0	0	0	0	0
17	0	0	0	0	0	0
18	307	309	383	419	418.6	309
19	0	0	0	0	0	0
20	0	0	0	.0	0	0
21	863	1,071	1,039	1,083	1,083.2	1,071
Total	8,926	10,033	9,671	13,197	13,190.5	10,033

*Flexibility constraints set at 75-125%
**Yield coefficients based on survey of agricultural experts
***Yield coefficients provided by C. R. Taylor

Appendix Table 5. Production of Corn, Grain Sorghum and Oats by Consuming Region for Pesticide Use Scenarios, 1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (10^6 Bu.)	Scenario 1 No Pesticides on Grain Crops or Soybeans ** (10^6 Bu.)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1)** (10^6 Bu.)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (10^6 Bu.)	Scenario 4 No-Till**
1	1,510	1,060	1,060	1,225.4	1,495
2	1,548	1,143	1,143	1,308.8	1,532
3	762	563	563	644.5	757
4	191	140	140	161.0	189
5	1,106	786	786	899.2	1,095
6	0	0	0	0	0
7	169	164	164	145.1	166
8	151	176	176	157.7	134
9	142	135	135	121.6	127
10	134	133	131	163.9	131
11	12	12	12	132.2	12
12	21	16	16	37.7	21
13	423	259	243	377.4	431
14	847	530	530	784.0	873
15	176	158	158	184.6	176
16	0	0	0	0	0
17	46	30	30	43.9	41
18	17	19	17	15.6	17
19	0	0	0	0	0
20	0	0	0	0	0
21	34	29	26	31.1	33
Total	7,289	5,353	5,330	6,433.7	7,230

*Flexibility constraints set at 75-125%
**Yield coefficients based on a survey of agricultural experts
***Yield coefficients provided by C.R. Taylor

Appendix Table 6. Production of Wheat, Barley and Rye by Consuming Region for Pesticide Use Scenario, 1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (10^6 Bu.)	Scenario 1 No Pesticides on Grain or Soybeans** (10^6 Bu.)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1)** (10^6 Bu.)	Scenario 3 No Pesticides on Grain Crops Soybeans or Cotton (2)*** (10^6 Bu.)	Scenario 4 No-Till** (10^6 Bu.)
1	51	47.3	43	43	51
2	37	34.4	32	32	37
3	86	80.5	88	88	86
4	28	33.1	35	35	28
5	102	94.8	87	87	102
6	0	0	0	0	0
7	16	20.7	15	15	16
8	9	9.1	9	9	9
9	10	9.9	9	9	10
10	8	8.1	5	6	8
11	0	0	0	0	0
12	19	19.1	8	8	16
13	319	311.8	262	264	319
14	443	430.9	345	345	444
15	377	372.1	334	334	377
16	249	235.3	187	187	249
17	39	36.1	22	22	39
18	25	24.7	23	23	25
19	0	0	0	0	0
20	191	180.8	126	126	191
21	67	65.7	61	60	67
Total	2,076	2,014.4	1,691	1,675	2,074

*Flexibility constraints set at 75-125%
**Yield coefficients based on survey of agricultural experts
***Yield coefficients provided by C.R. Taylor

Appendix Table 7. Oilmeal Production by Consuming Region for Pesticide Use
Scenarios, 1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (10^6 lbs.)	Scenario 1 No Pesticides on Grains or Soybeans** (10^6 lbs.)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1)** (10^6 lbs.)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (10^6 lbs.)	Scenario 4 No-Till** (10^6 lbs.)
1	10,935	8,202	8,202	9,087.7	10,827
2	14,374	9,944	9,806	10,199.6	14,233
3	560	420	420	473.0	555
4	4,134	2,414	2,414	2,716.4	4,093
5	8,559	6,215	6,215	7,113.2	8,476
6	0	0	0	0	0
7	45	38	38	40.1	43
8	1,792	1,678	1,662	1,719.0	1,712
9	3,033	2,961	2,771	2,862.4	2,668
10	3,727	2,537	2,380	3,087.8	3,810
11	0	0	0	0	0
12	9,297	6,536	6,031	6,878.6	9,507
13	1,319	1,186	1,202	1,296.9	1,282
14	2,655	1,916	1,916	2,240.1	2,603
15	476	357	357	417.8	467
16	0	0	0	0	0
17	0	0	0	0	0
18	168	214	161	161.3	168
19	0	0	0	0	0
20	0	0	0	0	0
21	655	635	520	519.9	655
Total	61,729	45,253	44,095	48,813.8	61,099

*Flexibility constraints set at 75-125%
**Yield coefficients based on survey of agricultural experts
***Yield coefficients provided by C. R. Taylor

Appendix Table 8. Insecticide Expenditures by Consuming Region for Pesticide Use Scenarios, 1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (10^6)	Scenario 1 No Pesticides on Grains or Soybeans** (10^6)	Scenario 2 No Pesticides on Grain, Soybeans or Cotton (1)** (10^6)	Scenario 3 No Pesticides on Grain, Soybeans or Cotton (2)*** (10^6)	Scenario 4 No-Till.** (10^6)
1	27	0	0	0	28
2	33	0	0	0	34
3	18	0	0	0	18
4	4	0	0	0	4
5	25	0	0	0	25
6	0	0	0	0	0
7	2	0	0	0	3
8	16	0	0	0	19
9	5	0	0	0	5
10	39	0	0	0	40
11	0	0	0	0	0
12	29	0	0	0	29
13	40	0	0	0	42
14	28	0	0	0	31
15	7	0	0	0	7
16	4	0	0	0	4
17	3	0	0	0	3
18	9	0	0	0	9
19	0	0	0	0	0
20	1	0	0	0	1
21	13	0	0	0	13
Total	303	0	0	0	315

*Flexibility constraints set at 75-125%
**Yield coefficients based on survey of agricultural experts
***Yield coefficients provided by C. R. Taylor

Appendix Table 9. Farmer Expenditures for Herbicides for Pesticide
Use Scenarios, 1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (10^6)	Scenario 1 No Pesticides on Grains or Soybeans** (10^6)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1)** (10^6)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (10^6)	Scenario 4 No-Till.** (10^6)
1	17.8	0	0	0	18.3
2	28.4	0	0	0	29.4
3	6.4	0	0	0	6.7
4	305.6	0	0	0	308.7
5	13.1	0	0	0	13.5
6	0	0	0	0	0
7	1.0	0	0	0	0
8	10.3	0	0	0	1.5
9	12.0	0	0	0	12.5
10	14.8	0	0	0	14.1
11	0.4	0	0	0	15.2
12	26.0	0	0	0	26.7
13	33.2	0	0	0	35.2
14	8.5	0	0	0	8.8
15	3.6	0	0	0	3.7
16	6.4	0	0	0	6.4
17	3.5	0	0	0	3.5
18	1.7	0	0	0	1.7
19	0	0	0	0	0
20	5.7	0	0	0	5.7
21	3.1	0	0	0	3.2
Total	501.5	0	0	0	515.0

*Flexibility constraints set at 75-125%
**Yield coefficients based on survey of agricultural experts
***Yield coefficients provided by C. R. Taylor

Appendix Table 10. Nitrogen Fertilizer Use for Pesticide Use
Scenarios, 1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (10^6 lbs.)	Scenario 1 No Pesticides on Grain Crops or Soybeans** (10^6 lbs.)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1)** (10^6 lbs.)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (10^6 lbs.)	Scenario 4 No-Till.** (10^6 lbs.)
1	1,526	1,526	1,526	1,526.2	1,526
2	1,809	1,898	1,905	1,905.2	1,806
3	911	946	946	917.1	912
4	227	239	239	233.5	227
5	1,306	1,308	1,308	1,305.9	1,306
6	0	0	0	0	0
7	165	169	167	166.8	165
8	279	357	358	357.7	253
9	265	267	280	280.3	239
10	354	456	469	462.5	355
11	28	38	38	33.1	28
12	227	222	300	313.4	217
13	1,031	1,065	1,024	1,019.8	1,039
14	1,927	2,073	2,073	2,069.4	1,992
15	371	443	443	404.7	372
16	122	125	125	122.6	122
17	70	73	73	73.2	64
18	84	96	94	94.2	84
19	0	0	0	0	0
20	218	217	217	217.7	218
21	243	246	247	244.3	243
Total	11,163	11,764	11,832	11,747.6	11,168

*Flexibility constraints set at 75-125%
**Yield coefficients based on survey of agricultural experts
***Yield coefficients provided by C.R. Taylor

Appendix Table 11. Potassium Fertilizer Use for Pesticide Scenarios,
1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (10^6 lbs.)	Scenario 1 No Pesticides on Grain Crops or Soybeans** (10^6 lbs.)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1)** (10^6 lbs.)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (10^6 lbs.)	Scenario 4 No-Till.** (10^6 lbs.)
1	1,037	1,037	1,037	1,037.5	1,037
2	1,034	1,075	1,085	1,085.0	1,032
3	691	704	704	697.5	693
4	232	248	248	241.9	232
5	1,189	1,193	1,193	1,188.8	1,189
6	0	0	0	0	0
7	136	139	139	138.6	136
8	272	321	322	322.0	257
9	221	230	237	236.9	203
10	384	478	483	462.0	389
11	18	24	24	20.7	18
12	208	242	268	251.0	207
13	91	99	95	92.0	91
14	111	121	121	121.0	115
15	39	45	45	41.5	39
16	1	1	1	.95	1
17	2	2	2	1.9	2
18	2	2	3	2.5	2
19	0	0	0	0	0
20	2	2	2	2.3	2
21	7	7	7	7.3	7
Total	5,677	5,920	6,016	5,951.4	5,652

*Flexibility constraints set at 75-125%
**Yield coefficients based on survey of agricultural experts
***Yield coefficients provided by C. R. Taylor

Appendix Table 12. Phosphorous Fertilizer Use for Pesticide
Use Scenarios, 1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (10^6 lbs.)	Scenario 1 No Pesticides on Grain Crops or Soybeans** (10^6 lbs.)	Scenario 2 No Pesticides on Grain Crops, Soybeans or Cotton (1)** (10^6 lbs.)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (10^6 lbs.)	Scenario 4 No-Till.** (10^6 lbs.)
1	844	844	844	844.3	844
2	978	1,017	1,022	1,022.2	978
3	629	654	654	635.1	629
4	187	199	199	194.2	187
5	966	971	971	966.4	966
6	0	0	0	0	0
7	149	152	152	152.0	149
8	207	240	241	241.3	195
9	214	223	229	228.7	197
10	286	354	358	342.8	289
11	12	16	16	14.3	12
12	183	212	236	221.4	183
13	383	411	393	390.0	386
14	433	483	483	482.5	450
15	305	352	352	329.3	305
16	90	91	91	91.3	90
17	14	16	16	15.6	13
18	26	27	28	27.6	13
19	0	0	0	0	0
20	20	21	21	20.5	20
21	56	55	56	55.8	56
Total	5,982	6,338	6,362	6,275.3	5,975

*Flexibility constraints set at 75-125%
**Yield coefficients based on survey of agricultural experts
***Yield coefficients provided by C.R. Taylor

Appendix Table 13.   Acreage of Corn, Grain Sorghum and Oats by Consuming
                     Region for Pesticide Use Scenarios, 1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (1000 AC)	Scenario 1 No Pesticides on Grain or Soybeans** (1000 AC)	Scenario 3 No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (1000 AC)
1	15,450.6	15,450.6	15,450.6
2	16,559.1	17,979.9	17,360.7
3	11,974.9	12,600.6	12,600.6
4	2,919.6	3,170.4	3,170.4
5	14,030.9	14,030.9	14,030.9
6	0	0	0
7	2,543.7	2,642.8	2,637.6
8	1,611.2	3,079.8	2,297.0
9	1,910.8	2,342.5	2,231.8
10	2,009.1	3,800.2	3,318.4
11	185.2	370.0	185.2
12	553.2	533.2	533.2
13	9,582.4	10,324.6	9,975.4
14	11,830.7	13,573.2	13,661.2
15	6,067.8	7,618.5	7,532.2
16	0	0	0
17	360.2	843.3	782.5
18	418.3	488.7	418.3
19	0	0	0
20	0	0	0
21	279.7	344.3	339.9
Total	98,267.4	109,193.5	106,525.9

  *   Flexibility constraints set at 50-150%
 **   Yield coefficients based on survey of agricultural experts
***   Yield coefficients provided by C.R. Taylor

Appendix Table 14.   Acreage of Wheat, Barley and Rye by Consuming Region
for Pesticide Use Scenarios, 1975 Benchmark, U.S.*

		Scenario 1	Scenario 3
Consuming Region	Benchmark Model (1000 AC)	No Pesticides on Grain or Soybeans** (1000 AC)	No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (1000 AC)
1	900.7	900.7	900.7
2	843.3	843.3	843.3
3	1,922.1	2,956.0	2,133.0
4	492.4	1,202.2	1,202.2
5	1,643.3	1,643.3	1,643.3
6	0	0	0
7	323.8	323.8	323.8
8	203.8	203.8	203.8
9	206.0	206.0	206.0
10	217.1	335.6	217.1
11	0	0	0
12	764.0	764.0	891.3
13	12,909.1	14,284.1	12,165.3
14	17,507.7	16,602.1	16,602.1
15	13,626.0	15,869.8	14,700.9
16	7,140.2	7,311.3	7,202.4
17	2,231.4	2,119.4	2,119.4
18	386.4	470.0	386.4
19	0	0	0
20	4,333.7	4,333.7	4,333.7
21	1,032.5	1,108.7	1,009.3
Total	66,683.5	71,477.8	67,083.9

   *   Flexibility constraints set at 50-150%
  **   Yield coefficients based on survey of agricultural experts
***   Yield coefficients by C.R. Taylor

Appendix Table 15. Soybean Acreage for Pesticide Use
                    Scenarios, 1975 Benchmark, U.S.*

		Scenario 1	Scenario 3
Consuming Region	Benchmark Model (1000 AC)	No Pesticides on Grain or Soybeans** (1000 AC)	No Pesticides on Grain Crops, Soybeans or Cotton (2)*** (1000 AC)
1	4,999.7	4,999.7	4,999.7
2	13,762.2	12,341.4	12,960.4
3	786.4	786.4	786.4
4	3,225.3	1,740.0	1,740.0
5	4,344.8	4,344.8	4,344.8
6	0	0	0
7	26.5	34.4	26.5
8	1,150.0	1,531.7	2,314.5
9	2,594.7	2,876.3	2,987.0
10	2,397.3	2,888.9	2,835.1
11	0	0	0
12	6,974.5	9,796.0	6,847.2
13	455.4	826.3	515.4
14	3,262.0	3,350.0	3,262.0
15	480.0	480.0	480.0
16	0	0	0
17	0	0	0
18	0	0	0
19	0	0	0
20	0	0	0
21	0	0	0
Total	44,458.8	45,995.9	44,099.0

 *   Flexibility constraints set at 50-150%
 ** Yield coefficients based on survey of agricultural experts
 *** Yield coefficients by C.R. Taylor

Appendix Table 16.   Production of Corn, Grain Sorghum and Oats by Consuming Region for Pesticide Use Scenarios, 1975 Benchmark, U.S.*

		Scenario 1	Scenario 3
Consuming Region	Benchmark Model (10^6 bu.)	No Pesticides on Grains or Soybeans** (10^6 bu.)	No Pesticides on Grains, Soybeans or Cotton (2)*** (10^6 bu.)
1	1,762.7	1,236.3	1,429.3
2	1,350.8	1,062.3	1,176.0
3	786.6	580.1	667.3
4	224.1	165.9	191.2
5	1,311.8	1,088.3	1,065.2
6	0	0	0
7	187.8	182.2	160.6
8	123.5	210.1	147.5
9	139.3	156.3	134.5
10	115.9	156.9	170.9
11	8.1	12.1	7.6
12	25.5	19.2	22.1
13	422.4	293.0	448.5
14	779.3	509.5	774.6
15	160.5	161.8	180.1
16	0	0	0
17	23.7	31.4	42.3
18	18.4	22.6	17.2
19	0	0	0
20	0	0	0
21	28.6	23.9	32.9
Total	7,468.9	5,911.9	6,667.8

 * Flexibility constraints set at 50-150%.
 ** Yield coefficients based on survey of agricultural experts.
*** Yield coefficients by C.R. Taylor.

Appendix Table 17.   Production of Wheat, Barley and Rye by
Consuming Region for Pesticide Use
Scenarios, 1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (10^6 Bu.)	Scenario 1 No Pesticides on Grains or Soybeans** (10^6 Bu.)	Scenario 3 No Pesticides on Grains, Soybeans or Cotton (2)*** (10^6 Bu.)
1	33.9	28.8	31.5
2	24.7	21.0	22.9
3	56.9	77.5	59.8
4	18.7	37.6	41.1
5	68.0	57.8	63.2
6	0	0	0
7	10.7	10.4	10.7
8	6.1	5.8	6.1
9	6.6	6.3	6.6
10	5.4	5.3	5.4
11	0	0	0
12	21.8	14.2	24.7
13	289.7	249.1	274.1
14	500.8	358.1	446.2
15	407.0	346.4	409.9
16	252.2	194.1	239.0
17	40.5	21.3	35.6
18	16.6	16.3	16.5
19	0	0	0
20	195.5	130.2	185.2
21	59.7	57.4	53.8
Total	2,014.8	1,637.6	1,932.9

 * Flexibility constraints set at 50-150%.
 ** Yield coefficients based on survey of agricultural experts.
*** Yield coefficients by C.R. Taylor.

Appendix Table 18.   Oilmeal Production by Consuming
Region for Pesticide Use Scenarios,
1975 Benchmark, U.S.*

Consuming Region	Benchmark Model (10^6 lbs)	Scenario 1 No Pesticides on Grains or Soybeans** (10^6 lbs)	Scenario 2 No Pesticides on Grains, Soybeans or Cotton (2)*** (10^6 lbs)
1	8,096.9	6,073.3	6,729.3
2	19,463.8	13,577.2	14,357.3
3	954.8	716.3	806.1
4	3,977.0	1,609.6	1,811.0
5	6,693.8	5,020.8	5,562.8
6	0	0	0
7	30.1	33.2	26.6
8	1,206.3	1,345.9	2,050.8
9	3,089.4	2,906.5	3,077.4
10	2,835.3	1,945.2	2,635.1
11	0	0	0
12	8,319.7	7,067.2	6,729.5
13	2,395.8	2,153.0	2,384.2
14	3,593.9	2,798.1	3,152.6
15	571.5	428.6	501.4
16	0	0	0
17	0	0	0
18	621.8	594.7	474.3
19	0	0	0
20	0	0	0
21	1,788.9	1,698.1	1,431.0
Total	63,639.0	47,967.7	51,879.4

  *   Flexibility constraints set at 50-150%.
 **   Yield coefficients based on survey of agricultural experts.
***   Yield coefficients by C.R. Taylor.