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Review

The Value of Herbicides in U.S. Crop Production

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The vast majority of crop hectares in the United States are treated with chemical herbicides annually. The adoption of herbicides for weed control was rapid in the 1950s and 1960s. Herbicides replaced the use of millions of workers to pull and hoe weeds by hand and greatly reduced the use of tillage for weed control. Costs of production were reduced and crop yields increased because herbicides were cheaper and more effective than hand weeding and cultivation. Organic crop growers cite weed control as their greatest difficulty in crop production because they are not permitted the use of chemical herbicides. They substitute hand weeding and cultivation for herbicides at a greatly increased cost and with reduced effectiveness. Aggregate studies that estimate the value of herbicides assume that growers would substitute a certain amount of hand weeding and tillage if chemicals were not used, which would not be sufficient to prevent yield losses totaling about 20% of U.S. crop production.

Key words: Herbicides; organic; agricultural history; economics; crop production.

Herbicides sprayed for weed control represent 60% of the volume and 65% of the expenditures for all pesticides used by U.S. farmers (Donaldson et al. 2002). Widespread herbicide use is a relatively recent development in U.S. agriculture in comparison with insecticides and fungicides, which were routinely used in inorganic, naturally derived chemical formulations on U.S. fruit and vegetable crops beginning in the early 1900s. By contrast, widespread use of herbicides to kill weeds did not begin until the introduction of synthetic organic chemicals in the late 1940s. Currently, herbicides are routinely used on more than 90% of the area of most U.S. crops (Table 1). Herbicides are used on 87 million ha of cropland in the United States. The importance of herbicides to U.S. crop production can be understood through a historical perspective and examinations of the practices of organic growers. Recent aggregate studies document the importance of herbicides to many U.S. crops by simulating the effects of their nonuse.

Historical Weed Control Perspective

In the early years of crop production in the United States, human labor was used to remove weeds from fields. As late as 1850, 65% of the population lived on farms and removing weeds was one of the main farm chores. The development of row-crop cultivators and other tillage tools powered by animals and tractors made mechanical control of weeds possible. A common recommendation for control of perennial weeds was to fallow a field for a year and cultivate it 12 to 14 times during that period (Freed 1980). For some crops, such as tomato (*Solanum lycopersicum* L.) in Florida, high weed populations caused growers to abandon cultivated fields after 5 or 6 yr and move to new land. Farmers showed little interest in inorganic chemical weed killers such as copper and arsenic because treatment required large quantities of the chemicals at a high per-hectare cost. Further, the frequently toxic, flammable, or corrosive chemicals seldom killed weeds effectively or consistently (Peterson 1967). Beginning in 1919, oils and kerosene found some utility as weed killers in crops that tolerated their use without excessive crop injury: citrus (*Citus* spp.), cranberry (*Vaccinium* spp.), and carrot (*Daucus carota* L.) (Timmons 1969). In the 1950s, about 1.9 million L of kerosene were sprayed annually in Massachusetts cranberry fields (Cross 1952).

Researchers in the early 1940s began to test (2,4-dichlorophenoxy)acetic acid (2,4-D), a new plant growth regulator chemical compound for herbicidal activity. It proved useful for selective control of broadleaf weeds without harm to grass crops such as wheat (*Triticum* spp.), corn (*Zea mays* L.), and rice (*Oryza* spp.). Similarly, propham (IPC) was tested and found to kill grasses without harming broadleaf crops. By 1962, companies marketed about 100 herbicides in 6,000 different formulations. Increased specificity for particular weed problems in individual crops under different soil and climatic conditions accounted for this rapid development of products (Peterson 1967). The number of weeds that could be killed at what cost using herbicides was calculated. For example, one estimate was that a spray operator could kill 20 million weeds on 4 ha in an hour for 50¢ (the cost of 0.5 L of 2,4-D [Smith 1956]).

For most crops, the historical record shows rapid adoption of herbicides in the United States in the 1950s and 1960s. This initial adoption was followed by continued use on 80 to 90% of crop area since that time (Figure 1). The historical record reveals that herbicides replaced or reduced the use of hand weeding and cultivation for weed control with an associated reduction in cost and increase in yield.

The adoption of herbicides was spurred by a desire to reduce weed control costs as labor became scarce and more expensive in the years after World War II. A mass exodus of farm labor occurred in the late 1940s and early 1950s as workers moved from rural areas to cities. Several southern states experienced a net loss of 200,000 to 300,000 farm

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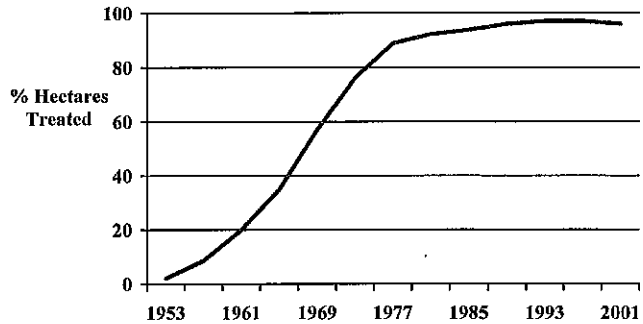
Table 1. Herbicide use and alternatives by crop[a]

Crop	Hectares treated %	Alternatives: Hand weeding h/ha	Alternatives: Tillage #/ha	% Yield loss w/o herbicides
Almond[b]	86	17	0	5
Apple	63	50	2	15
Artichoke	58	57	0	16
Asparagus	91	12	5	55
Blueberry	95	12	0	67
Broccoli	51	50	2	14
Canola	99	0	2	45
Carrot	98	35	2	48
Celery	85	149	4	0
Citrus[c]	95	0	0	0
Corn	98	12	4	20
Cotton	95	32	7	27
Cranberry	95	50	0	50
Cucumber	60	74	3	66
Dry bean	99	40	2	25
Grape	75	20	2	1
Green bean	96	30	2	20
Green pea	94	30	2	20
Hop	95	87	6	25
Hot pepper	95	149	0	0
Lettuce	62	94	2	13
Mint	95	45	0	58
Onion	88	158	2	43
Peach	66	15	0	11
Peanut	97	25	2	52
Potato	93	25	5	32
Raspberry	91	106	9	0
Rice	98	0	4	53
Sorghum	91	0	3	26
Soybean	96	12	4	26
Spinach	90	50	3	50
Strawberry	39	74	4	30
Sugar beet	98	37	2	29
Sugarcane	95	62	3	25
Sunflower	95	0	7	16
Sweet corn	90	12	3	25
Sweet potato	70	59	2	20
Tomato	96	92	8	23
Wheat	55	5	2	25
Wild rice	10	0	0	50

[a] From Gianessi and Sankula 2003.

[b] Alternatives are mowing and cover crops.

[c] Alternatives are mowing, increased fertilizer, and irrigation.



Note: Trendline of corn, cotton, soybean, sugarbeet, peanut, and rice.

Source: [Brodell et al., 1955, Strickler and Hinson 1962, USDA 1968, Eichers 1978, Duffy 1983, Andrilenas 1975, USDA 2001]

Figure 1. U.S. major crop area treated with herbicides.

workers within a decade. Louisiana sugarcane (*Saccharum* spp.) was so thoroughly infested with weeds in 1949 that production on at least one-third of the area was materially reduced and one-sixth of the area yielded only marginal crops (Stamper 1959). As a result of a scarce labor supply, the farm wage rate increased by 400% in the early 1950s. Growers who were used to paying $0.10/h were faced with paying $0.50/h in the early 1950s and $1.00/h in the 1960s (USDA 1996).

Chemical weed control substituted for 49 h of labor per hectare on 405,000 ha of cotton (*Gossypium* spp.) in Mississippi (Holstun et al. 1960). Growers were estimated to have saved $10 million per year. The adoption of chemical sprays for weed control is also credited for the greatest reduction in production costs for raspberry (*Rubus idaeus* L.), replacing nine cultivation trips and 106 h of hand weeding per hectare (Waldo 1959). The development of herbicides was seen as an absolute necessity for the survival of the sugar beet (*Beta vulgaris* L.) industry in the United States because of high requirements for dwindling availability of labor (Fults 1962).

In the 1950s, in an effort to deter juvenile delinquency, state and local public officials, civic organizations, and the sugar industry in the Red River Valley of North Dakota and Minnesota launched the Youth Beet Program to encourage teenagers to work in the beet fields during the summers (Norris 2005). One of the primary activities was hand weeding. The program did not succeed; most teenagers dropped out each year. Participants found the work to be unpleasant and too poorly paid. The average teenager in the program was able to remove weeds from 1.6 ha during the summer.

Use of the short-handled hoe was the primary weed control method for most vegetable crops in California from the early 1900s through the 1960s. Weeding of celery (*Apium graveolens* L.) took 111 h/ha, carrot took 69 h/ha, and strawberry (*Fragaria* spp.) took 69 h/ha (Adams 1938; Lange and Brendler 1965). Numerous complaints were received from farm workers who stated that they suffered permanent back damage as a result of using the short-handled hoe for extended periods of time. The California Industrial Safety Board issued a regulation that permanently banned the use of the short-handled hoe in 1975. Most growers switched to the use of herbicides, which proved to be more economical than the use of workers wielding hoes. The cost of herbicides plus application was $25/ha, in comparison to hand weeding costs of $247/ha for spinach (*Spinacia oleracea* L.), $198/ha for celery, $309/ha for onion (*Allium cepa* L.), and $988/ha for strawberry (Ashton 1960). The use of herbicides is credited with reducing the use of labor in California onion fields by 297 h/ha, which was equivalent to 2 million h/yr (Nylund et al. 1958).

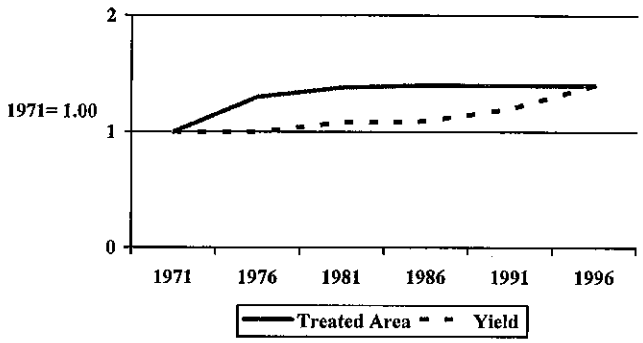
For many crops, herbicides substituted for and reduced the practice of cultivation. For example, herbicides reduced the number of tillage trips in almond (*Prunus dulcis* L.) orchards by 16 with grower savings of $52/ha (Meith and Parsons 1965). Cultivation had been shown to reduce the yields of several crops including potato (*Solanum tuberosum* L.) and asparagus (*Asparagus officinalis* L.) because of root pruning and crop damage. Four to six cultivations in asparagus fields

resulted in the loss of 5 to 7 d of spear production (Parker and Boydston 1990). One study demonstrated reduced potato yield of 3 to 21% for consecutive years due to root pruning (Nelson and Giles 1986). For certain crops, cultivation for weed control increased plant disease problems, which lowered yields. Pythium root rot was more prevalent in peach [*Prunus persica* (L.) Batsch] orchards where roots were damaged by cultivation. Research demonstrated that a 19% peach tree mortality rate occurred in 4 yr of disc weed control, while the chemical weed control system resulted in no loss (Taylor 1972). Herbicides contributed to increased peanut (*Arachis hypogaea* L.) yields directly, through better control of weeds, and indirectly, through disease prevention (Buchanan et al. 1982). Southern stem rot losses are particularly aggravated by vine damage resulting from cultivation (Swann 1980).

Cultivation can be quite effective if performed at the optimal time for weed removal. However, from the historical record, cultivation was not always performed in a timely fashion, particularly when fields were wet when weeds needed to be removed, preventing the use of tractors. As a result, yield losses due to weed competition often occurred, and in extreme cases, fields were not harvested because of weeds. Former President Jimmy Carter graphically described this problem in his autobiography about growing up on a Georgia farm:

> Depending entirely on draft animals and hand labor, small variations in the rain pattern were devastating...The first week or two without rain was not particularly deplored, and was not even mentioned in Sunday-morning prayers in church. The dry ground permitted the mule-drawn plows and hoes to restrain the ever-encroaching weeds and grass.
>
> However, when no plowing was possible because of several successive days of rain, the noxious plants were uncontrollable. Something like the terrible creeping and oozing things in horror movies, Bermuda grass, coffeeweed, cocklebur, johnsongrass, beggar-lice, and nut grass would emerge from what had been a clearly cultivated field, and in a few days our entire crop of young peanuts and cotton could be submerged in a sea of weeds. Often, despite the most heroic efforts by the best farmers, parts of the crop would have to be abandoned. Although partially salvaged, the remaining young plants were heavily damaged by the aggressive plowing and hoeing. During these rainy times, Daddy would pace at night, scan the western skies for a break in the clouds, and scour the community, often far from our own farm, to recruit any person willing to hoe or pull up weeds for day wages. (Carter 2001).

In a 1932 Illinois study, it was estimated 10% of the cropland had 50% or greater crop loss due to weeds in a "normal year" (Case and Mosher 1932). The U.S. Department of Agriculture (USDA) estimated that the average annual national loss due to weeds in the potential production of soybean [*Glycine max* (L.) Merr.] was 17% in the 1950s. One major reason for the loss was lack of timely weed removal with rotary hoes (USDA 1965). With widespread herbicide adoption in the 1990s, soybean yield losses to weeds were reduced to 7% (Bridges 1992). In river bottomlands, where soil was often too wet for timely cultivation, corn crops were often lost because weeds took over. In some areas, farmers stopped growing corn because of weed problems (Raleigh and



Source: [Brodell et al., 1955, Strickler and Hinson 1962, USDA 1968, Eichers 1978, Duffy 1983, Andrilenas 1975, USDA 2001, USDA 2000]

Figure 2. Soybean: Trends in yield and herbicide use.

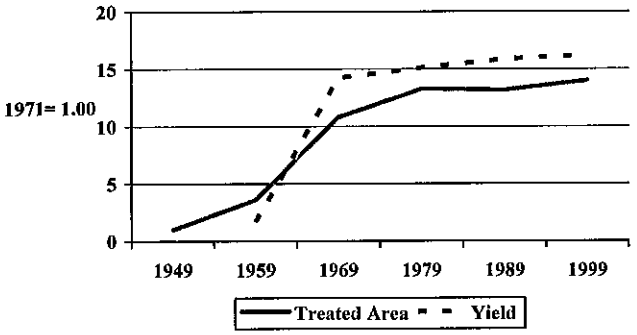
Berggren 1964). One report from 1947 states that an additional 25.4 million kg of corn were produced from 7,290 ha of bottomlands in Kentucky as a result of 2,4-D spraying (Hanson 1947).

For corn, the need to cultivate led to very wide plant spacing to accommodate cultivation on all four sides of each plant. With the substitution of herbicides, the plants in corn fields could be planted closer together, which increased per-hectare yields. Average corn plant populations increased from 30,000 plants per hectare in the 1950s to 50,000 plants per hectare at the end of the 1970s.

For most crops, historical data indicate an increase in yields due to herbicide use. Numerous experiments were conducted that compared yields using herbicides with yields using standard practices. Cucumber (*Cucumis sativus* L.) yield increased by 24%, dry bean (*Phaseolus* spp.) by 38%, sorghum (*Sorghum* spp.) by 34%, peach by 167%, potato by 29%, and rice by 160% (Burnside and Wicks 1964; Comes et al. 1962; Daniell and Hardcastle 1972; Glaze 1975; Mueller and Oelke 1965; Nelson and Giles 1989). A 4-yr study showed that wheat yields increased by 255 kg/ha when 2,4-D was used (Alley 1981).

Aggregate changes in national crop yields from the 1950s to the 1970s were influenced by several factors including adoption of herbicides, increased fertilization and irrigation, new plant hybrids, and the introduction of synthetic fungicides and insecticides. For two crops, corn and soybean, researchers have statistically determined the contribution of herbicides to improved yields. Herbicides accounted for 20% of the increase in corn yields 1964 through 1979 and 62% of the yield increase in soybean 1965 through 1979 (Schroder et al. 1981; Schroder et al. 1984). For both crops, yields increased as herbicide use increased (Figures 2 and 3).

Although statistical studies have not been conducted, a similar close relation between increased crop yields and increased herbicide use has been observed for other crops and published literature credits herbicide use as a primary factor for yield increases. The use of herbicides is cited as a primary factor in the doubling of peanut yields (Figure 4) (Grichar and Colburn 1993). Better weed control with herbicides is credited as an important factor in increased rice yield (Figure 5) (Smith et al. 1977).



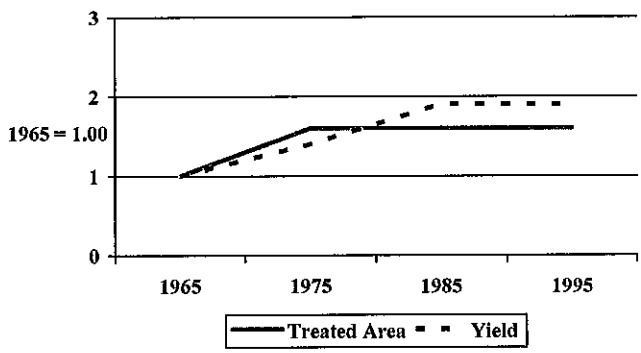
Source: [Brodell et al., 1955, Strickler and Hinson 1962, USDA 1968, Eichers 1978, Duffy 1983, Andrilenas 1975, USDA 2001, USDA 2000]

Figure 3. Corn: Trends in yield and herbicide use.

Although long-term herbicide use data are not available, the historical record clearly indicates that significant improvements in yield occurred for three crops only after the introduction of effective herbicides. Since the introduction of an effective herbicide (hexazinone) in the 1970s, blueberry (*Vaccinium angustifolium* Ait.) production in Maine has more than tripled, from an average of 9.1 million kg/yr to over 34 million kg/yr (Figure 6) (Yarborough et al. 1986, Yarborough and Ismail 1985). In the early 1970s the introduction of three major herbicides is credited as the most important factor in the doubling of cranberry yields from 1960 through 1978, whereas the registration of another herbicide (glyphosate) is credited with a 50% increase in cranberry yields in the 1980s (Figure 7) (Dana 1989; Eck 1990). Sugarcane yields in Louisiana increased significantly after the introduction of herbicides in the 1950s (Figure 8).

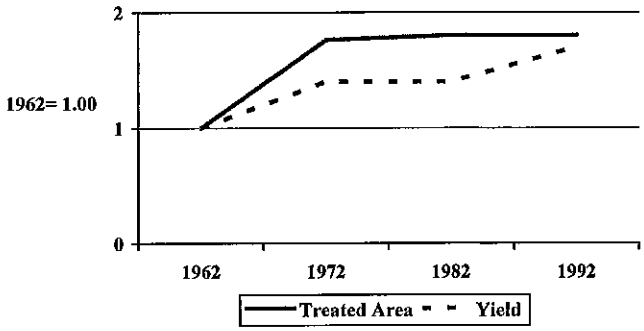
For several crops, including carrot, cotton, and onion, dramatic improvements in yield did not occur after the adoption of herbicides (Figure 9). For these crops, an adequate amount of hand labor had been previously used to remove weeds and prevent yield loss before the introduction of herbicides.

The historical record indicates that modern synthetic herbicides reduced the use of large quantities of oil and



Source: [Brodell et al., 1955, Strickler and Hinson 1962, USDA 1968, Eichers 1978, Duffy 1983, Andrilenas 1975, USDA 2001, USDA 2000]

Figure 4. Peanut: Trends in yield and herbicide use.



Source: [Brodell et al., 1955, Strickler and Hinson 1962, USDA 1968, Eichers 1978, Duffy 1983, USDA 2000]

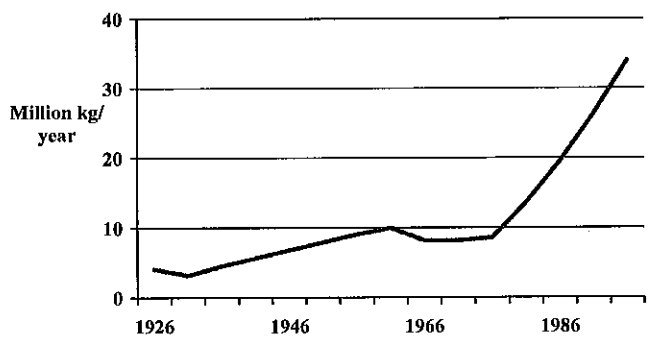
Figure 5. Rice: Trends in yield and herbicide use.

kerosene in cranberry by 2,810 L/ha of kerosene, in citrus by 850 L/ha of oil, and in carrot by 470 L/ha of oil (Cross 1952; Watwood 1959; Yarrick 1946).

Organic Crop Weed Control Practices

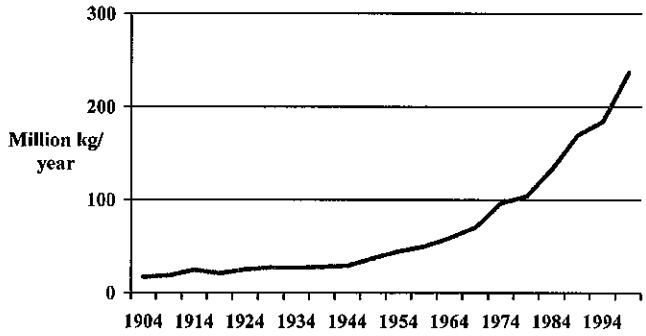
Organic crop growers do not use herbicides to control weed populations. USDA estimates that 565,600 ha of certified organic cropland were in the United States in 2003, which had steadily increased from 161,600 ha in 1992 (USDA 2005). However, certified organic cropland continues to represent only 0.5% of total U.S. cropland. The problem of controlling weeds without herbicides has been cited numerous times as the single biggest obstacle to crop production that organic crop growers encounter. Of 30 research areas, organic crop farmers ranked weed control as the number one priority in three national surveys (Walz 1999). Recently, Earthbound Farms, the largest organic farm in North America, described the high expense of their weed control operations:

> Controlling weeds without herbicides takes a lot of time and is very costly for us. We do all our weeding by tractor or by hand, which is very labor intensive. Conventional farmers spend only about $50 an acre on herbicides that knock out every weed in sight. Organic farmers may have to spend up to $1,000 an acre to keep weeds under control. (Earthbound Organic 2006)



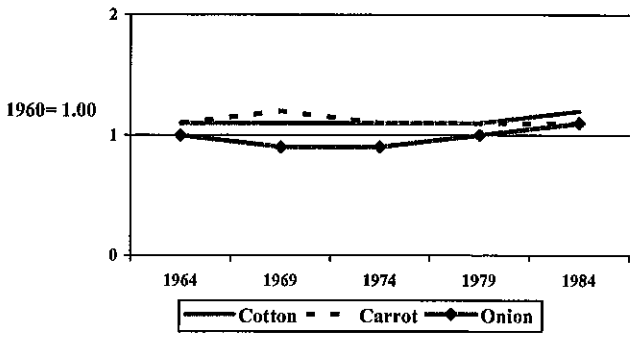
Source: [Yarborough 2005]

Figure 6. Maine wild blueberry production.



Source: [Eck 1990, USDA 2002]

Figure 7. U.S. cranberry production.

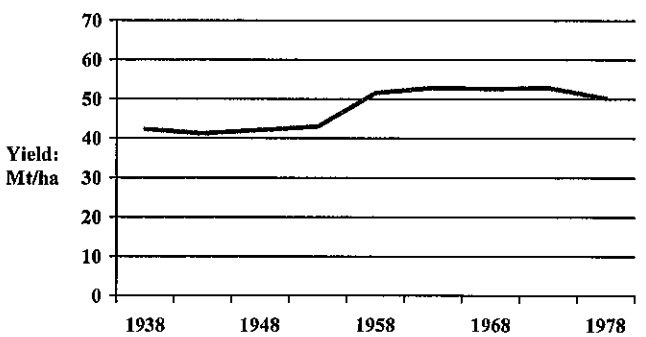


Source: [USDA 2000, Love 1994, Supak et al. 1992]

Figure 9. Yield index, U.S. cotton/carrot/onion.

Organic crop growers rely extensively on cultivation and hand weeding to control weed populations. Hand weeding used in organic crops ranged from 5 to 408 h/ha along with two to nine tillage operations (Table 2). Poor weed control is often cited as a major reason for lower yields in organic production. A 20-yr study in Iowa indicated that corn yields were 34% higher in the conventional vs. the organic operations, and multiyear studies in Nebraska and South Dakota resulted in conventional corn yields that were 17 to 20% higher than organic corn yields (Welsh 1999). Yields of organic corn in North Dakota are reported to be 25% lower than conventional corn yields (Swenson and Brummond 2000). Organic blueberry yields in Maine are reported to be 75% lower than conventional blueberry yields (Marra et al. 1995). Organic rice growers report that weed management is the most difficult part of organic production, and it is the major reason that organic rice yields are 50% lower than conventional yields (Rood 2002). Lower yields and higher costs for weed control labor are two of the major reasons that organic cotton must sell with high price premiums (Schneider 1993).

The problem of farming without herbicides was recently highlighted in an exemption from a farm worker protection rule granted to California organic growers (Gianessi and Reigner 2005). The state of California banned the practice of using workers to pull weeds by hand in 2004. The California Occupational Safety and Health Standards Board determined that the practice of pulling weeds by hand was more destructive to workers' backs than use of the short-handled hoe, which had been banned in 1975. Organic crop interests sought and were granted an exemption from the ban on hand weeding, claiming they would incur tremendous yield and profit losses if they were required to use laborers with long-handled hoes rather than hand weeders (Bolgenhorn 2004). Organic crop growers reported that workers with long-handled hoes would inadvertently damage or remove some of the vegetable plants while missing some of the weeds. Herbicides can control weeds and allow for vegetable plants to be grown in high densities. The organic crop growers were unwilling to accept the hoeing damage to their vegetable crops and to increase the spacing of the plants because of loss in yields.



Source: [Fielder et al. 1986]

Figure 8. Louisiana sugarcane yield.

Aggregate Studies of Herbicide Nonuse

In recent years several national studies have concluded that the nonuse of herbicides would lead to significantly lower crop yields because of the substitution of less efficacious or more injurious weed-control alternatives. USDA reports on strawberry, carrot, cotton, and processing tomato concluded that national production would decline by 30%, 48%, 27%, and 20%, respectively, without the use of herbicides and with the substitution of likely alternatives (Davis et al. 1998; Davis et al.

Table 2. Organic crop weed control practices

Crop	
Almond	17 h/ha hoeing (Asai et al. 1992)
Apple	Hand hoeing (50 h/ha) plus two diskings (Swezey et al. 2000)]
Cotton	9 cultivations; 30 h/ha hand weeding (Klonsky et al. 1995; Schneider 1993)
Cucumber	75 h/ha hand weeding; 3 cultivations (Klonsky et al. 1994)
Grape	20 h/ha hand weeding and 1 cultivation (CA); 8 cultivations and 32 h/ha hand weeding, (NY) (Klonsky et al. 1992; White 1995)
Green bean	42 h/ha hand weeding; 6 cultivations (Grubinger 1999)
Lettuce	2 cultivations; 45 h/ha hand weeding (Klonsky et al. 1994)
Onion	6 cultivations; 181 h/ha hoeing (Klonsky et al. 1994)
Peanut	124–408 h/ha weeding; 2 cultivations (Kvien et al. 1993)
Soybean	6 cultivations; 12 h/ha hand weeding (Dartt and Schwab 2001)
Sweet corn	3–5 cultivations (Klonsky et al. 1994); 5 h/ha hand labor (Grubinger 1999)
Tomato	6 cultivations; 37 h/ha hand weeding (Klonsky et al. 1993)

1999; Sorenson et al. 1997; USDA 1993). A USDA report for cranberry concluded that up to half of U.S. cranberry growers would eventually go out of business without herbicide use, since cranberry production would no longer be profitable when the beds became overwhelmed by weeds 5 to 10 yr after stand establishment (Mahr and Moffitt 1994). A study from Michigan State University concluded that apple (*Malus domestica* L. Borck) yields would decline by 10% without herbicides because of tree injury from mowers and cultivators (Ricks et al. 1993). An American Farm Bureau study concluded that wheat yields would decline by 30% on the Northern Plains without herbicides (Smith et al. 1990). The Weed Science Society of America (WSSA) published estimates by state for 46 crops that estimated yield changes likely to occur without herbicide use and the substitution of alternative Best Management Practices (Bridges 1992). The WSSA report estimated that yield losses due to weeds would increase in the United States by $15.5 billion/yr without herbicides.

All of these studies relied on university weed scientists to specify the likely changes in weed-control practices and yield if growers did not use herbicides. In most cases these simulations assumed that growers would be able to afford and employ enough laborers to provide only partial weed control. Studies have shown that crop yields need not decline without herbicide use if enough labor is used to remove weeds: corn required 150 h/ha, cotton 165 h/ha, and spinach 516 h/ha (Majek 1985; Nalewaja 1975; Patterson et al. 1991). However, the aggregate number of workers needed for the weeding would be so large as to make the simulation totally unrealistic. One writer concluded that hand weeding the nation's corn hectares without yield loss would require a labor force of 18 million people (Nalewaja 1975). Thus, most studies simulate an increase in hand weeding and cultivation that is inadequate to prevent yield loss. The American Farm Bureau estimated that California lettuce (*Lactuca sativa* L.) yields would decline by 13% without herbicides despite the substitution of two cultivations and 94 h of labor per hectare (Knutson 1993). Similarly, Texas onion yields were estimated to decline by 25% despite an additional cultivation and 79 h of labor (Knutson 1993).

The aggregate studies simulated the use of enough labor and cultivation for yield to be unaffected without herbicides in two instances. The American Farm Bureau estimated that an additional eight mowings and 165 h for hand weeding would be sufficient to prevent yield losses in Florida citrus orchards, while an additional cultivation with 27 more hours of weeding per hectare would prevent yield losses to weeds in California grape (*Vitis* spp.) vineyards without herbicides (Knutson 1993).

A recent study from the CropLife Foundation (CLF) organized the predicted yield loss estimates from the USDA, WSSA, and Farm Bureau studies into a comprehensive aggregate study estimating the likely impacts on crop yields and production costs if herbicides were not used (Gianessi and Reigner 2006). The CLF study relied on an extensive review of the historical literature (Gianessi and Sankula 2003). The herbicide replacement simulations for each crop are listed in Table 1 along with predicted changes in yield as a result of using the alternatives as replacements for herbicides.

In the aggregate, the CLF study estimates that U.S. crop production would decline by 135 billion kg of food and fiber or −20% with a loss in value of $16 billion. The CLF study estimates that growers currently spend $7 billion annually for herbicides and their application. The total cost of increased labor for hand weeding and increased cultivation is estimated at $17 billion for an incremental increase in production cost of $10 billion without herbicides. The need for fuel would be 1,280 million L greater since twice as many cultivation trips would be needed to replace herbicide sprays, and cultivators use four times more fuel per trip than herbicide sprayers. A minimum of 1.1 billion h of hand labor would be required at peak season for hand weeding, necessitating the employment of 7 million more agricultural workers. Even with increased cultivation and hand weeding, crop yields would be 20% lower. The CLF study estimates that 70 million workers would be required to prevent yield losses without herbicides.

Conclusions

Herbicides are used to control weed populations on 87 million ha of cropland in the United States. The major reason that organic crop hectarage totals only 565,600 ha in the United States is the difficulty of weed control without herbicides. A review of the practices of organic crop growers and a close examination of the historical record reveal the value of herbicides. The adoption of herbicides in the United States led to a significant decline in the use of labor for hand weeding and a decline in tillage for weed control, thereby lowering production costs and increasing crop yields. Organic crop growers use increased tillage and hand weeding instead of herbicides at a greater cost and with lower yields.

The value of herbicides can also be seen in the results of aggregate studies that simulate the impacts of their nonuse. Crop production in the United States would decline by 20% even with the substitution of tillage and hand weeding labor for herbicides. By controlling weeds effectively, herbicides do the work of 70 million laborers.

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