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James J. Kells
Major professor

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ECONOMICS OF WEED CONTROL SYSTEMS IN CORN USING BANDED HERBICIDES AND CULTIVATION

By

Lynnae Joyce Jess

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ABSTRACT

ECONOMICS OF WEED CONTROL SYSTEMS IN CORN USING BANDED HERBICIDES AND CULTIVATION

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Mechanical weed control practices such as cultivation represent an adoptable means for reducing herbicide use in field crops. However, limited adoption of this approach has occurred in Michigan due to lack of economic data. Field research was conducted from 1988 to 1992 to examine the interaction of herbicide and cultivation systems. Projected net returns were calculated on the 1990 to 1992 field data using three farm sizes and two soil types. Weed control systems involving only mechanical cultivation had the greatest variance in net returns among sites, while the broadcast herbicide systems and banded herbicide systems with cultivation had the least variance. With an optimal machinery complement, weed control systems involving herbicide banding and cultivation produced projected net returns comparable to broadcast herbicide systems. With a marginal machinery complement, projected net returns with systems involving herbicide banding were reduced due to the inability to complete cultivations on a timely basis.

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LITERATURE REVIEW

Introduction

Since early recorded history man has been controlling weeds. At first weeds were pulled by hand and then simple hand tools were used. In the early 1700's, horses started pulling plows and wheel hoes to control weeds. Then in the early 1900's the gasoline tractor was invented which made mechanical control of weeds possible and there was a rapid increase in crop production. In 1944, 2,4-D was introduced and farmers were able to expand productivity even more to keep up with expanding local and foreign markets.

For the first time satisfactory control of weeds seemed possible. Substituting lower-priced chemicals for higher-priced labor intensive weed control methods immediately reduced labor needs and increased the effectiveness of weed control and improved crop yields.

The growth of pesticide use was an integral part of the agricultural revolution that generated major changes in production techniques, shifts in input use, and growth in output and productivity. The mechanization revolution of the 1930's and 1940's was augmented by a biological revolution since 1945 in terms of fertilizer, pesticides and genetic stock (Carlson, et al., 1972). Because of the changes, farmers use more machinery, fuel and ag chemicals, but less labor (Osteen et al, 1989). These trends can be shown two ways. From 1947 to 1986 labor use fell 73% while ag productivity grew by 230%. Osteen also reported machinery and mechanical power use grew by 93% from 1947 to 1979 but fell during the 1980's due to less acres being farmed because of lower prices and government programs.

Only 10% of the crop land planted to corn, wheat and cotton was treated with herbicides in 1952, but by 1980 it was 90-95% (Osteen et al., 1989). The use of herbicides on corn and soybeans has increased twelvefold, and use increased from 30 million pounds active ingredient to 370 million pounds active ingredient from 1964 to 1982.

In 1962, Rachel Carson wrote "Silent Spring" in which she voiced her concerns about pesticides and their effect on the environment and wildlife. The negative effects of certain pesticides caused many people to become concerned about the high persistence and mammalian toxicity of some pesticides. These concerns have led to major changes in pesticide regulations. Issues have included food safety, farm worker safety, cancer risks, birth defects, wildlife mortality, ground water pollution and protection of endangered species.

The first regulatory policy for pesticides was the Insecticide Act of 1910 (Ware 1989). The act prohibited the manufacture, sale or transport of adulterated or misbranded pesticides. It also protected farmers and ranchers from possible improprieties in ineffective or indiscriminately toxic products. The Federal Insecticide, Fungicide, Rodenticide Act of 1947 (FIFRA) (Ware 1989) required that all toxic chemicals for sale in interstate commerce be registered against the manufacturers' claims of effectiveness. In the 1950's concern about food safety emerged. In 1954, the Federal Food, Drug and Cosmetic Act (FFDCA) was amended to simplify the procedure under which pesticide residues on raw ag commodities are regulated (Ware 1989). In 1964, FIFRA was amended due to environmental concerns brought about by Rachel Carson's "Silent Spring" (Ware 1989). The amendments included provisions for suspension and cancellation proceedings to prevent imminent hazards. The Environmental Protection Agency (EPA) was formed in 1970 and they were given the authority to administer FIFRA and regulatory portions of FDCA. In 1972, FIFRA was again amended to allow banning of a pesticide if it could be shown that a pesticide caused environmental damage (Ware 1989). In 1988, FIFRA amendments required that the reregistration process be done in an expeditious manner. EPA is evaluating the 600 active ingredients used in product formulation. EPA has determined that many of the most effective and heavily used pesticides also have significant leaching ability. These include the herbicides alachlor, atrazine, cyanazine and metolachlor (USDA, 1987). It appears that many herbicides are not removed effectively from drinking water by treatment or filter systems (Wnuk et al, 1987). Wnuk (1987) reported the maximum and mean levels of 10 herbicides detected in treated drinking water in Ohio and Iowa. In Iowa, 27 of the 33 public water supplies from surface water sources tested, or 82%, had two or more pesticides detected in drinking water samples; 73% had three or more; 58% had four or more and 21% had five or more. The mean detection levels were below 4 ppb.

Pesticides have been detected in the 16,606 wells in 42 states (USEPA 1992). The most commonly detected compounds are the insecticides aldicarb and carbofuran. The most commonly detected herbicide was atrazine. The USDA calculates that 1437 counties (46%) in the United States contain groundwater susceptible to contamination. Widespread and heavy use of pesticides has severely stressed some animals including honey bees and wild bee populations (Brown, 1978).

The economic impacts of removing a pesticide from the market is dependent on crop yield and quality and costs incurred to switch to alternative methods of pest control. Osteen and Kuchler (1986) did an economic analysis on the implications of potential bans of pesticides for corn and soybean growers. They found that banning all triazine and acetanilide herbicides, soil insecticides and seed treatments would have the greatest effects. Banning these pesticides would mean losses in yield potential and profits due to increased production costs.

More than 70% of the US corn acreage is treated with one or more triazine herbicides, with 60% treated with atrazine (Osteen et al., 1986). Osteen reported average corn yields would decrease 2-3% if only atrazine was removed from the market and 10% if all triazines were removed. His report showed 50% of corn acreage is treated with acetanilides; 30% is treated with alachlor and 20% with metolachlor.

Furthermore, of all the groups examined, the banning of triazines would have the greatest net effects after five years with a \$3.3-3.8 billion loss, followed by acetanilides with a \$2.1-2.7 billion loss. In all scenarios presented, Osteen found that farmers would gain and consumers would lose. The calculated health, safety and environmental risks that chemicals pose are interdependent. This is because risk measures depend on the intensity of health problems that a chemical causes as well as the probable exposure to that chemical. A ban could replace that chemical's exposure with exposure to a far more toxic substance. (Osteen et al., 1986).

Impact of Weeds on Corn Production

Weeds have long been recognized as a major source of loss of agriculture productivity. Annual losses due to weeds in crops combined with control costs are greater than the combined losses due to insects, plant diseases and nematodes. Maximum yield losses due to weeds can exceed 90% but actual losses are generally much lower (Rhoads et al, 1985).

Chandler (1981) found that the total monetary loss due to weeds in 13 field crops was approximately 5 billion dollars per year for the period of 1972 to 1976, 30% of which were losses in corn. In 1982, Shaw reported that annual losses due to weeds were responsible for a 10% reduction in productivity which amounted to \$12 billion. In addition he found that farmers spent \$3.6 billion on herbicides, and \$2.6 billion for cultural, ecological and biological methods of weed control. Weeds cost a total of more than \$18 billion a year in the United States.

Losses from weeds occur as a result of: lower quality farm products, poisoned livestock, increased cost of farm operations, harbored insects and diseases, depreciated land values, human health effects, water management problems and yield losses (Knake, 1962).

Weeds directly compete with crops for light, mineral nutrients, water and other growth factors. Weeds also reduce crop yields, crop quality, productivity and value of crop land. They increase the cost of farm operations such as cultivation, mowing, hoeing, herbicides and application equipment and harvesting the crop. Weeds also increase drying costs, fuel consumption and labor requirements along with serving as hosts for crop diseases and insects that directly attack a later growing crop and act as vectors for transmission of diseases (Chandler 1981, and Knake 1962).

Rhoads et al. (1985) found the weed level at which a yield loss occurs is dependent upon the crop grown, the types of weeds present and the length of time the weeds are allowed to compete with the crop.

Staniforth (1957) looked at the influence of fertilizer on corn yield and foxtail density. He found corn yield was reduced 14, 10 and 5 bushels per acre from mature foxtail infestations when 0, 70 and 140 pounds of nitrogen was applied per acre. As resources became less limiting, competition decreased. Nieto and Staniforth (1961) also examined the competition to corn from foxtail when nitrogen fertilizer was involved. When 0, 70 and 140 pounds of elemental nitrogen was applied per acre, corn yield was reduced by 20, 14 and 10 bushels per acre, respectively. They concluded that foxtail competition resulted not only from soil moisture, soil nitrogen, corn plant populations and foxtail infestations individually, but also by interactions from these factors.

Knake and Slife (1962) found that if giant foxtail was allowed to grow with corn to maturity, the weight of all dry matter produced remained relatively constant whether the dry matter was corn alone or corn and weeds. As the remaining number of foxtail increased there was a decrease in yield, cobs, stalks, stalk diameter, ear weight, light intensity at the ground and soil temperature. There was little or no effect on corn height, shelling percentage or moisture content. Beckett et al. (1988) reported an 18% reduction in corn yield with 4 giant foxtail clumps per foot of row.

Knake and Slife (1965) found that if foxtail began growing when corn emerged and was left until maturity, corn yields were reduced by 13%. Foxtail seeded three weeks or later after the corn was planted did not reduce yields. In 1969, the researchers reported when giant foxtail was removed when it reached a height of 3, 6, 9, and 12 inches, corn yield was reduced by 1, 2, 5, 7 and 18 bushels respectively (Knake and Slife, 1969).

Sibuga and Bandeen (1978) found that common lambsquarter is even more competitive than foxtail in corn. Common lambsquarter reduced yields 12.6% and 38.1% at varying densities. The decrease in crop yield almost equalled the increase in weed yield.

In 1964, Bunting and Ludwig found that weeds competing with corn for 2 to 4 weeks during early crop growth was long enough to reduce yields. Sibuga and Bandeen (1978) evaluated green foxtail and common lambsquarter competition in corn and also found that if weeds were not controlled during the early growth stages they would decrease corn yields. Staniforth (1964) also reported similar results.

These studies used 40" corn row spacings and each had high levels of weed infestations. In each of the studies, corn yield was decreased due to competition from the weeds.

Weeds can also have allelopathic effects on crops. Allelopathic potential has been suggested for about 90 weed species (Putnam, 1986). The harmful effects of weeds on crops and soils were observed by ancient Greek and Roman writers. In the 1800's, deCandolle (1832) suggested crop rotation may alleviate soil sickness problems he believed were due to the release of toxins into the soil by plants.

Bhowmik and Doll (1982) did greenhouse studies on the allelopathic effect of residues from common lambsquarter, redroot pigweed, velvetleaf and yellow foxtail. They found significant reductions in radicle elongation and the number of secondary roots of corn as the extract concentration increased. Giant foxtail residue reduced corn yield, and barnyardgrass and yellow foxtail residues reduced the nitrogen concentration in corn. The researchers felt the allelochemicals may have inhibited seedling growth by inhibiting cell division and/or cell elongation.

Non-Chemical Weed Control Practices

The major constraint to widespread adoption of sustainable agricultural practices is the shortage of effective, non-chemical pest control measures. However, there are some biological, cultural and mechanical weed control practices being used by farmers and researchers that fit well into sustainable agriculture.

Biological control of weeds is the use of living organisms to lower plant pest populations to the point where the plants are no longer an economic problem (Rosenthal et al, 1985).

Research over the past two decades has resulted in the classical approach and the bioherbicide approach for the biological control of weeds (Charudattan and Walker, 1982; and Templeton et al, 1986).

The classical approach introduces or releases a biocontrol agent into a weed population to establish and control the weed population. It requires no further manipulation (Templeton, 1979). Classical biological weed control has been in use for many years. In the 1860's, India controlled prickly pear cactus with a cochineal insect (Goeden, 1978). In 1902, Hawaii tried to control lantana by biological means (Goeden, 1978). Australia became active in biological weed-control research in the 1920's (Rosenthal et al, 1985). One result of their research was the use of a moth to reduce prickly pear infestations. There have been over 192 organisms established in different countries on 86 introduced weeds and 33 organisms established to control 25 native weed species (Julien, 1982).

There are many advantages to using classical biological weed control agents. These include: 1) a high degree of specificity for the target weed; 2) there are no effects on nontarget organisms; 3) an absence of weed resistance; 4) an absence of residue buildup in the environment; and 5) the potential impact from biotechnological research and development (Khachatourians, 1986; and Templeton et al., 1986).

There are also some disadvantages to the classical biological weed control approach. The biological control agent may not necessarily kill the weed outright, they may only lower the weed's competitive ability and they may also be slow-acting (Rosenthal et al, 1985).

The bioherbicide approach employs the massive release of a biocontrol agent to kill susceptible weeds (Templeton et al., 1986). Only the use of fungal pathogens as mycoherbicides has been studied in detail (Scheepens and vanZon, 1982; Templeton et al., 1986).

Two selective mycoherbicides have been registered. They are DeVine and Collego. DeVine is used to control the strangler vine in Florida citrus groves, and Collego is used to control northern jointvetch in rice and soybeans (Hatzios, 1987). Advances in microbial and plant biochemistry, plant cell culture, fermentation technology, molecular genetics, and genetic engineering now make it possible to exploit plants and microorganisms as potential sources of naturally occurring chemicals that could be developed as herbicides (Hatzios, 1987).

There are also some disadvantages to the use and production of mycoherbicides. These include: 1) they have to be registered with the EPA which may be a lengthy process; 2) suppression or killing of weeds may be slow; 3) stability under field conditions is highly dependent on environmental conditions; 4) production for large scale application may be costly; and 5) numerous fungi need to be discovered and developed as bioherbicides due to the high degree of specificity (Khachatourians, 1986; Templeton et al, 1986).

Cultural Control Methods

Cultural weed control includes farming practices that have direct and indirect effects on weeds. This includes crop rotation, vigorous varieties, proper row spacings and plant densities, proper seedbed preparation, planting date, adequate fertility, drainage, cover crops and mulches, insect and disease management and preventative weed control measures.

All states have a seed law that restricts the movement of weed seeds from other states. Farmers can also stem the movement of weeds by cleaning their equipment after field use and not moving livestock from field to field. Crop rotation is important in controlling weeds in annual and short-lived perennial crops. When one crop is grown year after year in the same location, the population of certain weed species will increase.

Allelopathy is defined as any negative or positive plant response mediated through chemicals produced by another plant. The USDA world collection of oats has been screened by Fay and Duke who found differences in the oat's ability to exude scopoletin (Fay et al., 1976). Scopoletin is a compound that is able to inhibit root growth.

In recent years rye has received renewed interest for its potential as an allelopathic crop to control weeds. In 1943, Faulkner (1943) reported the effects of rye as a weed control agent. The affect of rye on other plants have been shown by many researchers (Osvald, 1953; Robertson et al., 1976; and Nuttonson, 1985). In 1986, Barnes et al (1987) identified and purified the specific chemical in rye that inhibits weed growth.

There have also been attempts to use allelopathic chemicals as herbicides. Rosenthal et al. (1985) found that Rhizobitoxine, which is produced by some strains of Rhizobium japonicum, can be effective as an herbicide when used at doses as low as 3 oz/acre. He also reported there was a decrease in broadleaved weeds and an increase in nitrogen content and yield of grasses when 8 oz/acre of agarostemmin, a phytotoxin produced by *Agrostemma gilhage* L. was applied to pastures in Yugoslavia.

Mechanical Weed Control

Mechanical weed control in row crops after planting can be accomplished with a rotary hoe which is a broadcast method used when the crop is quite small, and a row cultivator which tills between the crop rows. Rotary hoes are designed to remove germinating and small weed seedlings and loosen crusted soil early in the growing season. Rea (1954) found that rotary hoeing once at 15-18 mph gave 65-70% control of weeds and two or more rotary hoeings gave 85-90% control without the use of herbicides. The rotary hoeing was done when the weeds had emerged (beyond the white stage) and the soil surface was dry. Springman et al. (1989) reported the rotary hoe worked best when operated above 5 mph in tilled fields with low to moderate residue levels.

Lovely et al. (1958) conducted research on the effectiveness of the rotary hoe at different weed growth stages and under various soil moisture conditions in soybeans. Rotary hoeing was performed when weeds had germinated but had not yet emerged. The rotary hoeing was performed at five day intervals. The researchers found that weed stands were reduced by 70-80%, but there was also a 10% soybean stand reduction. When rotary hoeing was delayed until weeds had emerged, there was a 50% reduction in weed control and in soybean yields.

Knake et al. (1965) looked at using rotary hoeing along with a preemergence herbicide. They found that rotary hoeing corn and soybeans treated with a preemergence herbicide did not reduce the effectiveness of the herbicide. During dry years, rotary hoeing improved weed control.

The row crop cultivator was a primary means of controlling weeds before herbicides were invented. Cultivators have been used since the early 1800's when they were pulled by a horse. In the 1960's, the cultivator was used more than any other piece of equipment in corn to control weeds (Armstrong et al., 1968). Many studies have shown that there is a yield advantage if row crops are cultivated at least once during the growing season even if the herbicide was controlling the weeds.

One of the first studies done on the combined effects of herbicide and cultivation was done by Lovely et al. (1958) in Iowa. They found that in soybeans, two cultivations alone resulted in a significant yield loss when compared to using a rotary hoe or cultivation along with an herbicide.

In 1958 and 1959, Meggitt (1960) evaluated the effect of cultivation with herbicide on two soil types. He found that one and sometimes two cultivations were needed for maximum corn yields unless there was a light soil texture and there was excellent soil tilth. In most cases he found no advantage from more than one cultivation. There was no difference between the cultivation done early in the growing season or at lay-by as long as the weeds were controlled early. Atrazine, 2,4-D and simazine provided good weed control even without any cultivations and a 12" weed-free band over the row was not sufficient to completely eliminate weed competition even though one cultivation was provided to remove weeds which grew in the center of the rows.

In 1968, Armstrong et al. (1968) looked at using herbicides along with rotary hoeing and cultivation. They found that the treatment of one rotary hoeing, two cultivations and 2,4-D had the highest yield at 97 bu/acre. When only cost was considered, performing two cultivations was the least expensive weed control method, but banding atrazine and cultivating once gave the highest net return.

In 1968, Upchurch and Selman (1968) also looked at herbicides in conjunction with mechanical methods. They concluded that lower rates of herbicide used with mechanical methods work just as well as higher rates of herbicides used alone.

Moomaw and Robinson (1970) looked at banding herbicides along with rotary hoeing and cultivation. They found that rotary hoeing and cultivating increased yields 11 to 34% compared to a half rate of atrazine and metolachlor alone, depending on the location of the test. A banded application of atrazine and metolachlor followed by mechanical control gave very good weed control and crop yields. Mechanical measures alone failed to control weeds. They concluded that mechanical weed control along with reduced preemergence herbicide rates was a sound approach to controlling weeds and minimizing herbicide use as long as there was not excessive weed pressure and mechanical measures were done in a timely manner.

Roberts and Ricketts (1979) found that the time of year that the soil is cultivated had a large effect on the flush of weed seedlings that developed from the viable seeds present in the soil. If a dry period followed soil disturbance, the number of weed seedlings was lower than expected.

Stoltenberg and Hall (1989) reported on a three-year study done in Iowa at eleven locations comparing herbicides and mechanical weed control methods. Over the three years at 63% of the locations, corn yields were not significantly different between the untreated control and any of the other weed management treatments. With light weed pressures, less aggressive weed management practices are needed to obtain maximum economic yields. The less chemically intensive weed management practices included banding the herbicide, timely rotary hoeing and timely cultivation.

In 1989, Doll et al. (1990) reported similar results. They found that mechanical weed control along with reduced rates of a preemergence herbicide gave adequate weed control based on the assumption that weed pressure was not excessive and that rotary hoeing and cultivation were done in a timely manner. They stated that the use of reduced herbicide rates along with mechanical control methods would have economic returns equal to a system where herbicides are applied at full labeled rates. Gunsolus (1990) also concluded that cultivation contributed to higher yields with the greatest impact coming from the first cultivation.

Economic Considerations

Weed control methods are usually rated on their effectiveness, but effectiveness alone seldom provides sufficient information to enable a grower to select which method is best. Other factors such as cost and return on the machinery, timeliness of the operations and alternative uses of labor should be taken into account for each weed control method. The grower also needs to keep in mind such things as peace of mind, convenience and personal preferences.

Armstrong, Leasure and Corbin (1968) looked at the comparison of mechanical and chemical weed control from an economic view point. The methods compared were two cultivations; one rotary hoe and two cultivations; one rotary hoe, two cultivations and one 2,4-D application; atrazine band application and one cultivation; atrazine preemergence broadcast and two cultivations; and a weed-free check. The weed-free check had the highest yield of 100 bu/acre. The weed management treatment of one rotary hoe, two cultivations and one 2,4-D spray yielded 97 bu/acre, while the atrazine preemergence broadcast and two cultivations yielded 96 bu/acre. The two cultivation method had the lowest yield at 83 bu/acre. However, when considering only yield and cost, the mechanical weed control methods had a slight advantage over systems including herbicides. Alternative uses of labor affected net income moderately. Costs used for weed control methods were for equipment costs, labor costs and herbicide costs. The lowest cost method of controlling weeds was two cultivations at a cost of $2.84. The highest cost method was atrazine preemergence with two cultivations at $10.45. These figures were based on a $1.50 per hour labor charge and 125 acres of corn.

Armstrong et al. (1968) also looked at a timeliness factor for mechanical control methods. They assumed a five day delay and yields were indexed on the basis of 100 bu/acre for the control. A 0.57 bu/acre/day yield reduction was assumed for each day's delay. This resulted in a net income decrease of $3.28 , or a 10 to 24% decrease, for the mechanical weed control methods with the assumed five day delay.

Several other researchers have looked at least cost modeling for calculating total cost of machinery systems. Burrows and Siemens (1974) and Hunt (1977) used least cost models for particular crop rotations to minimize total cost of machinery including the cost of timeliness. Limitations of these least cost methods include not being able to match equipment.

Hughes and Holtman (1976) developed a model which selects and matches machinery and power sources for a multicrop farm based upon time constraints. Singh (1978) and Wolak (1981) further developed a time constraint model. This approach determined "best" size for a machinery complement given date constraints, suitable field working days available and operation requirements. Cost of timeliness was not considered. In 1983, Rotz et al. (1983) developed a machinery selection model based on date constraints, suitable working days, operation requirements and cost of timeliness.

Rotz et al. (1983) based their model on several assumptions including management, machinery and economics. Farm sizes ranging from 80 to 2000 hectares were allowed. Various cropping sequences and three soil textures were used. Time available for various field work practices was based on actual farming practices. Machinery was selected by what was commercially available and all equipment matched in size. Costs of owning and operating the machine systems was determined using a model developed by Rotz et al. (1981). Timeliness cost was added as the actual cost for not doing a timely job. They found that as the probability of suitable weather decreased, smaller machinery became more feasible, but little change occurred to the economically optimum system. Changing from a clay to a sandy soil also allowed for smaller machinery. The larger the farm the more efficiently the machinery was used.

Several researchers have reported that neither cultivation nor herbicide alone consistently provide maximum net returns. Herbicide plus cultivation give the most reliable and economic means of controlling weeds (Snipes et al., 1984; Bridges et al., 1984; and Wilcut et al., 1987).

An economic analysis of two management systems for two cropping rotations was done by Lybecker et al. (1984). The first system involved one typically used on irrigated farms and was not expected to rapidly reduce the weed seed potential of soil. The second system used herbicides intensively to reduce the large weed seed reservoir that existed in the soil. The average return above variable cost was higher for the first system than for the second system under both cropping systems. The first system had a higher benefit under higher herbicide costs.

Doll et al. (1990) put together a table of corn yield, costs and relative returns per acre for an integrated weed management trial in 1989. The highest relative returns per acre came from the half rate of broadcast herbicide plus two mechanical weed control operations. The second highest relative return was the half rate banded herbicide plus three mechanical control operations followed by a half rate banded herbicide plus two mechanical operations. The three lowest relative return values were from the half rate of broadcast herbicide alone, followed by two or three mechanical control measures only.

Springman et al. (1990) states that the cost of owning and operating a cultivator is $3 to $7/acre which can be twice the cost of owning and operating a field sprayer ($2-3/acre). The yield response and weed control value of a well-managed cultivation program can range between $13 and $24/acre.

Apland (1990) suggests that field time variability has important implications for farm economic decisions because of the influence on both average income and income variability. He feels field time variability should be considered especially when an analysis focuses on the fixed resource decisions of farms, such as machinery, land investment and labor use.

Apland (1993) then constructed two linear programming models - one with fixed and the other with random field days - to examine the impacts of variability in field days on the average profit and variability of profit for a corn and soybean farm. He reported that as maximum acreage is increased, the expected net revenue increases at a decreasing rate showing that crop production on the additional acreage is carried out in a less timely manner. Apland concluded that when variability of field days is ignored, estimated economical machine sizes will be too low.

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Chapter 2

MECHANICAL WEED CONTROL PRACTICES FOR REDUCED HERBICIDE USE IN CORN

ABSTRACT

Mechanical cultivation may be necessary to control weed populations if herbicide applications are reduced. Research in 1988, 1989 and 1990 examined the effect of reduced herbicide inputs along with cultivation on weed control in corn. The main plots consisted of cultivating 0, 1, 2, or 3 times. Imposed on the main plots were three herbicide treatments: 1) no herbicide, 2) broadcast preemergence application of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] at 2.0 lb/acre and atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1.0 lb/acre; and 3) a preemergence banded herbicide application of metolachlor plus atrazine directly over the corn row. Dominant weed species were redroot pigweed (*Amaranthus retroflexus* L.), common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarter (*Chenopodium album* L.), eastern black nightshade (*Solanum ptycanthum* Dun.), velvetleaf (*Abutilon theophrasti* Medicus) and giant foxtail (*Setaria faberi* Herrm.). Weed densities were low in all of the studies except for 1989. In 1988, weed densities were low due to a drought. Cultivation increased mid-August weed densities in 1988 and decreased weed densities in 1989 and 1990. Cultivation increased corn yield in 1988 even in the absence of weeds. In 1990, cultivation controlled weeds resulting in increased corn yields. Weather during the cultivation period can greatly impact the success of a banded herbicide system using mechanical cultivation.

INTRODUCTION

A commitment has been made by the current presidential administration to reduce pesticide usage for environmental reasons and to improve the safety in the diets of infants and children. Weed control systems using mechanical cultivation along with banded herbicide could be implemented to reduce herbicide use thereby reducing overall pesticide usage. Meggitt (1960) compared a broadcast herbicide application to a banded (12 or 24") herbicide application. He found that regardless of the band width, two cultivations were required for weed control and to maintain corn yields. However, broadcast herbicide treatments also required two cultivations for optimum corn yield. Moomaw and Robison (1973) found that a 7 inch preemergence band of atrazine plus propachlor followed by cultivation effectively controlled weeds and maintained corn yield equal to that of wider herbicide bands or broadcast herbicide treatments. Doll et al. (1990) conducted weed control trials in Wisconsin in 1989 using best management practices. Reduced herbicide rates along with mechanical weed control practices minimized chemical use yet maintained adequate weed control and corn yield. The weed pressure was not excessive and the mechanical weed control practices were done in a timely manner. Gunsolus (1990) concluded that cultivation contributed to higher crop yields by reducing weed competition. The first cultivation provided the greatest reduction in weed populations. Mulder and Doll (1991) reported that corn yield, weed control and economic returns were greater when herbicides and mechanical weed control practices were combined compared to mechanical weed control practices alone.

Studies were initiated at Lapeer County and Macomb County to examine weed control systems using cultivation along with reduced herbicides. Weed populations and corn yield were measured within each cultivation and herbicide combination.

The objectives of the research were to: 1) examine the interaction of several herbicide and cultivation systems; 2) determine weed control as affected by herbicide and cultivation systems; and, 3) determine difference in corn yield as affected by herbicide and cultivation systems.

MATERIALS AND METHODS

Field research was conducted at the Simmon's farm in Lapeer County, MI in 1988, 1989 and 1990, and at the Kappa farm in Macomb County, MI in 1988. The Lapeer County site was a Capac fine sandy loam with 3.2% organic matter in 1988 and 1990, and 4.0% organic matter content in 1989. The soil pH was 6.7 to 6.9 for all three years and sites. The plot sites were planted to soybeans the previous year. The plots were chisel plowed in the fall and secondary tillage included tandem disking and field cultivation. In 1988 and 1990, 200 lb/acre of 82-0-0 (N-P_2O_5-K_2O) and 0-0-60 analysis fertilizer were applied prior to planting. Di-ammonium phosphate (DAP) (18-46-0) at 200 lb/acre was applied as a band treatment, 2 inches below and 2 inches beside the corn seed at planting. In 1989, 200 lb/acre of 82-0-0 and 200 lb/acre of 0-0-60 were applied prior to planting, and 100 lb/acre of 9-23-30 was applied as a banded treatment at planting. Fertilizer application was based on soil test recommendations from Michigan State University with a yield goal of 150 bu/acre. The entire experimental area was planted with Pioneer 3751 at a rate of 28,200 seeds/acre on May 6, 1988; May 17, 1989; and May 19, 1990.

The Macomb County site was a Parkhill Loam with 3.2% organic matter and soil pH of 7.2. The plot area was fall chisel plowed and secondary tillage included spring disking and field cultivation. Potash (0-0-60) at 100 lb/acre and 350 lb/acre of 46-0-0 were broadcast applied prior to field cultivation. A banded treatment of 300 lb/acre of 6-24-24 analysis fertilizer was applied 2 inches below and 2 inches to the side of the corn seed at planting. The entire experimental area was planted with Pioneer 3751 at a rate of 27,000 seeds/acre on May 3, 1988.

The experimental design was a two factor factorial arranged as a split-plot design. Individual plots were 15 X 50-ft in Macomb County, and 10 X 50-ft at the Lapeer County sites. The main plots consisted of zero, one, two and three cultivations. The one cultivation system was cultivated approximately three weeks after corn emergence; the two cultivation system was cultivated approximately two and four weeks after corn emergence; and the three cultivation system was cultivated approximately two, three and four weeks after emergence. In 1988, at the Macomb County site, plots were cultivated on June 9 for the one cultivation system; on June 3 and June 18 for the two cultivation system; and June 3, June 9 and June 18 for the three cultivation system. The Lapeer County site was cultivated on June 12 for the one cultivation system; June 4 and June 23 for the two cultivation system; and June 4, 12, and 23 for the three cultivation system. In 1989, the Lapeer County site received excessive rain and was cultivated only once on June 30. The Lapeer County site in 1990, was cultivated on June 28 for the one cultivation system; June 18 and July 8 for the two cultivation system; and June 18, 28 and July 8 for the three cultivation system. Plots were cultivated by the cooperating grower using farm equipment.

Imposed on the main plots were three weed management treatments which consisted of: 1) no herbicide; 2) broadcast preemergence application; and 3) preemergence banded herbicide application directly over the corn row. A 15" band was used at the Macomb County site, and a 10" band was used at the Lapeer County sites. A tank-mix combination of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl-*N*-(2-methoxy-1-methylethyl)acetamide] at 2.0 lb ai/acre plus atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1.0 lb ai/acre was applied. All herbicide applications were made with a tractor-mounted compressed air sprayer. Nozzle type, pressure and spray volume are reported in Table 1.

Corn populations were measured in the center two rows of each plot. Quadrats (10 X 36 inch) were placed over the corn row and between the corn rows to determine weed density. The center two rows of corn were harvested, grain moisture recorded, and yields adjusted to 15.5% moisture. Rainfall data are shown in Tables 2 and 3. The statistical package used was

MSTAT[1] (Microcomputer statistical program).

Table 1. Spray equipment and information.

	1988		1989		1990	
	Band	Broadcast	Band	Broadcast	Band	Broadcast
Nozzles	8004E[a]	8003[a]	8003E[a]	8003[a]	4002E[a]	8003[a]
Pressure (psi)	30	30	30	30	36	36
Spray Volume (gpa)	44	22	44	22	30.5	22

[a] 8004E = 80° even flat fan nozzle delivering 0.4 gpm; 8003 = 80° tapered flat fan nozzle delivering 0.3 gpm; 8003E = 80° even flat fan nozzle delivering 0.3 gpm; 4002E = 40° even flat fan nozzle delivering 0.2 gpm.

[1] MSTAT (Microcomputer statistical program), East Lansing, MI

Table 2. Rainfall in relationship to planting date for Lapeer.

DAYS AFTER PLANTING	1988	1989	1990
	------------	inches	------------
-7 - 0	0.00	0.71	2.24
0 - 7	0.04	0.39	0.71
8 - 14	0.79	2.25	0.18
15 - 21	0.27	0.80	0.69
22 -28	0.33	1.83	1.60
29 - 35	0.13*	1.85	0.75*
36 - 42	0.00†	0.55	0.58†
43 - 49	0.12*	0.00†	0.02
50 - 56	0.00	0.00	0.57*
57 - 63	0.00	0.08	1.54
64 - 70	0.00	1.93	0.40
71 - 77	0.00	0.17	0.24
78 - 84	0.00	1.25	0.00
85 - 91	0.00	1.48	1.09

* First and second cultivation of the two cultivation system
† First cultivation of one cultivation system
Three cultivation system took place at all three times

Table 3. Rainfall in relationship to planting date for Macomb.

DAYS AFTER PLANTING	1988
	- inches -
-7 - 0	0.13
0 - 7	0.31
8 - 14	0.40
15 - 21	0.02
22 - 28	0.00
29 - 35	1.00*
36 - 42	0.10†
43 - 49	0.00*
50 - 56	0.00
57 - 63	0.01
64 - 70	0.00
71 - 77	0.01
78 - 84	1.41
85 - 91	1.25

* First and second of the two cultivation system
† First cultivation of the one cultivation system
Three cultivation system took place at all three times

RESULTS AND DISCUSSION

<u>**Macomb County 1988.**</u>

Weed Density in the Corn Row. The banded and broadcast herbicide treatments had less than 1 plant/ft^2 in the corn row (Figure 1a). The no herbicide treatment had 0.7 plants/ft^2 with no cultivations. Weed numbers in the corn row decreased to 0.3 plants/ft^2 with one cultivation, and then increased significantly to 2.5 plants/ft^2 with two cultivations. The spring of 1988 was very dry (Table 3). In the two cultivation system, soil disturbance by cultivation during a period of adequate moisture may have stimulated weed emergence and thus weed densities in the row. The reduction seen with the three cultivation system may have been caused by soil being thrown into the row by the cultivator covering up the weed seedlings.

Weed Density Between the Row. The broadcast herbicide system had virtually no weeds between the corn row (Figure 1b). The banded herbicide treatments had intermediate levels of weed densities. The highest weed densities were found in the no herbicide treatments with the two and three cultivation systems (4.0 plants/ft^2 and 2.4 plants/ft^2 respectively) having weed densities significantly higher than the broadcast herbicide with two and three cultivations (0.1 plants/ft^2 and 0.1 plants/ft^2 respectively). There was not a significant difference between the zero and one cultivation systems in any of the herbicide treatments.

Corn Yield. Plots not treated with herbicide or cultivated produced a grain yield of 114 bu/acre (Figure 2). Plots cultivated three times had a significantly higher yield than where corn was not cultivated in the no herbicide treatments and the broadcast herbicide treatments. Although cultivation in the no herbicide treatments increased weed density corn yield was increased. Further, cultivation increased yield in the broadcast herbicide treatments where weeds were adequately controlled, suggesting the effect of cultivation on corn yield was related to some other factor than weed control. Siemens et al. (1985) found that cultivation increased corn yields on a fine textured soil in the absence of weeds.

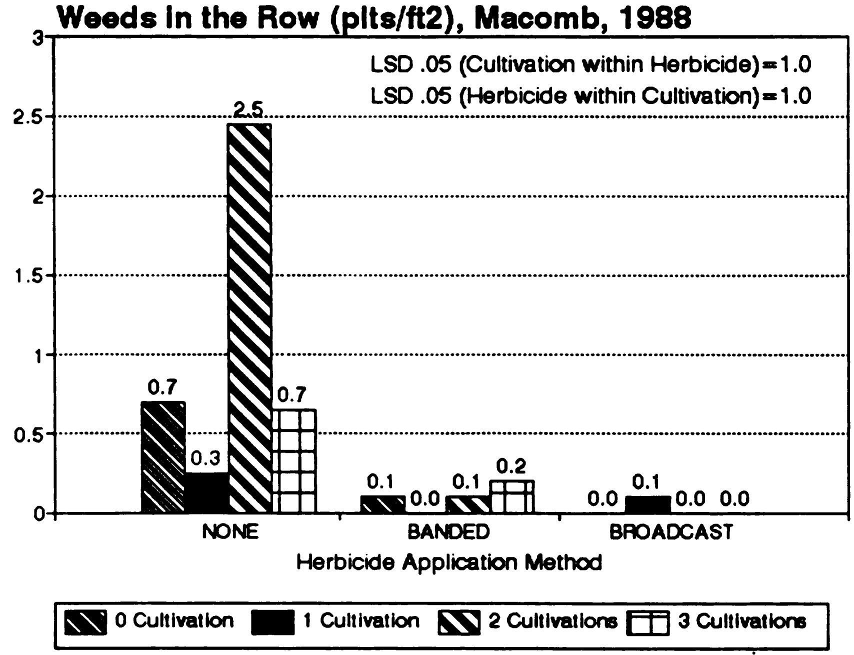

Figure 1a. Weeds in the corn row as affected by herbicide and cultivation, Macomb, 1988.

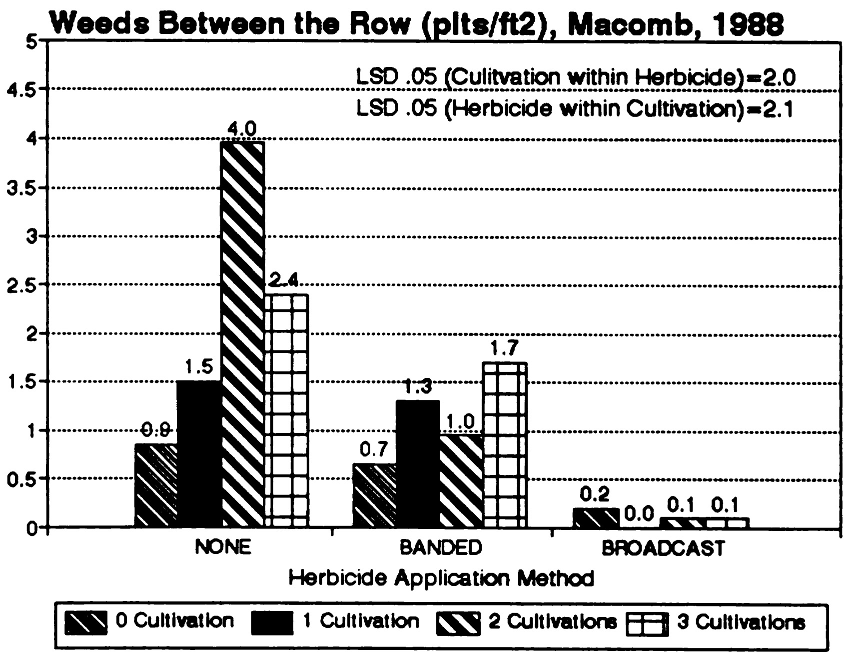

Figure 1b. Weeds between the corn row as affected by herbicide and cultivation, Macomb, 1988.

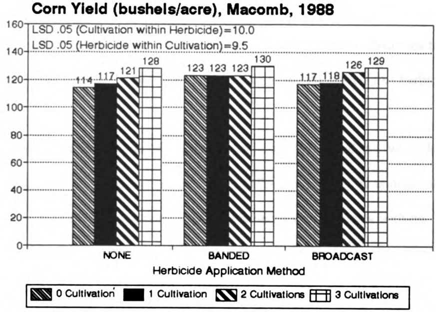

Figure 2. Corn yield as affected by herbicide and cultivation, Macomb, 1988.

Lapeer County 1988.

Weed Density in the Row. The broadcast herbicide treatments had no more than 1 weed/ 2 ft^2 (Figure 3a). There was a significant reduction in weed population between the no herbicide and broadcast treatments with three cultivations (2.4 plants/ft^2 and 0.5 plants/ft^2). There was an increase in weed numbers from zero cultivations (1.3 plants/ft^2) to three cultivations (2.4 plants/ft^2) in the no herbicide treatment and from zero cultivations (0.3 plants/ft^2) to two cultivations (2.2 plants/ft^2) in the banded herbicide treatments. The Lapeer site was also very dry early in the spring and received some rain in June (Table 2) when the cultivations took place. Cultivation appeared to stimulate weed germination in the no and banded herbicide treatments.

Weed Density Between the Row. The broadcast herbicide treatments had low weed densities between the row (Figure 3b). There was no significant difference among the number of cultivations within each herbicide treatment. Each of the herbicide treatments with no cultivation had the lowest number of weeds/ft^2. Cultivation appeared to stimulate weed germination in the no herbicide and banded herbicide treatments between the corn rows as it did in the corn row.

Corn Yield. Corn receiving no herbicide or cultivation produced a grain yield of 97 bu/acre (Figure 4) which was lower than any system which included a herbicide or cultivation. Cultivating the broadcast herbicide treatment twice produced a significantly higher yield (148 bu/acre) than cultivating once (125 bu/acre). Cultivation had similar results where no herbicide was applied. The banded herbicide treatment with two cultivations also had a higher yield than the no cultivation system even though the increase was not statistically significant. These differences in yield occurred with very little difference in weed numbers. Cultivation may have had an effect on yield due to an agronomic factor other than weed control.

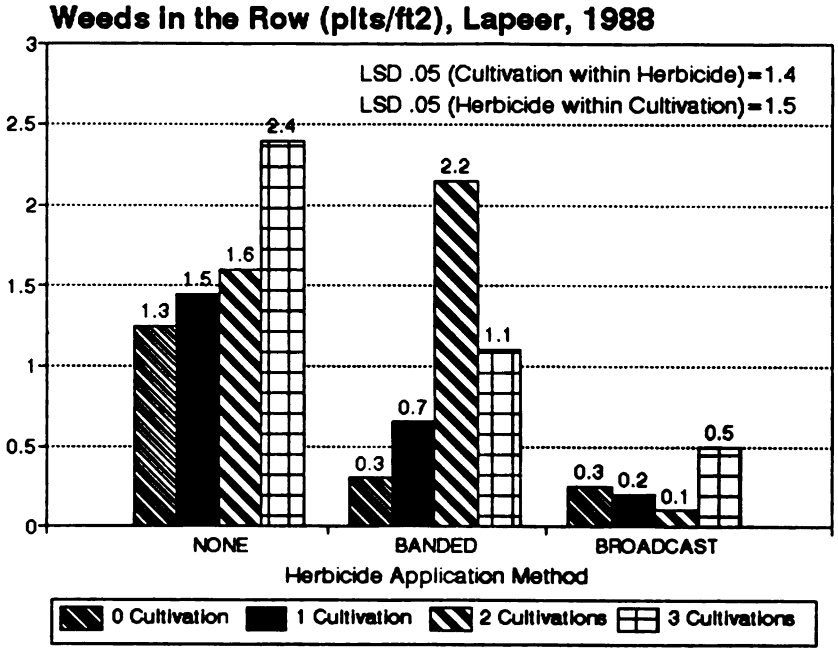

Figure 3a. Weeds in the corn row as affected by herbicide and cultivation, Lapeer, 1988.

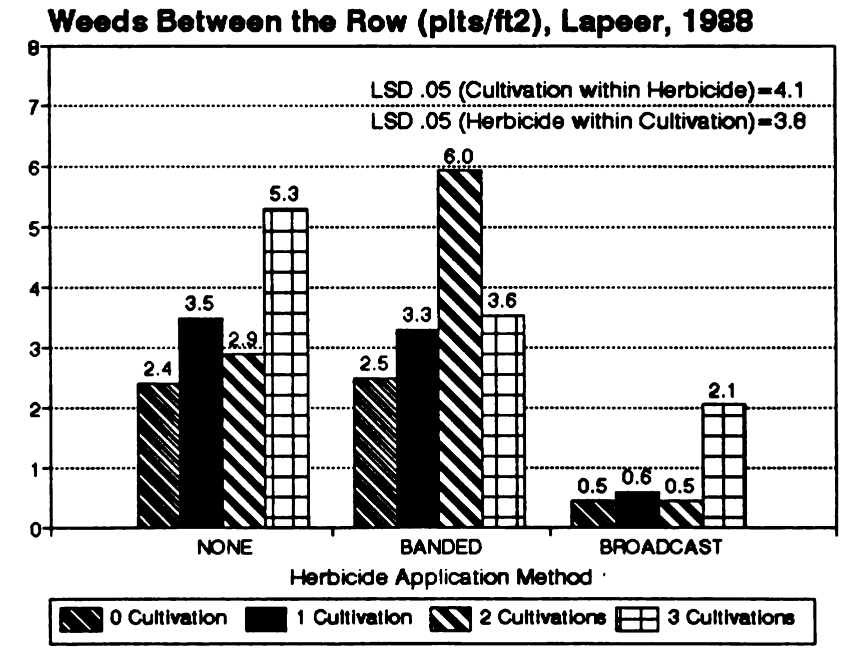

Figure 3b. Weeds between the corn row as affected by herbicide and cultivation, Lapeer, 1988.

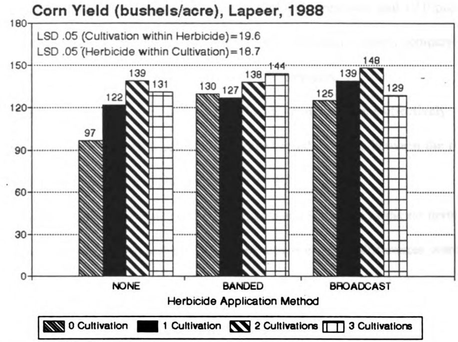

Figure 4. Corn yield as affected by herbicide and cultivation, Lapeer, 1988.

Lapeer County 1989.

Weed Density in the Row. The 1989 Lapeer County study had the highest weed densities of the four studies. The spring of 1989 was very wet (Table 2) and the farmer was not able to cultivate according to the prescribed schedule. Therefore, only one cultivation was performed before the corn became too tall to cultivate. The banded and broadcast herbicide treatments had virtually no weeds in the row (Figure 5a). The no herbicide treatment had 19.0 plants/ft^2 for the no cultivation system and 15.1 plants/ft^2 for the one cultivation system, compared to less than 1 plant/ft^2 in the banded and broadcast herbicide treatments.

Weed Density Between the Row. The broadcast herbicide treatment alone effectively controlled the weeds (Figure 5b). One cultivation reduced weed numbers between the row in both the no herbicide and banded herbicide treatments by 90%.

Corn Yield. Cultivation increased corn yield by 8 bu/acre and 9 bu/acre in the no herbicide and banded herbicide treatments respectively (Figure 6), however, these differences were not statistically significant. There was a significant increase in yield from the no herbicide/no cultivation system (104 bu/acre) to the broadcast herbicide/no cultivation system (132 bu/acre).

Lapeer County 1990.

Weed Density in the Row. None of the broadcast herbicide treatments had more than 2 plants/ft^2 in the corn row (Figure 7a). Plots receiving no herbicide or cultivation had 7.5 plants/ft^2 in the corn row. Cultivating twice improved weed control in the row by over 30%. This reduction could possibly be due to soil being thrown into the corn row, thus covering up small weeds. Banded herbicide treatments without cultivation significantly reduced weed populations to 2.5 plants/ft^2. Cultivation of the banded herbicide treatments did not improve weed control in the row. Weed populations in the corn row were not significantly different in the banded herbicide treatments compared to the broadcast herbicide treatments.

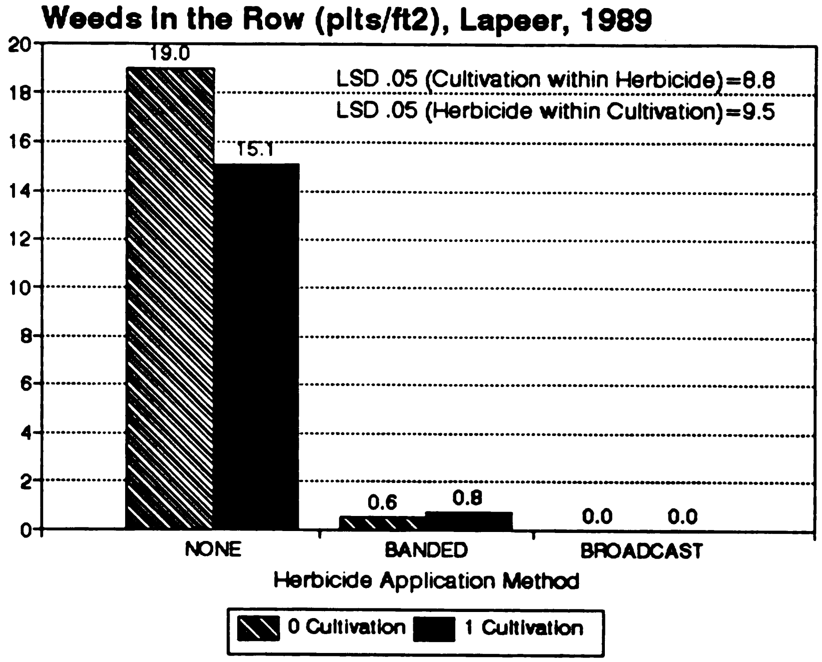

Figure 5a. Weeds in the corn row as affected by herbicide and cultivation, Lapeer, 1989.

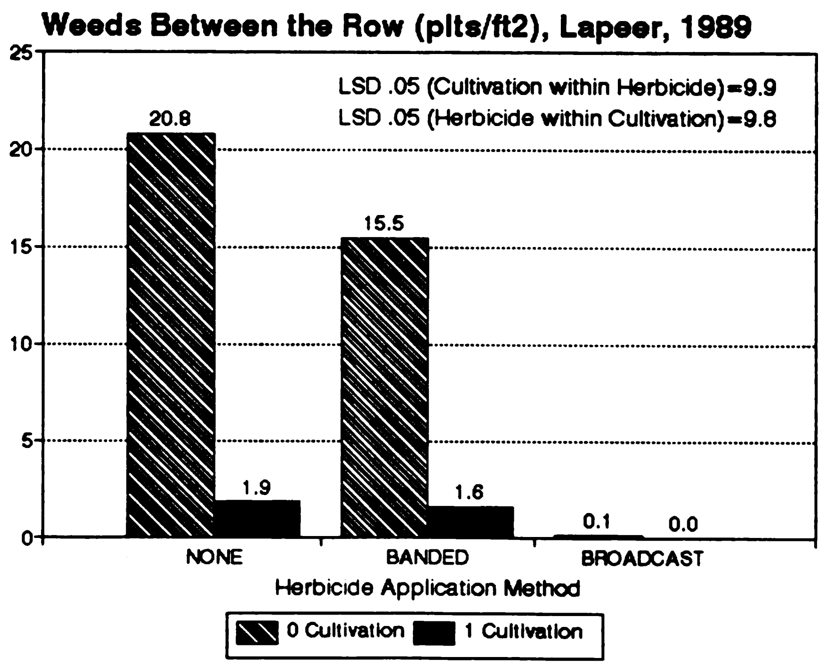

Figure 5b. Weeds between the corn row as affected by herbicide and cultivation, Lapeer, 1989.

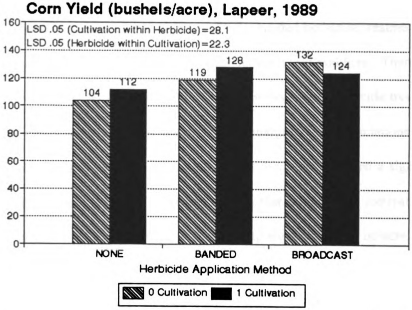

Figure 6. Corn yield as affected by herbicide and cultivation, Lapeer, 1989.

Weed Density Between the Row. There were less than 2 plants/ft^2 between the rows in the broadcast herbicide treatments (Figure 7b). Weed populations between the corn row were reduced 45% by one cultivation in the no herbicide treatment. Subsequent cultivations did not further reduce weed numbers. Weed numbers were reduced when a banded or broadcast herbicide was applied and no cultivation was performed when compared to the no herbicide treatment. One cultivation reduced weed numbers in the banded herbicide treatment from 3.9 plants/ft^2 to 2.2 plants/ft^2. Further cultivations did not reduce weed numbers. There was no significant reduction in weed density with cultivation in the broadcast herbicide treatment.

Corn Yield. Corn yields were low in all systems due to marginal corn populations resulting from early soil crusting. Corn receiving no herbicide or cultivation produced a significantly lower grain yield (23 bu/acre) (Figure 8) than any of the other herbicide or cultivation systems. Corn yield increased to 49 bu/acre with one cultivation and to 64 bu/acre with two cultivations. The weed populations in and between the row (Figure 7a and 7b) decreased following the cultivations, thus increasing corn yield. Banded herbicide treatments with no supplemental cultivation had a grain yield of 57 bu/acre. Supplemental cultivations did not significantly lower weed populations in or between the corn row (Figure 7a and 7b) and yields did not increase significantly. The banded herbicide treatments did not differ in yield from the broadcast herbicide treatments with the exception of the broadcast herbicide/one cultivation system. There were very few weeds in the broadcast herbicide/no cultivation system and cultivation did not decrease weed numbers. There was a significant increase in corn yield from 65 bu/acre for the broadcast herbicide/no cultivation system to 100 bu/acre for the broadcast herbicide/one cultivation system. The yield then decreased for the two and three cultivation systems at 68 bu/acre and 73 bu/acre respectively. These yield changes may be due to an agronomic factor other than weed control which was not identified in this study.

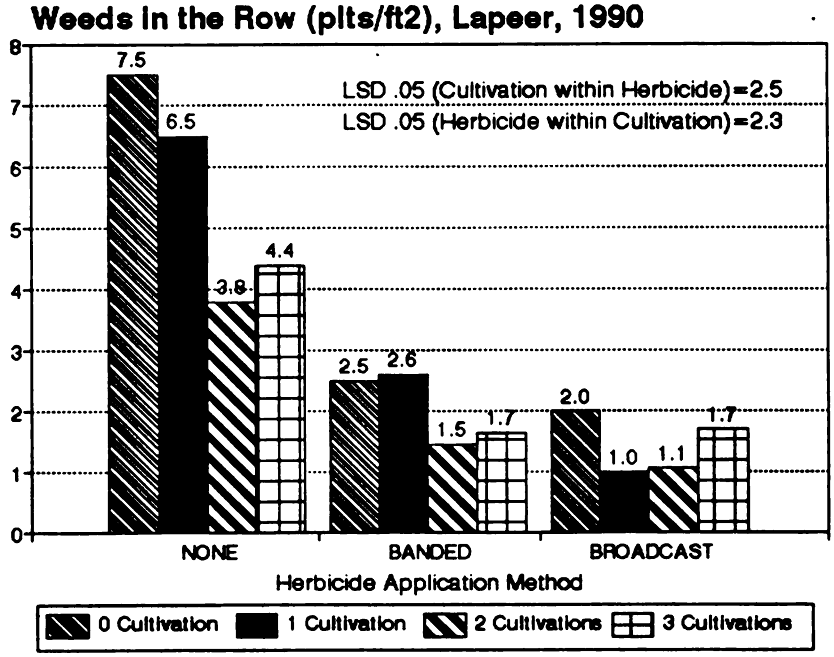

Figure 7a. Weeds in the corn row as affected by herbicide and cultivation, Lapeer, 1990.

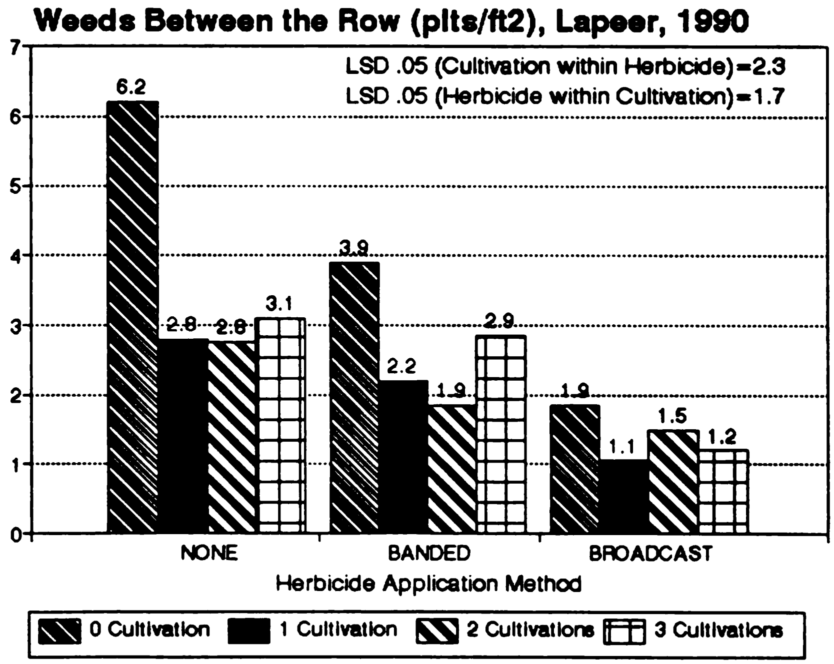

Figure 7b. Weeds between the corn row as affected by herbicide and cultivation, Lapeer, 1990.

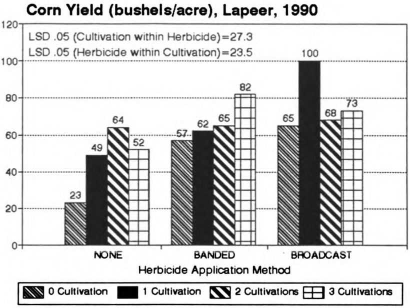

Figure 8. Corn yield as affected by herbicide and cultivation, Lapeer, 1990.

Discussion.

Weed densities were very low in and between the corn row at all sites with the exception of the Lapeer County site in 1989. In 1988, the spring was very dry for both the Lapeer County and Macomb County sites. In comparison, the spring of 1989 was very wet at the Lapeer County site resulting in only one cultivation in the experimental area. Corn yields were extremely variable in Lapeer County for all three years of the study making corn yield comparisons among weed control systems difficult.

Cultivation increased the mid-August weed densities at the Lapeer and Macomb County sites for the no herbicide and banded herbicide treatments in 1988 (the broadcast herbicide treatment had virtually no weeds), but decreased weed densities at the Lapeer County site in 1989 and 1990. Even though weed densities increased with cultivation in 1988, there was also an increase in corn yield. This suggests that the increase in corn yield may be related to some factor other than weed control. Cultivation did not significantly improve corn yields in the Lapeer County site in 1989. In 1990, cultivation did control weeds resulting in an increase in corn yields. The 1990 research results concur with research conducted by Staniforth (1957, 1964), Nieto and Staniforth (1961), Knake and Slife (1962, 1965, 1969), Beckett et al. (1988) and Sibuga and Bandeen (1978). Each of these studies used 40" corn row spacings and had weed densities from 4 clumps/ft to 60 plants/ft. Each researcher considered these high weed infestations. Corn yield was decreased in each study as weed densities increased.

The data indicates that a banded herbicide with cultivation carries with it a risk of unfavorable weather to complete cultivations in a timely basis. Weather related risks should be included in a grower's decision when selecting weed control strategies.

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Chapter 3

AN ECONOMIC COMPARISON OF WEED CONTROL STRATEGIES IN CORN

ABSTRACT

Mechanical weed control practices such as cultivation represent the most readily adoptable means for reducing herbicide use. A split-plot design was implemented with 0, 1, or 2 cultivations as the main plot with three herbicide treatments imposed on the main plots. In 1990 and 1991, the herbicide treatments were: 1) no herbicide; 2) broadcast preemergence application of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] at 2.0 lb/acre and atrazine [6-chloro-*N*-ethyl-*N*'-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1.0 lb/acre; and 3) a preemergence banded herbicide application of metolachlor plus atrazine (10 inch band directly over the corn row). In 1991 and 1992, postemergence herbicide treatments were: 1) no herbicide; 2) a broadcast postemergence application of bromoxynil [3,5-dibromo-4-hydroxybenzonitrile], at 0.38 lb/acre, nicosulfuron [2-[[4,6-dimethoxypyrimidin-2-yl)aminocarbonyl]aminosulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide], at 0.031 lb/acre and nonionic surfactant at 0.25% (v/v), and 3) a postemergence banded application (10 inches directly over the corn row) of bromoxynil and nicosulfuron. Cultivation only controlled weeds and improved corn yield over no weed control practices, but yields were not similar to treatments containing herbicides. The greatest increase in yield from mechanical weed control occurred with the first cultivation. Corn treated with banded preemergence or postemergence herbicide treatments followed by one cultivation produced yields comparable to a broadcast herbicide treatment without cultivation.

When weather risks (timeliness factors) and cost factors (i.e. production and machinery costs) were figured, broadcasting preemergence herbicides with one or two cultivations had the highest economic returns in 1990. In 1991, the banded preemergence herbicide treatment with one cultivation had a higher net return than the broadcast preemergence herbicide with no cultivation. Corn yield in the banded herbicide treatment followed by two cultivations was comparable to the broadcast herbicide treatment with one cultivation. In the 1991 postemergence study, the greatest net return resulted from banding herbicides followed by two cultivations. Banding postemergence herbicides followed by one mechanical cultivation gave similar net returns to the broadcast herbicide with two cultivations. In 1992, banding postemergence herbicides followed by one cultivation had the highest economic returns. Cultivation with a banded herbicide can be effectively substituted for broadcast herbicides without significant weather related risk (at least 75% of the time) if an optimal equipment complement is available.

INTRODUCTION

Pesticide use has become a controversial subject in recent years after the Alar scare in 1990 and with the issuance of the National Academy of Science report, "Pesticides in the Diets of Infants and Children"[2]. Growers and researchers are looking for ways to reduce pesticide use, but still maintain production efficiency and profit. Weed control systems using mechanical cultivation in conjunction with reduced herbicide use could be implemented to reduce pesticide use. Meggitt (1960) compared broadcast herbicide applications to banded herbicide applications in 12 and 24 inch bands. Two cultivations were required to maintain weed control and corn yield when herbicides were either broadcast or banded, regardless of the

[2]National Research Council, "Pesticides in the Diets of Infants and Children",National Academy Press, Washington, D.C. 1993.

band width. Armstrong et al. (1968) found a two cultivation system was the least expensive weed control system. However, the system with the highest net return was one with banded atrazine preemergence followed by one cultivation. Moomaw and Robinson (1973) concluded that a 7-inch band of atrazine plus propachlor followed by cultivation was as effective as wider herbicide bands or broadcast herbicide treatments.

In 1989, "Best management weed control trials" were conducted in Wisconsin by Doll et al. (1990). The researchers reported that the use of mechanical weed control systems along with reduced rates of broadcast preemergence herbicides minimized pesticide use and maintained adequate weed control. Gunsolus (1990) concluded that cultivation contributed to higher yields with the greatest impact coming from the first cultivation. Mulder and Doll (1991) found that weed control, crop yield and economic returns were greatest when herbicides and mechanical weed control practices were combined.

Apland (1993) examined how critical the timing of field operations is to the economic efficiency of crop farms. He reported that fluctuations in field days significantly hampered the ability to expand crop acreage and that increased variation in field days would lead to increased yield variability.

The objectives of this research project were: 1) To examine the interaction of several herbicide and cultivation systems; 2) To determine which herbicide and cultivation system provided the highest yield; 3) To determine projected yield using a timeliness factor for the cultivation systems; and 4) To determine projected net returns, on three farm sizes and two soil types using an in-depth economic analysis.

MATERIALS AND METHODS

Preemergence Study

Field research was conducted at the Michigan State University Crop and Soil Science Research Farm at East Lansing, MI, in 1990 and 1991. The soil was a Capac loam with 3.4% organic matter and soil pH of 6.4 and 7.1, in 1990 and 1991, respectively. In 1990, the plot area was fall chisel plowed. In 1991, the plot was spring chisel plowed due to excessive rain the previous fall. Secondary tillage included spring disking and field cultivation. In 1990, 270 lb/acre of a 46-0-0 (N-P_2O_5-K_2O) analysis fertilizer and 100 lb/acre of a 0-0-60 analysis fertilizer was broadcast prior to field cultivation. Three hundred lb/acre of 6-24-24 was applied as a banded treatment, two inches below and two inches beside the corn seed at planting. In 1991, 210 lb/acre of 46-0-0 was broadcast applied prior to field cultivation and 380 lb/acre of 6-24-24 was applied as a banded treatment at planting. Fertilizer application was based on soil test recommendations from Michigan State University with a 140 bu/acre yield goal. The entire experimental area was planted with Pioneer 3751 at a rate of 25,000 seeds/acre on May 8, 1990, and May 15, 1991.

The experimental design was a two factor factorial arranged as a split-plot design. The main plots consisted of zero, one and two cultivation[3] treatments. With the one cultivation system, plots were cultivated 28 days after corn emergence. With the two cultivation system, plots were cultivated 21 days after corn emergence and again 42 days after corn emergence in 1990. In 1991, plots were cultivated 14 days after corn emergence and again 28 days after corn emergence. Dates of herbicide application, cultivations, air temperature and plant heights are reported in Table 1. Imposed on the main plots were three different weed management treatments which consisted of: 1) no herbicide; 2) broadcast preemergence herbicide

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[3]John Deere 875 minimum tillage c-shank cultivator, Deere and Co., Moline, IL 61265-1304.

application, and 3) preemergence banded (10 in.) herbicide application directly over the corn row. A tank-mix combination of metolachlor [2-chloro-*N*-(2-ethyl-6-methylphenyl)-*N*-(2-methoxy-1-methylethyl)acetamide] at 2.0 lb ai/acre plus atrazine [6-chloro-*N*-ethyl-*N'*-(1-methylethyl)-1,3,5-triazine-2,4-diamine] at 1.0 lb ai/acre was applied.

Corn yield was determined by harvesting the center two rows with a combine. Grain moisture was recorded, and yields were adjusted to 15.5% moisture.

Table 1. Weed control operations and associated air temperatures and plant heights.

1990	Date	Air Temp	Height			
			ZEAMX[a]	SETFA[a]	AMARE[a]	CHEAL[a]
		(°F)	(in)			
Metolachlor (2.0 lb/acre)+ Atrazine (1.0 lb/acre)	May 11	41	--	--	--	--
1 Cultivation	June 16	82	14	2	2	2
2 Cultivation: 1st	June 6	66	7	3	2	2
2 Cultivation: 2nd	June 26	81	23	1	1	1

1991	Date	Air Temp	Height			
			ZEAMX	SETFA	AMARE	ABUTH[a]
		(°F)	(in)			
Metolachlor (2.0 lb/acre)+ Atrazine (1.0 lb/acre)	May 17	88	--	--	--	--
1st Cultivation	June 4	81	10	4	2	3
2nd Cultivation	June 18	82	24	2	1	2

[a] Abbreviations: ABUTH, velvetleaf (*Abutilon theophrasti*); AMARE, redroot pigweed (*Amaranthus retroflexus*); CHEAL, common lambsquarters (*Chenopodium album*); SETFA, giant foxtail (*Setaria faberii*); and ZEAMX, corn (Zea mays)

Postemergence Study

Field research was conducted at the Michigan State University Crop and Soil Science Research Farm at East Lansing, MI, in 1991 and 1992. The soil was a Capac loam with soil pH of 7.1 and 7.2, in 1991 and 1992, respectively. The organic matter content was 3.4% in 1991 and 3.1% in 1992. In 1991, the plot area was chisel plowed, disked, and field cultivated in the spring. Prior to spring field cultivation, 210 lb/acre of 46-0-0 was broadcast applied and 380 lb/acre of 6-24-24 was applied in the corn row at planting. Plots were planted with Pioneer 3751 on May 15. In 1992, the plots were moldboard plowed in the fall, and disked and field cultivated twice in the spring. Prior to spring field cultivation, 272 lb/acre of 46-0-0 was broadcast applied and 325 lb/acre of 6-24-24 was applied in the corn row at planting. All plots were planted with Pioneer 3751 on May 16.

The experimental design was a two factor factorial arranged as a split-plot. The main plots consisted of either 0, 1, or 2 cultivations. The first cultivation was June 7 and the second cultivation June 21 in 1991. In 1992, the first cultivation was June 2 and the second was done June 16. Cultivation dates were based on calendar dates starting 14 days after corn emergence. Imposed on the main plots were three herbicide treatments which consisted of: 1) no herbicide; 2) broadcast postemergence herbicide application and 3) banded (10 in.) postemergence herbicides applied directly over the corn row. A tank-mix combination of bromoxynil, [3,5-dibromo-4-hydroxybenzonitrile], at 0.38 lb ai/acre, nicosulfuron, [2-[[(4,6-dimethoxypyrimidin-2-yl)aminocarbonyl]aminosulfonyl]-*N,N*-dimethyl-3-pyridinecarboxamide], at 0.031 lb ai/acre, and NIS[4] at 0.25% v/v was applied. Dates of weed control operations, air temperatures and plant heights appear in Table 2.

The center two rows of corn were harvested with a combine, grain moisture was recorded,

[4]X-77 Nonionic-type spreader and activator. Valent U.S.A. Corp., 1333 N. California Blvd., P.O. Box 8025, Walnut Creek, CA 94596-8025.

and yields adjusted to 15.5% moisture. Data for rainfall are shown in Table 3. Seasonal rainfall in relation to the 30 year average for the experimental location is presented in Table 4. The statistical package used was MSTAT[5] (Microcomputer statistical program).

[5]MSTAT (Microcomputer statistical program), East Lansing, MI.

Table 2. Weed control operations and associated air temperatures and plant heights.

1991	Date	Air Temp	Height: ZEAMX[a]	SETFA[a]	AMARE[a]	ABUTH[a]
		(°F)	(in)			
Bromoxynil (0.38 lb/ac) Nicosulfuron (0.031 lb/ac) NIS[b] (0.25% v/v)	June 3	70	10	5	1	3
1st Cultivation	June 7	79	14	6	5	5
2nd Cultivation	June 21	88	30	2	1	1
1992	**Date**	**Air Temp**	**Height: ZEAMX**	**AMARE**	**CHEAL**	**AMBEL[a]**
		(°F)	(in)			
Bromoxynil (0.38 lb/ac) Nicosulfuron (0.031 lb/ac) NIS (0.25% v/v)	June 11	83	9	1	2	1.5
1st Cultivation	June 2	NA	3	0.25	1	--
2nd Cultivation	June 16	NA	14	2	2	4

[a] Abbreviations: ABUTH, velvetleaf (*Abutilon theophrasti*); AMARE, redroot pigweed (*Amaranthus retroflexus*); AMBEL (*Ambrosia artemisiifolia*); SETFA, giant foxtail (*Setaria faberii*); and ZEAMX, corn (*Zea mays*).

[b] X-77, Nonionic-type spreader and activator.

Table 3. Rainfall in Relationship to Planting Date

Days After Planting	1990	1991	1992
	-----------	inches	----------
-7 - 0	0.78	0.05	0.07
0 - 7	0.44	0.30	0.14
8 - 14	2.00	0.92	0.18
15 - 30	0.16	2.29	1.95
31 - 60	2.10	3.04	3.69
61 - 90	3.28	5.56	0.15

Table 4. 30 year rainfall averages and monthly rainfall amounts for Michigan State University.

	MICHIGAN STATE UNIVERSITY			
	30 Yr. Avg.	1990	1991	1992
April	2.88	2.13	4.89	5.13
May	2.57	3.74	2.16	2.41
June	3.50	4.48	2.82	3.27
July	2.78	3.57	4.31	6.49

Economic/Risk Analysis

The economic/risk analysis was completed for three simulated farm sizes (200, 600 and 1200 acres). Quattro Pro 4.0[6] was the spreadsheet program used to run the economic analysis. The crop rotation was corn-soybean-wheat with each crop grown on 1/3 of the acres. Field hours available for cultivation were estimated for a well drained sandy loam and poorly drained clay loam using information from "Prediction of Suitable Days for Field Work" (Rosenberg, et al, 1982). The predicted portion of days suitable for non-harvest field

[6]Quattro Pro 4.0, Borland International, Inc., Scotts Valley, CA 95067-0001.

operations at a 0.8 level of probability was chosen for the two soil types. This indicated the minimum number of days that could be expected to be suitable for field work in eight years out of ten. June 1 through June 20 was the period chosen to complete all cultivations. The predicted proportion of days suitable for cultivation was multiplied by 20 days and then multiplied by 10 hours/day to get field hours available for cultivation. (Ten hours/day were assumed to be available for most field crop farmers for cultivation.) It was assumed that yield did not change provided the cultivation was preformed within this time frame. It was also assumed that it takes the same amount of time to cultivate a clay soil as it does to cultivate a sandy soil.

Field hours needed to complete all cultivations were estimated by MACHSEL (Rotz, 1983). The field hours needed for cultivation were then subtracted from field hours available to determine surplus or deficit field time available for cultivation.

Projected yields were calculated based on full yield if all cultivations were completed during the specified time. A yield penalty was assessed to acres not receiving all cultivations. The proportion of the acres that did not get cultivated were assumed to yield the amount of the lesser cultivation. For a two cultivation system, the following equation was used to calculate weighted yields: (-deficit hours/field hours available for cultivation)*yield from one cultivation+((1-(-deficit hours/field hours available for cultivation))*yield from two cultivations.

Optimum machinery sizes were selected using MACHSEL computer program. This computer program is used to select a "best" complement of machinery based upon both time constraints and total cost, including the cost of timeliness to determine the least cost complement. Implements were chosen by MACHSEL to complement different farm size requirements based on an 80% probability of completing the field work in a timely manner. Ownership costs include depreciation, interest, insurance and shelter. Operating costs include labor, repairs/maintenance, fuel, oil, filters and grease. Tillage and planting equipment were assigned to the primary tractors while other implements were assigned to secondary tractors. Machinery costs were then calculated for the proportion of acres planted to corn (Table 5).

Projected net returns were then figured (Figure 1) based on the following equation: (corn acres * [(price of corn/bu - cost of drying/bu) * projected yield - cost of herbicide/acre - variable costs/acre] - machinery costs/acre). The following price assumptions were made: $2.50/bu corn, $7.50 hourly wage, $6.12/acre[7] for preemergence banded herbicide, $18.36/acre for preemergence broadcast herbicide, $9.32/acre for postemergence banded herbicide, $27.49/acre for postemergence broadcast herbicide, $0.30/bu drying charge, and $100.90/A non-weed variable costs[8].

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[7]Herbicide costs were taken from the Michigan State University "Corn Herb" computer program, 1993 version.

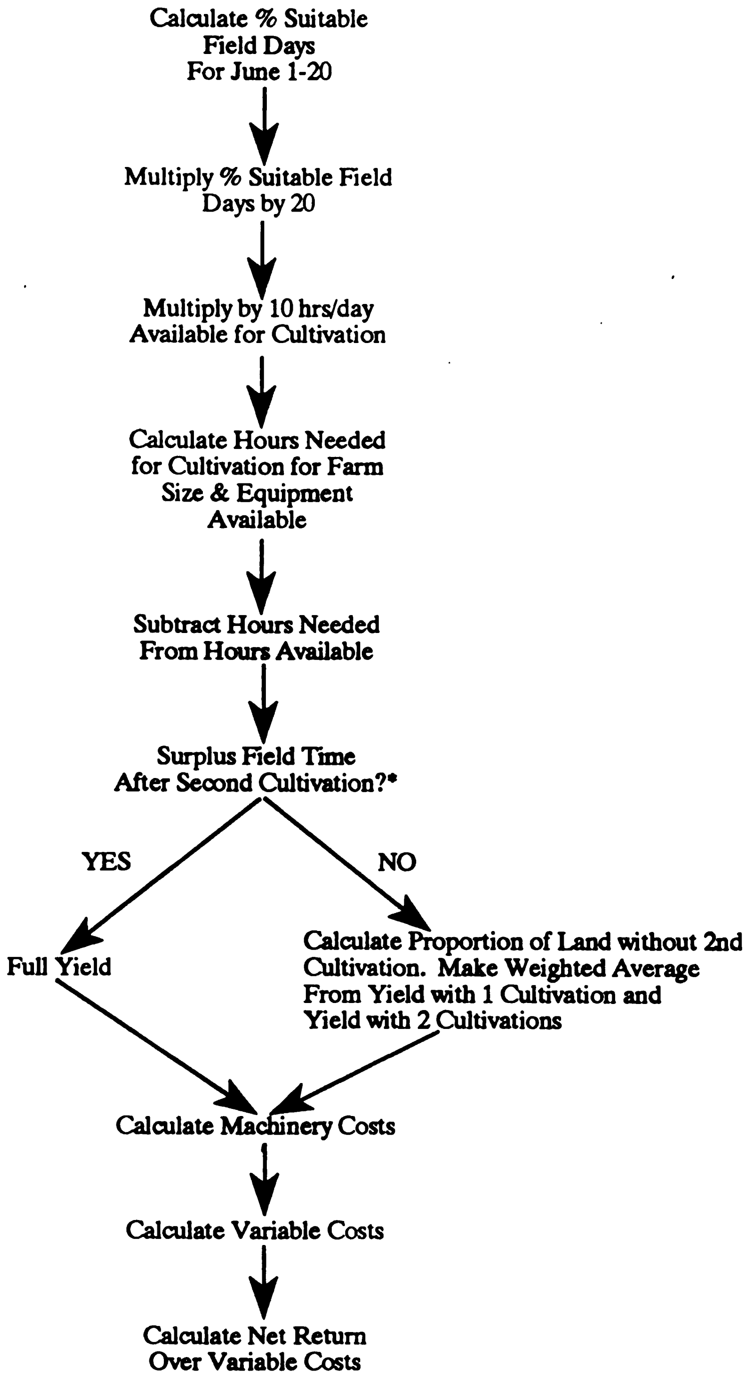
[8] Cost values were taken from Michigan State University Agricultural Economics Report NO. 556, "1992 Crops and Livestock Budgets Estimates for Michigan", by Nott et al, January 1992.

Table 5. Machinery costs per acre for the portion of corn acres.

Herbicide	Cultivation	200A	600A	1200A
		($/A)		
None	0	139.89	67.40	58.68
	1	145.41	70.62	64.78
	2	149.32	72.74	66.52
Banded	0	142.47	68.47	62.24
	1	146.79	71.69	65.44
	2	151.92	77.69	67.06
Broadcast	0	144.33	70.13	64.21
	1	149.90	73.37	67.41
	2	152.96	75.51	69.15

Sub-optimal Machinery Set. The machinery set for the 600 acre farm was then imposed on the representative 1200 acre farm to observe the results of using a sub-optimal machinery set on a larger farm. The projected yield equation used yields from the one and zero cultivation systems. The projected net return equation remained the same.

Figure 1. Flow chart used to calculate projected net returns.



* Similar calculations were made for field time available after the first cultivation. However, as there was always a surplus; no yield adjustments were necessary.

RESULTS AND DISCUSSION

Actual Yields

Preemergence Study 1990. Corn which received no herbicide or cultivation yielded 46 bushels per acre (Figure 2). The yield increased to 101 bushels per acre when cultivated once. There was not a significant increase in yield from a second cultivation. Corn which received a banded herbicide application yielded 124 and 159 bu/acre with zero or one cultivation, respectively. No significant yield increase occurred with a second cultivation. Corn receiving a broadcast herbicide and no cultivation yielded 173 bu/acre. There was no significant yield increase from supplemental cultivations.

Preemergence Study 1991. Corn which received no herbicide or cultivation produced a grain yield of 97 bu/acre (Figure 3). Corn grain yield increased significantly to 153 bu/acre when cultivated once. The second cultivation did not increase yield significantly. A banded application of the herbicide with no and one cultivation yielded 117 and 166 bu/acre, respectively. No significant yield increase occurred with a second cultivation. The broadcast herbicide treatment with no cultivation yielded 165 bu/acre. This yield was similar to the banded herbicide treatments with one or two cultivations. Broadcast herbicide with two cultivations increased corn grain yield compared to the broadcast herbicide treatment alone.

Postemergence Study 1991. Corn which received no herbicide or cultivation yielded 54 bushels per acre (Figure 4). Corn grain yield increased significantly to 102 and 105 bu/acre, respectively, following one or two cultivations. Corn grain yield was 137 bu/acre when the herbicide was banded and there was no cultivation. Yield increased significantly when one or two cultivations were performed. The broadcast herbicide treatment with no cultivation yielded 171 bu/acre and there was not a significant increase in yield with one or two cultivations. There was not a significant yield increase between one and two cultivations in each of the herbicide treatments. The highest yield was obtained from banded herbicides and

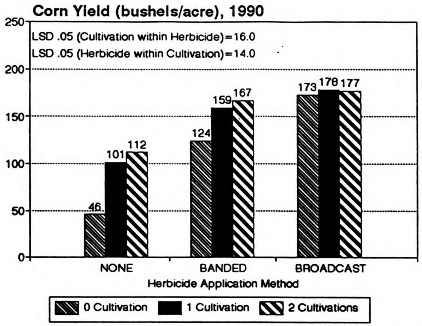


Figure 2. Corn yield as affected by preemergence herbicide and cultivation, 1990.

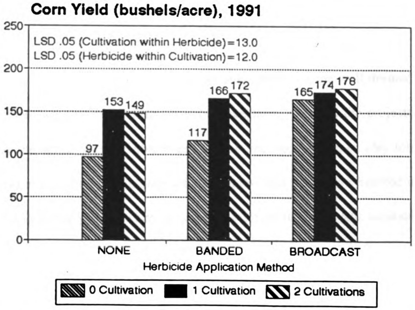


Figure 3. Corn yield as affected by preemergence herbicide and cultivation, 1991.

cultivating twice (180 bu/acre). There was a significant increase in yield between the no herbicide/no cultivation and the banded herbicide/no cultivation, and again, between the banded herbicide/no cultivation and the broadcast herbicide/no cultivation treatments. There was also an increase between the no herbicide with one or two cultivations and the banded or broadcast herbicide with one or two cultivations. There was not a significant increase between the banded and broadcast herbicide treatments with one or two cultivations.

Postemergence Study 1992. Corn receiving no herbicide or cultivation produced a grain yield of 39 bu/acre (Figure 5). Corn grain yield increased significantly to 80 bu/acre following a single cultivation. Yield also increased significantly after a second cultivation to 123 bu/acre. Corn receiving a banded herbicide treatment and no cultivation yielded 96 bu/acre. Yield was increased to 168 bu/acre by one cultivation. Corn yield was not significantly increased by a second cultivation. Broadcast herbicide treatments without supplemental cultivation yielded 164 bu/acre, and yield was not increased from supplemental cultivations. The banded herbicide treatments with supplemental cultivations had comparable yields to any of the broadcast herbicide treatments.

Projected Yields

There were surplus field hours available for all cultivations on the well drained sandy loam soil. Therefore, there were no yield differences between farm sizes and the projected yields were the same as the actual yields (Table 6 and 7). On the poorly drained clay loam soil, the 200 acre farm had ample time to complete all cultivations and therefore observed no yield differences from the actual yields. There was a slight deficit in field hours available for the second cultivation on the poorly drained clay loam soil for the 600 and 1200 acre farms.

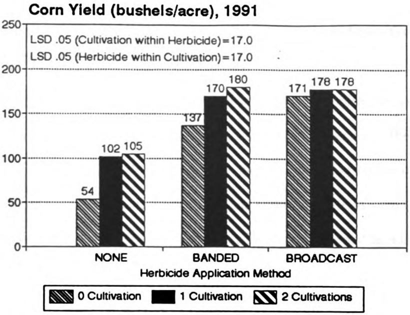


Figure 4. Corn yield as affected by postemergence herbicide and cultivation, 1991.

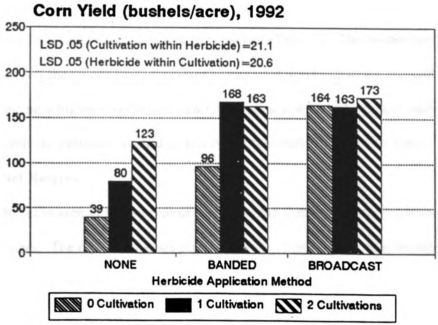


Figure 5. Corn yield as affected by postemergence herbicide and cultivation, 1992

Preemergence Study 1990. The deficit in field hours available to complete the second cultivation for the 600 and 1200 farm sizes resulted in less than a two bushel decrease in projected yields for the no herbicide treatments (Table 6). The yield reduction was less than one bushel for the banded and broadcast treatments.

Preemergence Study 1991. The deficit in hours available to complete the second cultivation resulted in less than a one bushel increase for the no herbicide treatment. This was due to the one cultivation system having a higher yield than the two cultivation system in the study. The banded and broadcast treatments had less than a one bushel decrease in yield (Table 6).

Postemergence Study 1991. The 600 and 1200 acre no herbicide and broadcast treatments with two cultivations had less than a one bushel difference in projected yield when compared to the 200 acre farm size (Table 7). The banded herbicide treatments with two cultivations had less than a two bushel decrease in yield due to the deficit hours available to complete cultivations.

Postemergence Study 1992. The deficit in hours available for the second cultivation in the 600 and 1200 acre farm systems resulted in less than a six bushel decrease for the no herbicide treatment when compared to the 200 acre farm system (Table 7). The banded herbicide treatment had less than a one bushel increase in projected yield due to the one cultivation system producing a higher yield than the two cultivation system. The deficit time in the broadcast herbicide treatment resulted in less than a two bushel decrease in yield.

Projected Net Returns

The differences seen in the net returns are due to the machinery costs associated with each of the farm sizes. The machinery costs per acre decreased as the farm size increased.

Preemergence Study 1990. The highest net return was for the broadcast herbicide/one cultivation system, with $121/acre, $198/acre and $204/acre for the 200, 600 and 1200 acre farm systems respectively (Table 8). All of the broadcast herbicide treatments (zero, one or

Table 6. Projected yields for Michigan State University preemergence sites for 1990 and 1991.

Herbicide	Cultivation	Projected Yields					
		Well Drained Sandy Loam			Poorly Drained Clay Loam		
		200 A	600 A	1200 A	200 A	600 A	1200 A
1990		(Bu/A)					
NONE	0	46	46	46	46	46	46
	1	101	101	101	101	101	101
	2	112	112	112	112	110	111
BANDED	0	123	123	123	123	123	123
	1	159	159	159	159	159	159
	2	167	167	167	167	166	166
BROADCAST	0	173	173	173	173	173	173
	1	177	177	177	177	177	177
	2	177	177	177	177	177	177
1991							
NONE	0	96	96	96	96	96	96
	1	153	153	153	153	153	153
	2	149	149	149	149	150	150
BANDED	0	117	117	117	117	117	117
	1	166	166	166	166	166	166
	2	170	170	170	170	170	170
BROADCAST	0	165	165	165	165	165	165
	1	174	174	174	174	174	174
	2	178	178	178	178	178	178

Table 7. Projected yields for Michigan State University postemergence sites for 1991 and 1992.

		Projected Yields					
		Well Drained Sandy Loam			Poorly Drained Clay Loam		
Herbicide	Cultivation	200 A	600 A	1200 A	200 A	600 A	1200 A
1991		- - - - - - - - - - - - - - - - - (Bu/A) - - - - - - - - - - - - - - - - -					
NONE	0	54	54	54	54	54	54
	1	102	102	102	102	102	102
	2	105	105	105	105	104	104
BANDED	0	137	137	137	137	137	137
	1	170	170	170	170	170	170
	2	180	180	180	180	178	178
BROADCAST	0	171	171	171	171	171	171
	1	178	178	178	178	178	178
	2	178	178	178	178	178	178
1992							
NONE	0	39	39	39	39	39	39
	1	80	80	80	80	80	80
	2	123	123	123	123	117	118
BANDED	0	96	96	96	96	96	96
	1	168	168	168	168	168	168
	2	163	163	163	163	164	164
BROADCAST	0	164	164	164	164	164	164
	1	163	163	163	163	163	163
	2	173	173	173	173	171	171

two cultivations) had higher net returns than any of the banded herbicide treatments. There was a negative net return for all farm sizes and both soil types when there was no herbicide applied and no cultivation. The 200 acre farm also had a negative net return for the no herbicide with one and two cultivations.

Preemergence Study 1991. The highest net return occurred with the broadcast herbicide/two cultivation treatment on all farm sizes and both soil types (Table 8). The well drained sandy loam soil had projected net returns of $120/acre, $197/acre and $203/acre for the 200, 600 and 1200 acre farms respectively. The 600 and 1200 acre farm system had a slightly lower net return on the poorly drained soil due to the deficit in cultivation time. The banded herbicide treatments with one and two cultivations had higher net returns than the broadcast herbicide/no cultivation treatment. The no herbicide/two cultivation treatments on the poorly drained clay loam had slightly higher net returns on the 600 and 1200 acre farm systems. Due to a deficit in cultivation time, the yield for the one cultivation system was used for the portion of the acres not receiving the second cultivation. In this study, the one cultivation system yielded higher than the two cultivation system. The no herbicide/no cultivation treatments had the lowest net returns, with only the 200 acre farm having a negative net return.

Postemergence Study 1991. The highest net return occurred on the banded herbicide/two cultivation treatments ($136/acre, $210/acre and $221/acre on the 200, 600 and 1200 acre farms respectively) (Table 9). The poorly drained clay loam soil had a slightly lower net return for the 600 and 1200 acre farms. The banded herbicide/one cultivation treatment had higher net returns than the broadcast herbicide/no cultivation treatments. The no herbicide/no cultivation treatments had negative net returns for all farm sizes. The 200 acre farm had a negative net return for the one and two cultivation systems with no herbicide also.

Table 8. Projected net returns for Michigan State University preemergence sites for 1990 and 1991.

		Projected Net Returns					
		Well Drained Sandy Loam			Poorly Drained Clay Loam		
Herbicide	Cultivation	200 A	600 A	1200 A	200 A	600 A	1200 A
1990		($/A)					
NONE	0	-140	-67	-58	-140	-67	-58
	1	-24	51	56	-24	51	56
	2	-4	73	79	-4	69	76
BANDED	0	22	96	102	22	96	102
	1	95	170	176	95	170	176
	2	109	183	194	109	181	191
BROADCAST	0	116	191	196	116	191	196
	1	121	198	204	121	198	204
	2	118	195	201	118	195	202
1991							
NONE	0	-28	44	53	-28	44	53
	1	91	165	171	91	165	171
	2	78	155	161	78	156	162
BANDED	0	9	83	89	9	83	89
	1	112	187	193	112	187	193
	2	116	190	201	116	189	200
BROADCAST	0	99	173	179	99	173	179
	1	113	189	195	113	189	195
	2	120	197	203	120	196	202

Postemergence Study 1992. The highest net return occurred on the banded herbicide/one cultivation treatments (Table 9). The 200, 600 and 1200 acre farms had net returns of $116/acre, $191/acre and $197/acre respectively. The 600 acre and 1200 acre farms with banded herbicide/two cultivation systems had slightly higher net returns on the poorly drained clay loam soil when compared to the well drained sandy loam. There was a deficit in field time available for completion of the second cultivation on these farms. The yield of the one cultivation system, which was higher, was used for the acres not receiving the second cultivation.

Sub-optimal Machinery Set. The well drained sandy loam soils using the 600 acre machinery complement had the same yield as the 1200 acre farm (Table 10) using the correct machinery complement. There was sufficient time to do the full cultivation on the well drained sandy loam soil. The poorly drained clay loam did have a deficit of hours available to complete the cultivation. Therefore, a decrease in yield was observed. There was a slight decrease in projected net returns for the broadcast herbicide programs, but there was a larger yield decrease for the no herbicide and banded herbicide treatments. The 1992 broadcast postemergence treatment had an increase in net returns for the poorly drained soils. This is due to the zero cultivation treatments having a higher yield than the one cultivation treatments. There is less than a $1/acre difference.

When the two preemergence and the two postemergence studies are averaged over the two years (Table 11), there is very little difference between the broadcast treatments on the well drained sandy loam or the poorly drained clay loam. The preemergence study has a $12/acre difference from the well drained to the poorly drained soil for the no herbicide treatment and the postemergence study had a $15/acre difference. In the preemergence study, the broadcast herbicide treatment had a higher net return than the banded treatment. In the postemergence study, the banded herbicide treatment had a higher net return than the broadcast treatment.

Table 9. Projected net returns for Michigan State University postemergence sites for 1991 and 1992.

		Projected Net Returns					
		Well Drained Sandy Loam			Poorly Drained Clay Loam		
Herbicide	Cultivation	200 A	600 A	1200 A	200 A	600 A	1200 A
1991		($/A)					
NONE	0	-122	-50	-41	-122	-50	-41
	1	-21	53	59	-21	53	59
	2	-20	56	62	-20	56	62
BANDED	0	52	126	132	52	126	132
	1	120	195	202	120	195	202
	2	136	210	221	136	207	218
BROADCAST	0	113	187	193	113	187	193
	1	122	199	205	122	199	205
	2	119	196	202	119	196	202
1992							
NONE	0	-156	-83	-74	-156	-83	-75
	1	-71	4	10	-71	4	10
	2	20	96	103	20	84	91
BANDED	0	-39	35	41	-39	35	41
	1	116	191	197	116	191	197
	2	100	174	185	100	175	186
BROADCAST	0	97	171	177	97	171	177
	1	90	167	173	90	167	173
	2	107	185	191	107	182	189

Table 10. Projected yields and net returns for a 1200 acre farm with equipment complement adequate for a 600 acre farm.

	Projected Yields		Projected Net Returns	
Herbicide	Well Drained Sandy Loam	Poorly Drained Clay Loam	Well Drained Sandy Loam	Poorly Drained Clay Loam
1990	------- (Bu/A) -------		--------- ($/A) ---------	
None	101	94	56	41
Banded Pre	159	154	176	166
Broadcast Pre	177	177	204	202
1991				
None	153	146	171	155
Banded Pre	166	160	193	179
Broadcast Pre	174	172	195	193
1991				
None	102	96	59	45
Banded Post	170	166	198	189
Broadcast Post	178	177	196	194
1992				
None	80	75	10	-2
Banded Post	168	159	194	173
Broadcast Post	163	163	163	164

Table 11. Projected yields and net return per acre averaged over years for a marginal machinery set.

	Projected Yields		Projected Net Returns	
	Well Drained	Poorly Drained	Well Drained	Poorly Drained
Herbicide	-------- (Bu/A) --------		-------- ($/A) --------	
None	127	120	114	98
Banded Pre[1]	162	157	185	173
Broadcast Pre	176	175	199	197
None	91	85	35	22
Banded Post[2]	169	162	196	181
Broadcast Post	171	170	180	179

[1] Preemergence studies at Michigan State University, 1990 and 1991.
[2] Postemergence studies at Michigan State University, 1991 and 1992

Discussion

Cultivation alone improved corn yields but did not produce yields as high as the herbicide treatments. The first cultivation gave the greatest increase in yield in each herbicide system. Banded herbicide treatments with one cultivation produced a grain yield comparable to the broadcast herbicide without cultivation. The banded herbicide with two cultivations had comparable yields to the broadcast herbicide with one or two cultivation treatments. When prices, costs and timeliness factor were incorporated into each of the herbicide and cultivation systems on two soil types, the highest net return on either soil type was for the broadcast preemergence herbicide with one cultivation treatment in 1990. When three farm sizes were considered, the 1200 acre farm had the highest net return at $204/acre compared to $198/acre and $121/acre for the 600 and 200 acre farms respectively. In the 1991 preemergence study, the broadcast herbicide with two cultivation treatment on the sandy loam had the highest net return. The 200 acre farm had the same net return for the sandy loam and the clay loam soil types. The 600 and 1200 acre farms had a slightly lower net return on the clay loam for the broadcast herbicide with two cultivation system due to a deficit in time to complete all cultivations. In the postemergence studies, the banded herbicide with two cultivation systems had the highest net returns in 1991. The clay loam soil had a slightly lower net return due to a deficit in field hours available to complete the cultivations. In 1992, the banded herbicide with one cultivation system had a higher net return than all the broadcast treatments. These results are similar to the simplified economic analysis done by Jason Woods[9] in 1992.

The projected net returns per acre increased with farm size due to the decreasing machinery costs. As farm size increased, machinery costs can be spread over more acres

[9] Woods, J.J., "Reduced Herbicide Inputs for Corn and Soybean Production", A Thesis submitted to Michigan State University, 1992.

making costs per acre decrease.

The broadcast herbicide treatment with one or two cultivations had the highest projected net return for the preemergence study (Table 12). However, the banded herbicide treatment with one or two cultivations had the highest projected net return for the postemergence study.

When projected net returns per acre are averaged over the four studies (Table 13), the banded herbicide with two cultivations had the highest net return for the 200 and 1200 acre farms. The broadcast herbicide treatment with two cultivations had a higher net return than the banded herbicide treatment with two cultivations for the 600 acre farm. The difference was less than two dollars per acre. Weed control systems involving only mechanical cultivation had the greatest variance in net returns among sites (Table 14). Broadcast herbicide systems and banded herbicide systems with cultivation had the least variance in net returns among sites. This indicates the use of only mechanical weed control poses a high risk of variability in net returns, while using a broadcast herbicide system or a banded herbicide system with cultivation poses a lower risk of variability in net returns.

With an optimal machinery complement, weed control systems involving herbicide banding and cultivation produced net returns comparable to systems involving a broadcast herbicide. With a marginal machinery complement, net returns with systems involving herbicide banding were reduced due to the inability to complete cultivations on a timely basis. In the preemergence study, the broadcast herbicide treatment gave the highest returns. In the postemergence study, the banded herbicide treatment gave the highest returns. However, the advantage of banding the postemergence herbicide rather than broadcasting is much reduced when there is less than optimal equipment and field time is limiting. By contrast, the advantage of broadcasting preemergence herbicides increases when field time becomes inadequate.

Table 12. Projected net returns averaged over studies.

Herbicide	Cultivation	Projected Net Returns: Well Drained Sandy Loam 200 A	600 A	1200 A	Poorly Drained Clay Loam 200 A	600 A	1200 A
Preemergence		- - - - - - - -	- - - - - - - -	- - - - - - - -	($/A) - - - - - - - -	- - - - - - - -	- - - - - - - -
NONE	0	-84	-12	-3	-84	-12	-3
	1	34	108	114	34	108	114
	2	37	114	120	37	113	119
BANDED	0	16	90	96	16	90	96
	1	104	179	185	104	179	185
	2	113	187	198	113	185	196
BROADCAST	0	108	182	188	108	182	188
	1	117	194	200	117	194	200
	2	119	196	202	119	196	202
Postemergence							
NONE	0	-139	-67	-58	-139	-67	-58
	1	-46	29	35	-46	29	35
	2	0	76	83	0	70	77
BANDED	0	7	81	87	7	81	87
	1	118	193	200	118	193	200
	2	118	192	203	118	191	202
BROADCAST	0	105	179	185	105	179	185
	1	106	183	189	106	183	189
	2	113	191	197	113	189	196

Table 13. Projected net returns averaged over four studies, 1990-1992.

Herbicide	Cultivation	Well Drained Sandy Loam 200A	600A	1200A	Poorly Drained Clay Loam 200A	600A	1200A
		------- ($/A) -------			------- ($/A) -------		
None	0	-111	-39	-30	-111	-39	-30
	1	-6	68	74	-6	68	74
	2	18	95	101	18	91	98
Banded	0	9	83	89	9	83	89
	1	109	184	190	109	184	190
	2	114	188	198	114	186	197
Broadcast	0	102	176	182	102	176	182
	1	107	184	190	107	184	190
	2	111	189	195	111	188	194

Table 14. Projected net returns per acre as the average, low, high and difference of four studies, 1990-1992.

Herbicide	Cultivation	Average	Low	High	Difference
		------------------ ($/A) ------------------			
None	0	-30	-75	53	128
	1	74	10	171	161
	2	101	62	161	99
Banded	0	91	41	132	91
	1	192	176	202	26
	2	200	185	221	36
Broadcast	0	186	177	196	19
	1	194	173	205	32
	2	200	191	203	12

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