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WEED MANAGEMENT IN POTATOES TO
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By

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ABSTRACT

WEED MANAGEMENT FOR IMPROVED POTATO INTEGRATED PEST MANAGEMENT (IPM)

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Field studies with redroot pigweed (*Amaranthus retroflexus*) and barnyardgrass (*Echinochloa crus-galli*) seeded at 1, 2, and 4 plants/m, either within or between the potato (*Solanum tuberosum*) row resulted in one weed/m seeded within the crop row at planting time causing a yield reduction of at least 20%. Weeds seeded between the crop row after hilling (40 - 49 days after planting) did not reduce yield. In other field research, 'Atlantic' variety of potato was a better competitor with a natural infestation of weeds than 'Russet Burbank' on coarse textured mineral soil, but 'Russet Burbank' was a better competitor on muck soil. When this study was monitored for pest insects, larval Colorado potato beetles were most abundant in early hilled and weed free plots.

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REVIEW OF LITERATURE

INTERFERENCE

Interference is a broad term that encompasses all factors that may reduce plant growth. Putnam (53) lists three sub-disciplines which fall under the category of interference: allelopathy; allelomediation; and competition. Allelopathy is defined as the interaction of interspecific and intraspecific allelochemicals of both higher plants and microbes. These interactions may be beneficial or detrimental to plant growth. Allelomediation refers to the selective harboring of an herbivore by a plant which selectively attacks other plants, thus giving the harboring plant an advantage over neighboring plants. In agriculture, allelomediation is important in relation to microbes and arthropods. Competition is a common term that implies one organism actively seeking to control, or controlling, the growth requirements of another organism (53). Competition generally results from one plant being better suited for growth and survival than another. The more competitive plants tend to germinate faster and exhibit vigorous early growth of both above and below ground parts (27).

In relation to agriculture, competition occurs as a result of a finite system that contains a limited amount of resources for sustaining optimum growth at a specific density. If this density is exceeded, growth of one or more of the less competitive plant species will be hindereded (67). Plants respond to changes in density via phenotypical plasticity, which refers to the plant's ability to alter its growth i.e., amount of tillering, branching, and height, depending on the density (27).

In a finite, competitive system plants compete for moisture, nutrients, light, or carbon dioxide (1, 27, 30). Carbon dioxide is ubiquitous and seldom a factor limiting plant growth. Since it is extremely difficult to manipulate CO_2 concentration in the field it is usually neglected in the literature pertaining to competition (30, 55).

Plants which utilize the C_4 photosynthetic pathways have different characteristics than plants with C_3 photosynthetic pathways. Ribulose bisphosphate carboxylase (RuBP carboxylase) is the main enzyme in carbon fixation and has a high affinity for both O_2 and CO_2. Conditions of high O_2 concentration favor photorespiration which limits carbon fixation. C_4 plants separate RuBP carboxylase spatially within the plant whereas C_3 plants do not. C_4 plants have direct contact between the mesophyll cells and the bundle sheath separating O_2 from RuBP carboxylase and is known as Kranz anatomy (26). Water is lost when a plant's stomates are open allowing CO_2 to diffuse into the plant. C_4 plants limit the time stomates are open, and thus reducing water loss, by the ability of aspartate and malate to combine with CO_2 and transport it to the mesophyll cells where photosynthesis occurs. However, C_3 plants cannot transport CO_2, thus the stomates remain open longer to achieve a higher CO_2 concentration for photosynthesis.

Competition is not an intrinsic property of a specific plant, but rather a comparison between plants and within various environmental conditions (51). Black et al. (6) have reported that C_4 plants are generally better competitors than C_3 plants. The biochemistry and physiology of C_4 plants provide a growth advantage under competitive conditions (6, 50, 51). Baskin and Baskin reviewed the literature and concluded that C_4 plants do not have an inherent competitive advantage over C_3 plants. Plants are most competitive when they are in their preferred environments, regardless of whether they are C_4 or C_3 plants (4).

Moisture is an important factor that may limit plant growth (30, 67). Leaf expansion is very sensitive to water stress, and when leaf expansion is decreased, the surface area for photosynthetic assimilation decreases (51). Since plant roots absorb soil moisture, the most competitive plants appear to be those with root systems that thoroughly explore a volume of soil (8, 30).

Plants compete for nutrients, with nitrogen frequently being the limiting nutrient (51). Due to nitrogen's mobility in the soil, the plants with the root system best adapted for its interception have the competitive advantage (30). Ozturk et al. (50) showed neither C_4 nor C_3 plants are consistently more competitive for nitrogen.

In a greenhouse competition study between redroot pigweed (Amaranthus retroflexus L.) and tomatoes (Lycopersicon esculentum Mill.), the dry weight of tomatoes was reduced when nutrients and moisture were below the optimum level (40). However, further decreases in tomato dry weight resulted when grown with redroot pigweed under the same stressed conditions.

Light can also be a major factor limiting plant growth (30, 55). Radiant energy is critical to many plant processes such as transpiration, photomorphogenesis, photoperiodism, chlorophyll synthesis, chloroplast development, seed germination, stem elongation, leaf expansion, light induced plant movements, and light induced enzyme synthesis and regulations (30). Most of these processes require a ratio of light from specific regions of the light spectrum and if the ratio is disrupted, these processes can be hindered.

The light spectrum is altered when passed through a canopy of leaves and allows more far red light to pass through than red light (73). Seed germination requires a high ratio of red light to far red light, and since the canopy drastically reduces the ratio of red light to far red light, seed germination can be limited (73). This filtered light is also less photosynthetically effective (30). Shading can also disrupt the Kranz anatomy in a normal C_4 leaf (51).

INTERFERENCE STUDIES

Various experimental designs are available to study weed/crop competition in the field and under artificial conditions. This discussion will be limited to those designs which will be used in later chapters. An additive design experiment compares the relative aggressiveness of a series of competitors compared to an indicator species (30). This design simulates the field situation of weed infestations in a crop. The experiment uses an indicator plant (crop) at a fixed density, and the density of the competitor (weed) is varied. The growth parameters of both species are measured (30, 51, 67).

A replacement design, or substitutive experiment, is another method of studying plants' interactions. This design involves two species, but the total density of plants remains constant and the ratio of the species is varied. Replacement designs help determine plant species interactions and group these interactions as either no effect, a strong competitor, mutual antagonism, and symbiosis (30, 67). Both additive and replacement designs have been utilized in determining the effect mixed populations of weeds have on a crop.

Dawson (22) proposed two time periods where weed/crop interactions are critical to evaluate for optimum yields. Additive designs appear to be used most frequently when researching the critical periods of weed control to ensure maximum yield. The first time period involves how long the weeds emerging with the crop can compete before being removed without a reduction in yield. The second critical time period is the number of weeks into the season a crop must be kept weed free to avoid crop loss. A grower can then determine the necessary residual time a herbicide must have as well as the time period for control of escape or late germinating weeds to ensure maximum yield. The length of the first time period is dependent on the vigor of the weed species and its ability to capture the factors needed for growth. For example, if moisture is the competitive factor, the length of time that plants can compete without a yield reduction is shorter than if light is the competitive factor (21).

Dawson (21) found in his period threshold studies that for each week a crop remained weed free, the crop yield increased and total weed weight decreased until a plateau was reached. Weed growth was never zero. When half the crop was removed after a certain period of time, weed growth increased in the non-crop area, but growth remained suppressed in the cropped area (21).

The second stage of the period threshold involves a grower controlling the weeds early in the season until the crop has reached a stage where weeds can be suppressed through interference (21). A crop's ability to compete is diminished by any factor that reduces the vigor of the crop or decreases the stand (21). A plant with an advantage in one growth requirement will, in time, compete with the other plants for other growth requirements, making it very difficult to determine which is the most limiting component of growth (21, 30).

Critical period results vary depending on the crop, the weeds, and the environmental conditions. Therefore, generalized statements applying specific results to a wide range of circumstances may be invalid.

Attempts have been made to define competitive relationships and to use these for threshold models. These models determine when a plant begins to be a detriment to other plants. Radosevich and Holt (55) reviewed plant characteristics they felt must be considered in developing threshold models. The first consideration is the plant's plasticity, i.e., the ability to vary vegetative growth depending on density. Greater plasticity means that the number of plants is less critical in relation to other parameters. Secondly, plasticity of weeds allows competition to result from low plant densities. Third, the seed bank in the soil makes predictions of what may germinate and compete very difficult. Fourth, natural weed communities are mixed species, and the models must consider the reaction of a particular species to others. Fifth, crop rotations must consider the weed threshold of subsequent crops not only the present season threshold. The following crop may be sensitive to herbicides needed to control a specific weed, thus maximum weed control may not be possible if a sensitive crop is in the rotation. Finally, thresholds should not be based only on simple economics of yield gains versus cost of treatment. Rather they should include such peripheral areas as ease of harvest, crop quality and impact of pests and beneficial organisms (55).

Radosevich and Holt (55) further stated, competitive relationships must include the spatial arrangement of the weeds, timing of germination, and the growth rate of the plants. The more competitive plants are separated from other plants, established before other plants, and grow quicker than their neighbors (55). Competitive characteristics can be modified or reversed by changes in growth parameters, e.g., precipitation, fertility or temperature (86).

Dexter and Evans (23) found when predicting yield losses due to weed competition that measurements of precipitation, maximum-minimum soil temperatures 10 centimeters below the soil surface, and weed density gave a much more accurate coefficient of determination than only using weed density.

Oliver (49) explored the concept of a sphere of influence. Sphere of influence is the effect a single weed has on a crop plant at regular distance intervals away from the crop plant. Oliver concluded it was an accurate method in assessing the interference of low densities of weeds on a weed/crop relationship.

Coble developed a model to evaluate mixed weed population situations, particularly weed problems arising from incomplete control. A competitive index was developed for individual weed species from a linear regression model of soybean (Glycine max L.) yield on weed densities. The competitive load is determined for each species by multiplying the competitive index times the average number of weeds per 10 meter of row. The competitive load for all individual species is summed to determine the total competitive load. Each unit of increase in the total competitive load resulted in approximately 5% decrease in soybean yield (16).

Dawson's period threshold, Oliver's sphere of influence, and Coble's competitive index all allow for a tolerance of weeds in the crop. These models dictate weed management decisions to be made when a given weed species is over a specific threshold. The zero threshold concept, on the other hand, views any control less than 100% as unacceptable (46). The zero threshold concept is difficult to justify in modern agricultural practices on the basis of cost/benefit. Many growers however, place an intangible value on 100% weed control.

Studies have also been conducted to examine weed density effects on yield, both for monoculture and mixed weed populations. Some researchers, however, feel that density is not as crucial as the total dry mass production of the weeds (45, 76). Thurlow and Buchanan (76) hypothesize that due to the plasticity of weeds, the density is not as good an indicator of yield loss as total dry matter. Mohammed and Sweet (39) found similar dry weight when 16 redroot pigweeds/m^2 were grown or 256 redroot pigweeds/m^2.

Numerous competition studies have been conducted with pigweed species. Moolani et al. (41) found smooth pigweed (*Amaranthus hybridus* L.) infesting corn (*Zea mays* L.) reduced the dry weight of corn one unit for each unit of increase in the dry weight of smooth pigweed. Soybean dry weight was reduced 1 1/3 unit for each unit redroot pigweed increased (41). Buchanan et al. (10) studied weed effects on cotton (*Gossypium hirsutum* L.) yield and reported that yield decreased as the density of redroot pigweed and sicklepod (*Cassia obtusifolia* L.) increased. Weeds did not interfere with harvest except at high densities (10). Schweizer (64) examined redroot pigweed interference with sugarbeets (*Beta vulgaris* L.) and the yield of sugarbeets and sucrose content decreased as weed densities increased.

Fennemore et al. (25) conducted a replacement study with beans

(*Phaseolus vulgaris* L.), barnyardgrass (*Echinochloa crus-galli* (L.) Beauv.), and black nightshade (*Solanum nigrum* L.). The beans suppressed the relative growth rate of barnyardgrass for the first 37 days after germination. The relative growth rate of barnyardgrass later increased and surpassed that of the beans. Yield reductions due to late season competition could therefore occur. Similarly, Dawson (20) found weeds that germinated soon after the crop caused the greatest reduction in irrigated bean yield, although the period of competition did not occur for weeks afterwards.

Shurtleff and Coble (66) examined numerous broadleaf weeds in soybeans. Leaf area of the soybeans increased as the distance from the weeds increased, and the researchers concluded the range of reduction in soybean leaf area caused by a weed's location was a good method of predicting an individual weed's competitiveness (66). Similarly, Thurlow and Buchanan (77) found sicklepod seeded in the drill at the same time as soybeans were usually less competitive than when seeded 15 cm or more from the drill row due to the competitive nature of the soybean plant. Both broadleaf and grass weeds grown with cotton had a greater reduction in yield when grown within the row than between the row (59). Most studies assume cultivation will remove the weeds from between the rows, thus weed pressure within the crop row is more detrimental in field situations.

Studies On Weed Interference in Potatoes

VanHeemst (77) compared numerous crops and rated the crops according to their ability to compete with weeds. Only wheat (*Triticum aestivum*

L.) and peas (<u>Pisum sativum</u> L.) surpass potatoes (<u>Solanum tuberosum</u> L.) in their relative mean yields in weedy plots compared to weed-free plots.

Research determining the critical period for weed control in potatoes has been conducted overseas as well as in the United States. In two Indian studies, 45 days and 4 to 6 weeks of a weed-free period were required for optimum growth (69, 75). A weed-free period of only 25 days was required in Chile (61). In the United States, Vitolo (81) found 6 to 8 weeks of competition from grass weeds could be tolerated in 'Superior' potatoes while only a two-week weed-free period was required for maximum yield. In North Dakota, yield reductions resulted after 8 weeks of mixed weed competition (45). A Lebanese study concluded that 9 weeks of competition with broadleaf weeds could be tolerated (63).

Nelson and Thoreson (45) and Saghir and Markoullis (63), concluded that weeds reduced tuber yield due to a decrease in both the number of tubers and average size of tubers. A 10% increase in dry weight of weeds, decreased the fresh tuber yield 12% (45). However, the weeds did not affect the specific gravity of the potatoes (45).

Varieties may impact weed control due to their various growth habits and thus affect their competitiveness with weeds. Potato varieties with fast emergence, rapid early growth, and an upright dense canopy are best at suppressing weed growth. Potatoes that provide the maximum amount of shade the earliest and for the longest duration are the best competitors (87). 'Superior', an early maturing variety, appeared to be a weaker competitor over the full season when compared with late season potato varieties (54, 65). 'Katahdin' and 'Hudson', longer season varieties, without herbicide were able to suppress weeds similar to 'Superior' with herbicide treatments (65).

COMPETITIVE CHARACTERISTICS

Roush and Radosevich (62) examined various growth parameters to determine which had the greatest influence on establishing a hierarchy of growth ability among four species, *Echinochloa crus-galli* (L.) Beauv., *Amaranthus retroflexus* L., *Chenopodium album* L., and *Solanum nodiflorum* Jacq.. Relative growth rate did not vary among the four species. However, unit leaf rate (ULR), leaf area ratio (LAR), and plant dry weight best fit the linear regression of aggressivity (A) (37, 62).

Agressivity = 1/2 (W/X)-(Y/Z) where,

W = yield of individual plant per species in monoculture
X = yield of individual plants per species in monoculture averaged over reps
Y = yield of individual plant per species in mixed culture
Z = yield of individual plants per species in mixed culture averaged over reps.

Kroh and Stephenson (35) developed the Competitive Index (CI) to determine the competitive ability of a plant species. CI is determined by:

CI = mean plant weight of each species in monoculture divided by mean plant weight of the species in a mixed species treatment.

CI is one for intraspecific competition. A CI greater than one indicates a plant is more competitive than its neighbors, and conversely, a CI less than one means that the plant is less competitive. A ranking of competitiveness is determined by summing the CI of each species to give an overall total and the species with the highest total is the most competitive.

REDROOT PIGWEED - *Amaranthus retroflexus* L.

Redroot pigweed is an annual plant found in disturbed areas where annual weeds predominate (83). It is found on all soil types ranging from sandy loam to clay to muck, and appears to grow best in soils with pH above 6.0 (83).

Weaver and McWilliams (83) reviewed the literature on three species of *Amaranthus*, including *A. retroflexus*. Redroot pigweed has growth characteristics which aid in its ability to compete with other weeds and crops. The stem of the plant is erect, up to 2 meters tall, and may be either simple of branched. The leaves are alternate and are either ovate or rhombic-ovate. The plant's height, branching, and dense leaves all contribute to increase the plant's light interception capabilities. The plant may take a more prostrate growth habit if it is greatly disturbed. Redroot pigweed has a shallow taproot system and small numerous flowers crowded into dense blunt spikes forming terminal panicles (83).

Redroot pigweed is a C_4 plant with typical Kranz leaf anatomy. It has a low CO_2 compensation point, high transpiration efficiency, and high light saturation for photosynthesis. Optimum temperature for photosynthesis is 30^{o} to 40^{o} C. Relative growth rate and leaf expansion increase with increasing temperature and irradiance (83).

Tenhenen found that redroot pigweed had photosynthetic rates approximately equal to common lambsquarters (*Chenopodium album* L.) when compared at a maximum leaf temperature of 15^{o} C. This temperature was less than optimum for pigweed, yet its highly efficient utilization of light and low rates of CO_2 respiration at night allowed it to have a photosynthetic rate similar to a C_3 plant in this study (74).

Redroot pigweed is a faculative short-day flowering plant capable of producing 100,000 seeds per plant with 96% of the seeds viable (83). Siriwardana and Zimdahl (70) found the average redroot pigweed produces 67 times more seed than barnyardgrass. Studies looking at the longevity of the seeds in the soil have found seeds to survive from 18 months to 40 years (11, 83).

Young plants, up to four weeks after emergence, are quite susceptible to cultivation. Older plants are often able to recover from cultivation (83).

BARNYARDGRASS - *Echinochloa crus-galli* (L.) Beauv.

Barnyardgrass, like redroot pigweed, has a C_4 photosynthetic pathway, and therefore prefers high light intensity for photosynthesis, and high optimum temperature for growth (32). It is an annual weed that is favored by disturbed environments (32).

Barnyardgrass is member of the Poaceae family. It is considered polymorphic due to its wide variety of morphologic variation. Several characteristics allow it to be competitive with other weed species and crops. Barnyardgrass has a stout stem which may reach 1.5 meters in height. One stem may produce up to 15 tillers and the main stem may produce up to eight leaves. The height, tillering, and leaves all contribute to the plant's ability to capture light. Barnyardgrass has a fibrous root system. The panicles are composed of numerous racemes, which may be either spreading, descending, or branched. A single plant may produce up to 7,000 seeds with 90% of the seeds viable (29, 32, 34).

There is a decline in the number of tillers and panicles produced when barnyardgrass is in a crowded, competitive situation as well as a reduction in height and dry weight of the plant (5, 47).

Barnyardgrass will grow in a wide variety of soils but prefers moist or wet soils (70). Slightly compacted soils favor its emergence (32). Weise (85) found barnyardgrass' competitiveness to be adversely affected under water stress conditions. Nussbaum et al. (47) cited barnyardgrass as an inefficient user of water. This finding is not consistent with C_4 plant characteristics (6, 52).

Barnyardgrass flowers over a wide range of photo-periods (32, 80). Reproductive phase can begin with four to five fully expanded leaves (34). Formation of reproductive shoots is negligible when under approximately 70% shade (5).

Echinochloa crus-galli var. Frumentacea (Roxb). has been cultivated as a forage grass and its seeds used for bird feed. This variety is characterized by its thick, appressed racemes and turgid, awnless spikelets (31).

Barnyardgrass and Redroot Pigweed

Barnyardgrass and redroot pigweed have a high optimum soil temperature range for germination, 30° to 40° C (32, 47, 83). Increasing soil temperatures decrease the time of emergence for both species (79, 83, 85). These two weeds, therefore, emerge in late spring, due to their high temperature requirement, and continue to emerge through late summer (3, 19, 48, 83). Vengris discovered that barnyardgrass seedlings emerging on July 20 in Massachusetts produced mature seeds (79), while redroot pigweed emerging after the first of August produced a negligible number of mature seeds (78). For both species, the earliest plants to emerge, produced the largest amount of dry matter and in turn were the best competitors. The number of days from emergence to maturity for barnyardgrass progressively decreased as the emergence date became progressively later (80). Emergence of barnyardgrass and redroot pigweed appears to be under the control of the phytochrome system, but is greatly enhanced by temperature (72, 83).

For both barnyardgrass and redroot pigweed, greater depth of seed increases viability (72). As time of burial increases, viability decreases (72). Roche and Muzik (60) found that barnyardgrass could emerge from a six inch depth and give a competitive stand. Wiese (85) found no redroot pigweed to emerge from a four inch depth of either silty-clay loam or sandy loam soils. Barnyardgrass' ability to emerge from greater depths than pigweed may account for its emergence pattern not being affected by cultivation. Peak emergence of both weeds is at the 1 to 4 cm depth (19, 85). Emergence of both weed species was favored on a fine sandy loam compared to a silty clay loam in Texas (85), while in Nebraska results with redroot pigweed were contradictory (11).

Cultivation results in bringing weed seed to the surface where the likelihood of germination is increased. Cultivation followed by rainfall resulted in a flush of germination of redroot pigweed (24, 48, 58). Shallow tillage of barnyardgrass after May did not have an appreciable influence on barnyardgrass emergence (48). Baskin and Baskin (3) concluded that soil disturbance brought redroot pigweed seeds to the surface and resulted in higher redroot pigweed emergence due to its high light requirements.

Both weed species respond favorably to additions of nutrients to the soil. The greatest response was due to an addition of nitrogen, and the least response was due to potassium (32, 33, 83). Both species show they can accumulate high levels of nitrates in their tissue even to levels toxic to wildlife (32, 83).

In both additive and replacement studies, barnyardgrass was more competitive than redroot pigweed (38, 62). Siriwardana and Zimdahl found redroot pigweed to emerge quicker than barnyardgrass at equal depths and concluded in this case early emergence did not lead to greater competitiveness. Barnyardgrass' competitiveness was favored by lessening the intraspecific competition of barnyardgrass via a smaller barnyardgrass to redroot pigweed ratio, deeper seed depth, or higher soil moisture (70).

Gressel and Holm found that aqueous extracts from the seeds of both barnyardgrass and redroot pigweed exhibited some seed germination inhibiting properties. Barnyardgrass extract also decreased root growth of pepper (*Capsicum frutescens* L.) by more than 20% (28).

POTATOES - *Solanum tuberosum* L.

Potato varieties have varying growth characteristics, such as leaflet size, speed of early growth, and ability to maintain a dense canopy that allow them to effectively compete with weeds (71, 87). Collins (17) analyzed canopy size and found branching to have a major influence on a variety's relative size. 'Russet Burbank' is a late maturing variety and 'Atlantic' is a medium to late maturing variety. Both are classified as varieties with large amounts of biomass. 'Russet Burbank' has four pairs of primary leaflets and 'Atlantic' only three pairs. 'Atlantic', however, has more secondary and tertiary leaflets (14, 84). Cultural practices are very similar for both varieties, however, 'Russet Burbank' is more sensitive to water stress and early die complex (Verticillium wilt and nematodes) (14). 'Atlantic' is susceptible to internal brown spots and both 'Atlantic' and 'Russet Burbank' are susceptible to hollow heart.

INFLUENCE OF POTATO PRODUCTION ON WEEDS

Weeds are the greatest factor limiting potato yield (57). Weed pressure in potato crops has increased with such improved potato production techniques as irrigation, optimum nutrient supply, better disease and insect control and the use of varieties that lack a dense canopy (18). The improved potato production techniques also favor weed growth. Nelson and Thoreson (45) reported that as the total dry weight of weeds is increased, the tuber yield is decreased.

Herbicides and mechanical tillage are the conventional options available for weed control in potatoes (18). Herbicides for Michigan potato production are generally applied at planting or prior to the crop's emergence (56). Pre-emergence herbicides such as metribuzin (4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one), linuron (N'-3,4-dichlorophenyl)-N-methoxy-N-methlyurea), and metolachlor (2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl)acetamide) are usually applied for weed control in potatoes (56). Potatoes generally require at least two weeks from planting until emergence, thus, there is a period of two weeks that pre-emergence herbicides can be applied. The time required for a competitive canopy to herbicides can be applied. The time required for a competitive canopy to develop depends on the potato variety. Therefore, growers using chemical means of weed control must apply a herbicide with soil residual activity to control weeds until the crop is able to compete with emerging weeds. Post-emergence herbicide options are limited to metribuzin and sethoxydim (2-, 1-(ethoxyimino)butly -5-, 2-(ethylthio)propyl -3-hydroxy-2-cyclohexen-1-one) (56).

No weed control options are available for broadleaf weeds appearing late in the growing season when the canopy begins to senesce and the foliage becomes sparser (18).

Research on the effect of these late developing weeds on tuber yield is not available, but they do produce seeds which could detrimentally affect subsequent crops and these weeds may hinder the harvesting operation (13).

Numerous studies have been conducted evaluating the effectiveness of cultivation on weeds and on crop growth. Studies on cultivation show no advantageous effects on tuber yield, therefore, these studies conclude that cultivation should only be used for weed control purposes (7, 13, 18, 42, 44, 57).

Hilling potatoes serves as a cultivation to control weeds emerging between the crop rows (7, 44). Rioux et al. (57) found that hilling potatoes just prior to emergence gave the best weed control. Weeds emerged at various times, making it difficult to time the hilling operation with weed emergence. Hilling time had no effect on the efficacy of herbicides. Rioux et. al. recommended that hilling should be done to maximize the vegetative growth of the plant, not as a weed control method.

Mechanical tillage and hilling will disrupt the layer of herbicide applied to the soil, thus permitting weeds to emerge. These operations will also bring new weed seeds to the surface, increasing the chances of a new flush of weed germination (24, 57, 58).

In reviewing the literature on moisture and potato growth Singh (68) found that soil moisture was an important factor in potato production. Tuber yield was greatest when the moisture level of the soil remained above 50% of the field capacity. Maintaining high soil moisture levels eliminated moisture stress and increased both top growth and leaf surface area. Increased leaf surface area, in turn, increased the shading ability of the plant (67).

Nitrogen is required for maximum potato production, particularly during the tuberization process (8, 9, 44). Bradley and Pratt concluded that if large amounts of irrigated water are needed, additional nitrogen may be required to avoid nitrogen stress (9, 43).

Watson (82) found that the cultural practices such as fertility and adequate soil moisture, which increase yield, can result in an increase in leaf growth. Thus Watson concluded, to maximize yield the leaf area should be at its maximum when the environmental conditions are optimum for photosynthesis. The length of time that the maximum leaf area is present should also be increased (15, 82). Burstall (12) showed that a particular leaf area value will provide greater ground cover earlier in the season than late in the season due to lodging.

Allen and Scott (2) examined yield and leaf area index and came to very similar conclusions as Watson. A linear relationship existed between both total dry weight and tuber dry weight and the amount of radiation intercepted by the potato canopy (2). Allen and Scott's article also led to an examination and discussion of cultural practices to increase the leaf area index of the potato crop. Increasing yield as a result of greater leaf area also improved the potato plant's shading ability and may reduce weed germination and suppress weed growth.

Potato production is generally on coarse textured soils. In Michigan, approximately 1/10 of the potato production is on high organic soils, or muck. Michigan has 1.8 million hectares of organic soils (third in total area in the United States) (36). Literature pertaining to potato production on muck soils is very limited. No publications were found investigating weed control or weed interference in potatoes on muck soils.

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REDROOT PIGWEED (*Amaranthus retroflexus* L.) AND BARNYARDGRASS (*Echinochloa crus-galli* L. Beauv.) INTERFERENCE IN POTATOES (*Solanum tuberosum* L., var. 'Atlantic')[1]

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Abstract. In field studies of barnyardgrass and redroot pigweed seeded at densities of 1, 2, and 4 weeds/m within the 'Atlantic' crop row at potato planting and between the crop row after hilling, barnyardgrass was not more competitive than redroot pigweed. Neither redroot pigwweed nor barnyardgrass seeded between the crop row at time of hilling reduced aboveground potato biomass or tuber yield. Weed density of 1 weed/m of either species within the crop row reduced tuber yield both years. Redroot pigweed seeded within the crop row had greater dry weight than barnyardgrass, but barnyardgrass reduced aboveground potato biomass more than redroot pigweed in the row in 1987, yet both weeds were equally competitive in regards to tuber yield. In 1988 redroot pigweed reduced tuber yield 7% more than barnyardgrass. Tuber yield correlated well with weed density/plot and weed biomass/total plant biomass, respectively. Neither specific gravity nor tuber quality were altered by the presence of either weed species at any density.

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'Atlantic' and 'Russet Burbank' potatoes were equally competitive when aboveground biomass was measured under moist soil conditions in greenhouse replacement series experiments. Barnyardgrass and redroot pigweed were less competitive than either potato variety, and barnyardgrass was more competitive than redroot pigweed.

Nomenclature: Potato, Solanum tuberosum L.; redroot pigweed, Amaranthus retroflexus L. #[3] AMARE; barnyardgrass, Echinochloa crus-galli (L.) Beauv. # ECHCG.

Additional index words. Aboveground biomass, canopy closure, interference, photosynthetic active radiation (PAR), tuber quality, AMARE, ECHCG.

[3]Letters following this symbol are a WSSA-approved computer code from Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 309 West Clark Street, Champaign, IL 61820.

INTRODUCTION

The first step in developing an integrated pest management program is determining if a pest reduces crop yield or alters crop quality. Coble (5) developed a competitive index for various weeds in soybeans (Glycine max (L.) Merr.), and determined the infestation level of various weed species where crop yield was reduced. Dawson (7, 8) discussed the concept of a weed fre period prior to weed infestation where soybean yield would not be reduced as well as a time period that the crop and weeds could compete before weed removal without causing a yield reduction. Weed competition thresholds and weed free periods have not been as extensively developed in other crops, including corn (Zea mays L.), cotton (Gossypium hirustum L.), sugar beets (Beta vulgaris L.), and potatoes (3, 4, 14, 15, 24, 31).

Research has shown potatoes to be a competitive crop (30). Singh et al. (26) and Thakral et al. (29) reported that 45 days or a 4 to 6 week weed free period was required for optimum tuber yield. In other research (23), the greatest reduction in tuber yield occurred after 9 weeks of interference from a natural infestation of weeds, with redroot pigweed one of the predominant weed species. Vitolo et al. (31) found that a natural stand of grasses, including barnyardgrass, could compete with potatoes ('Superior') for 6-8 weeks before yield was reduced. Also, a 2 to 4 week weed free period was sufficient to assure maximum yield (31). Researchers in have primarily evaluated the influence of 'natural infestations' of weeds on tuber yield, with weed pressure primarily occurring within the crop row (15). Nelson et al. (15) and Saghir et al. (23), concluded that weeds reduced tuber yield due to a decrease in both the number of tubers and the average size of tubers. A 10% increase in dry weight of weeds, decreased fresh tuber yield 12% (15). However, the presence of weeds did not alter the specific gravity of the potatoes (23). These authors found no literature examining competitive thresholds for individual weed species in potatoes.

Hilling of potatoes is a common cultural practice which shields tubers from light, assists in harvest, and serves as a means of mechanical weed control. The hilling process, however, disturbs the herbicide treated soil and brings weed seeds to the soil surface where weed seed germination may occur (9, 20). The effect these late emerging weeds have on yield has not been documented.

Plants capable of gaining an early growth advantage due to early emergence or greater relative growth rates are capable of capturing limited resources and 'outcompeting' neighbors (6). Plants compete for various resources, including moisture, nutrients, and light (1, 10, 11). Competition occurs for light because the upper plant canopy absorbs a major portion of the photosynthetically active radiation (PAR), which results in the shorter plants being less competitive since they receive a lower percentage of PAR (11). Allen and Scott (2) examined yield and leaf area index for potatoes. A linear relationship existed between both total dry weight and tuber dry weight and the amount of PAR intercepted by the potato canopy.

Redroot pigweed and barnyardgrass are two common weed pests in potato production. Moolani et al. (4) reported redroot pigweed at a 2.5 cm spacing in the row reduced corn yield 39% and soybean 55%. Redroot pigweed in cotton reduced yield linearly as the density increased from 0 to 32 weeds/15 m of row.

Both barnyardgrass and redroot pigweed are C_4 plants, thus their relative growth rate increases with warmer conditions because C_4 plants have a higher optimum temperature for growth (17). Cultivation and hilling practices resulted in increased redroot pigweed germination (21), but neither practice influenced barnyardgrass emergence (16).

Barnyardgrass was more competitive than redroot pigweed in both additive and replacement series greenhouse experiments (13, 22). Siriwardana and Zimdahl found redroot pigweed to emerge sooner than barnyardgrass when seeded at equal depths, but concluded that earlier emergence did not lead to greater competitiveness. Barnyardgrass's competitiveness was favored by a lower barnyardgrass to redroot pigweed ratio, higher soil moisture, or deeper seed depth (27). In other research comparing the emergence of barnyardgrass and redroot pigweed (33), barnyardgrass and redroot pigweed emerged from a 0.3 to 8 cm depth in a greenhouse experiment, with optimum emergence at 0.5 cm.

Replacement experiments in the greenhouse were initiated to evaluate the influence of barnyardgrass and redroot pigweed on the growth of two potato varieties under high moisture conditions. Field research was initiated to determine at what density redroot pigweed and barnyardgrass reduce tuber quality and/or yield when seeded in the crop row at planting or between the crop row after hilling. Since potato size and quality are critical for maximum economic return, sizing, internal defects, and specific gravity were compared among the various treatments.

MATERIALS AND METHODS

Greenhouse. The competitiveness of redroot pigweed, barnyardgrass, and two potato varieties, 'Russet Burbank' and 'Atlantic', was determined in greenhouse replacement experiments. The soil was a sandy loam soil complex of Montcalm (sandy, mixed, frigid, Alfic, Haplorthod) and McBride (coarse-loamy, mixed, frigid Alfic Fragiorthod) soil series with an organic matter content of 1.7% and 1.5% and soil pH of 5.8 and 5.2, for the first and second experiments, respectively.

Each 20 cm pot utilized one indicator weed species or potato variety. This indicator plant was grown with one of the other three plants in ratios of 0:4, 1:3, 2:2, 3:1, or 4:0. All 4 plants in a pot were arranged in a square design, spaced 4 cm apart. Barnyardgrass and redroot pigweed seeds were placed at a 0.5 cm depth. The potato sprout sets were extracted with a fruit baller and planted 7.5 cm deep. Seeds and sprout sets were planted the same day and later thinned to one weed or stem per pot location. There were four replications in the first experiment, and three replications when the experiment was repeated.

The plants were surface watered initially, and then subirrigated with water or a dilute fertilizer solution of 20-10-20 (N-P-K) to maintain moist soil conditions. The greenhouse temperature ranged from $18^{o}C$ to $29^{o}C$. The natural lighting in the greenhouse was supplemented with sodium lights which were on a 16 hr daylength. The range of light intensity was 350 $\mu E\ cm^{-2}\ sec^{-1}$. Forty-three days after planting, plant biomass above the soil line was removed from each pot, dried to a constant weight, and dry weight of each plant was recorded. Dry weights were then averaged for the species and/or varieties in each pot.

Field studies. The interference of barnyardgrass and redroot pigweed on irrigated potatoes was determined in field experiments in 1987 and 1988 at the Montcalm Potato research Farm, in Entrican, MI. Research plots were established on a sandy loam soil complex of Montcalm (sandy, mixed, frigid Alfic Haplorthod) and McBride (coarse-loamy, mixed, frigid Alfic Fragiorthod) soil series with an organic matter content of 1.9%, and a soil pH of 5.7 and 5.2, in 1987 and 1988, respectively.

Field preparation and fertilization utilized standard cultural practices and Michigan State University (MSU) soil test recommendations. Muriate of potash (0-0-60) was applied at 224 kg/ha in 1987, prior to spring plowing. Potatoes (variety 'Atlantic') were planted on April 30, 1987 and April 27, 1988. An 18 cm band application of 560 kg/ha of 20-10-10 (N-P-K) fertilizer and 2.4 kg/ha of aldicarb 15G (2-methyl-2-(methylthio) propionaldehyde O-(methylcarbamoyl) oxume) was applied at planting each year. Subsequent applications of nitrogen (28% liquid ammonium nitrate at 84 kg/ha) were applied through the irrigation system 48, 67, and 89 days after planting in 1987. In 1988, 26 kg/ha of 28% liquid ammonium nitrate was applied through the irrigation system 62 and 86 days after planting. Solid set irrigation was utilized after hilling both years using the MSU irrigation scheduling program for potatoes. Plots were scouted for insects and disease and were treated accordingly.

Plots consisted of three potato rows, 6.1 m in length, on an 86 cm spacing. Potato seed pieces were planted 21 cm apart in the row. Plots were hilled once, on June 9, 1987 and June 16, 1988, when the potatoes were 32 cm tall.

The experiment consisted of 13 treatments with six replications arranged in a randomized complete block. The design was a three factor factorial plus a weed free control. The three factors were: 1) weed species, either redroot pigweed or barnyardgrass; 2) weed location, with weeds seeded within the crop row at the time of potato planting or between the potato row after hilling; and 3) weed density of either 1, 2, or 4 weeds/meter of row (100, 50, and 25 cm between weeds, respectively).

Redroot pigweed and barnyardgrass (var. frumentacea (Robx)) were seeded in the crop row within one day of potato planting or hilling (dependent upon treatment), and later thinned to the desired density.

Undesirable weeds were controlled by hoeing and hand-weeding. The weed density was accurate prior to canopy closure both years.

Potato height, PAR, and potato leaf area were measured within one day of hilling (40 days after planting (DAP)), at canopy closure ((leaves from adjoining rows began to touch) (54 DAP)), and as the potato plants began to senesce (109 DAP) in 1987. In 1988, potato and weed height, PAR, and leaf area were measured at the time of hilling (49 DAP), and at canopy closure (67 DAP). Three samples/plot in four of the replications were measured, and an average from each plot used in data analysis. PAR was measured with a photometer[4] which provided total quantum flux density between 400 and 700 nm. Measurements were taken above the canopy and at the soil surface both within and between the crop row at 91, 213, and 457 cm from the edge of the plot. Values are reported as percent absorption = (Sa-Sb)/Sa, where Sa is the reading above the canopy and Sb is the reading below the canopy. Leaf area was measured using a portable leaf area meter[5]. The same three plants in selected plots were measured each time.

Samples of the three plant species were harvested on August 12 of both years (105 DAP in 1987 and 106 DAP in 1988), and fresh weight, dry weight, plant height and leaf area measured. Plant height, fresh weight, and dry weight were regressed on leaf area.

The aboveground portion from 4 plants of each species was harvested at the time of potato senescence (109 and 106 DAP, in 1987 and 1988,

[4]Li-cor LI-185B Quantum radiometer/photometer, Lincoln, NE 68504.
[5]Li-cor LI 3000 Portable leaf area meter, Lincoln, NE 68504.

respectively). Two potato plants were selected from each border row of each plot. Two weeds seeded within the crop row were selected from each border row, and two weeds were chosen from 2 locations in plots where weeds were seeded between the crop row after hilling. Sample plants were dried to a constant weight and averaged for data analysis. Immediately prior to vine kill, (September 14, 1987 and September 6, 1988) four random weed samples were collected in plots where weeds were seeded after hilling. Plants were dried to a constant weight and an average used for data analysis to determine if weed weight increased from time of senescence to harvest time.

Plots were desiccated on September 14, 1987 and September 8, 1988 with diquat (6,7-dihydrodipyrido 1,2-alpha:2',1'-c pyrazinediium ion) at 0.28 kg/ha and non-ionic surfactant[6] at 0.5% (v/v). Weeds were mowed 14 days later and plots beaten with a mechanical beater for ease in harvesting.

The center row of each plot was harvested. The tubers were graded as follows: less than 5 cm in diameter; 5 to 8 cm in diameter; over 8 cm in diameter; and off types. Graded tubers were weighed, and the weight of all tubers over 5 cm was added to determine the weight (metric tons/ha) of marketable tubers. Specific gravity was calculated (ratio of weight in air to weight in water), and 15 tubers (5 to 8 cm in diameter) from each plot were cut from stem to distal end and examined for internal defects.

Data analysis. All data from both field and greenhouse studies were

[6]X-77 Spreader (alkylarylpolyoxyethylene, glycols, free fatty acids, and isopropanol). Chevron Chem. Co., San Francisco, CA 94119.

subjected to analyses of variance, and main effects and interactions tested for significance. Treatment means were compared using a least significant difference (LSD) test at $P \leq 0.05$ if significant main effects and/or interactions occurred. Redroot pigweed, barnyardgrass, and the two potato varieties, 'Atlantic' and 'Russet Burbank' were ranked by competitive indices (CI) and relative competitive abilities (RCA), as developed by Krohl and Stephenson (12). CI's were calculated based on plant dry weight. CI = mean plant weight of the species (variety) in a treatment/mean plant weight of the same species (variety) grown alone. If the CI was greater than one, intraspecific competition was greater than interspecific competition, and if CI was less than one, interspecific competition predominated. RCA's were determined by summing the CI's of each species or variety, with a greater RCA indicating a more competitive plant. Field weed density data were subjected to regression analyses. The resulting equations were compared using a homogeneity of beta variance test (28). Data were not combined over years because of significant year by treatment interactions.

RESULTS AND DISCUSSION

GREENHOUSE STUDIES. Under moist soil conditions, barnyardgrass was a superior competitor to redroot pigweed, yet both potato varieties were more competitive than either weed species (Table 1). Barnyardgrass has been reported to be more competitive than redroot pigweed in previous research (27). The CI (competitive index) for pigweed was less than 1 for both potato varieties and barnyardgrass, showing pigweed competed more with itself than other barnyardgrass or the potato varieties. Barnyardgrass competed more with itself than potatoes, but more interspecific competition occurred with redroot pigweed. Intraspecific competition occurred for 'Atlantic' when grown with all other plants. Intraspecific competition occurred for 'Russet Burbank' in combination with both weed species, but interspecific competition developed when grown with 'Atlantic'.

The 'Atlantic' and 'Russet Burbank' potato varieties had the same ranking for competitive abilities. Previous studies ranking the competitiveness of potato varieties found 'Russet Burbank' to be less competitive than 'Katahdin' and 'Hudson', both late season varieties (25). Raby et al. found 'Russet Burbank' to be more competitive than 'Superior' (18). Ranking of the same varieties by different researchers can be inconsistent (25), but generally the longer season varieties are more competitive than early season potato varieties. 'Russet Burbank' and 'Atlantic' are both considered late season varieties. Potatoes were more competitive than either weed species evaluated, and barnyardgrass was more competitive than redroot pigweed.

FIELD STUDIES: Weed height. Barnyardgrass was significantly taller than redroot pigweed at hilling time (49 DAP) and canopy closure (67 DAP) when seeded within the crop row when measured in 1988 (Table 2). Barnyardgrass emerged prior to redroot pigweed in 1987 and 1988. The earlier emergence of barnyardgrass compared to pigweed under field conditions was reported previously by Ogg and Dawson (16). Early

Table 1. Competitive indexes (CI) and relative competitive ability (RCA) for redroot pigweed, barnyardgrass, and two potato varieties ('Atlantic' and 'Russet Burbank'). Determined by greenhouse replacement studies, 1988.

	CI[a]				
Plants evaluated	AMARE	ECHCG	'ATL'	'RB'	RCA[b]
AMARE	1.0	0.7	0.9	0.8	3.4
ECHCG	1.4	1.0	1.0	0.9	4.2
'ATLANTIC'	1.6	1.3	1.0	1.2	5.0
'RUSSET BURBANK'	1.3	1.9	0.8	1.0	5.0

[a]CI=Competitive index= $\frac{\text{mean plant weight of species (variety) in a treatment}}{\text{mean plant weight of species (variety) in a pure stand}}$

[b]RCA=Relative competitive ability = sum of CI's for each species (variety).

Table 2. Height of weeds seeded within the crop row, measured at hilling time and canopy closure in 1988. Data was combined over weed densities.

	Height	
Weed species	Hilling time	Canopy closure
	-------------(cm/plant)----------	
AMARE	33	69
ECHCG	51	92
Significance[a]	*	*

Comparisons of numbers between columns is not valid.

[a]*-designates significant difference between means of the main effect.

emergence may increase the competitiveness of a species (19), although other research has not supported this hypothesis (27).

Weed weight. The dry weight of either weed species seeded between the crop row was less than the weight of weeds planted within the crop row in both 1987 and 1988. The dry weight of redroot pigweed seeded in the crop row was greater than that of barnyardgrass in the crop row in 1987 only (Table 3). There was no difference in the dry weight of the weed species when seeded between the rows after hilling in 1987 or 1988. There was no change in the dry weight of weeds seeded between the crop row from August 17 to September 14 in 1987, at 28 g/plant. However in 1988, plant dry weight for weeds seeded between the crop row when measured on September 6, had increased 295% compared to weed dry weight on August 12, 22 g/plant to 65 g/plant.

The average height of both weeds seeded at the time of potato planting was equal to or greater than the average height of the potato when measured at hilling time and canopy closure. After canopy closure, weeds continued to grow taller while the potato became more prostrate in growth habit and less able to compete for light. Weeds which emerged between the crop row after hilling did not reach potato canopy height prior to canopy closure and were unable to absorb adequate PAR for growth. Weeds remained stunted in 1988 until canopy senescence at which time increased radiation increased weed growth.

The dry weight of the individual weeds did not decrease as density increased. Redroot pigweed and barnyardgrass seeded at 4 plants/m within the crop row was not great enough to reduce intraspecific weed dry weight. Similarly, only 20% of the change in dry weed biomass of individual plants was correlated to the change in weed density in both

Table 3. Dry weight of individual weeds measured at potato senescence in 1987 and 1988. Data was combined over weed densities.

	Dry weights	
Weed species x location	1987	1988
	(g/plant)	
AMARE within row	236	189
AMARE between row	25	26
ECHCG within row	125	152
ECHCG between row	32	18
LSD (0.05)[a]	45	35

[a]Comparison of numbers between columns is not valid.

1987 and 1988. Thus the dry weight of either weed species on an individual plant basis did not demonstrate plasticity either year.

Total weed biomass. Total weed biomass varied with weed species, location, and density in 1987 (Table 4). Redroot pigweed seeded at 4 plants/m in the crop row had the greatest biomass/plot. Barnyardgrass seeded within the crop row at 2 and 4 plants/m and redroot pigweed at 2 plants/m within the crop row produced similar dry weed biomass. In 1988, both weed species when seeded within the crop row at 4 plants/m produced the greatest total biomass, followed by either weed species seeded within the row at 2 plants/m. Both weed species at all densities when seeded between the crop row in 1987 and 1988 produced less weed dry weight than if seeded within the crop row. The greater dry weed biomass of redroot pigweed at 4 plants/m of row compared to barnyardgrass at 4 plants/m of row in 1987 was due to an increase in dry matter of individual pigweed plants (Table 3). For the first 45 days after planting in 1987, the plots received 6.5 cm of moisture compared to 3.1 cm in the same time period in 1988. Lack of early moisture may have hindered the early growth of redroot pigweed in 1988, whereas barnyardgrass germinated earlier and growth decreased compared to growth in 1987.

As weed density increased, total weed biomass increased both years for weeds seeded in the row (Table 5). In 1987, weed density predicted 69% and 74% of the variability of redroot pigweed and barnyardgrass total biomass when seeded in the row, respectively. Weed density was a predictor of at least 72% of the variability in total weed biomass for both redroot pigweed and barnyardgrass when seeded in or between the rows in 1988.

Potato height. Potato heights in 1988 averaged 32 cm and 54 cm at the time of hilling, and canopy closure, respectively, and did not vary

Table 4. Total weed dry weight/plot when measured at potato senescence in 1987 and 1988.

Density x weed species x location	Dry weight/plot 1987	1988
	---------------(kg)---------------	
1 AMARE/m within row	1.5	1.1
2 AMARE/m within row	2.7	2.4
4 AMARE/m within row	6.1	4.7
1 ECHCG/m within row	0.6	0.8
2 ECHCG/m within row	1.8	2.3
4 ECHCG/m within row	3.0	3.3
1 AMARE/m between row	0.2	0.2
2 AMARE/m between row	0.4	0.3
4 AMARE/m between row	0.2	0.6
1 ECHCG/m between row	0.1	0.1
2 ECHCG/m between row	0.3	0.2
4 ECHCG/m between row	1.4	0.5
LSD (0.05)[a]	1.4	1.0

[a]Comparison of numbers between columns is not valid.

Table 5. Weed density regressed on total weed biomass/plot in 1987 and 1988.

	1987		1988	
Weed species x location	r^2	Equation line	r^2	Equation line
AMARE within crop row	0.69	y = -87.4 + 247.7x	0.72	y = -18.7 + 193.6x
AMARE between crop row	NS	y = 105.7 + 9.6x	0.78	y = 10.2 + 23.6x
ECHCG within crop row	0.74	y = 22.4 + 125.6x	0.73	y = 109.4 + 141.1x
ECHCG between crop row	0.25	y = -178.6 + 58.0x	0.84	y = -7.4 + 19.0x
Least significant difference of a slope line (0.05)[a]		79.3		53.4

Least significant differences of the slope line was determined by individual T-tests to test independent regression lines for homogeneity (28).

[a]Comparisons between years are not valid.

between treatments (Table 6). However, in 1987 potato height at hilling time varied with weed species and weed density, possibly due to uneven potato emergence (Table 6). By canopy closure, potato height did not vary significantly between treatments in either year, averaging 57 cm in 1987 and 54 cm in 1988.

Aboveground potato biomass. Weed species and location influenced aboveground potato biomass in 1987, while only weed location influenced aboveground biomass in 1988. There was a greater reduction of potato biomass by barnyardgrass compared to redroot pigweed seeded in the row in 1987 46 g/plant and 53 g/plant, respectively. Potato aboveground biomass in both years was greatest in plots seeded with weeds between the crop row, averaging 55 g/plant when weeds were seeded between the row and 39 g/plant when weeds were seeded in the crop row. Potato biomass in weed free plots did not differ significantly from plots with weeds seeded between the crop row except in 1987 with barnyardgrass at 1 and 2 plants/m between the row. Weed free plots had greater aboveground potato biomass than plots with barnyardgrass or redroot pigweed seeded in the row in 1987, and all pigweed plots in 1988. Barnyardgrass in the crop row in 1988 at 2 and 4 plants/m did not reduce aboveground potato biomass.

In previous greenhouse research, barnyardgrass was more competitive than redroot pigweed on a fresh weight basis, yet reduction in soil moisture increased the competitiveness of redroot pigweed (27). In 1988, only 3.1 cm of moisture was recorded for 45 DAP, compared to 6.5 cm for the same period in 1987. Therefore, redroot pigweed appeared to be more competitive under the lower soil moisture conditions found in 1988.

Field observations of redroot pigweed indicate that the architecture

Table 6. Potato height measured at hilling time[a] and canopy closure[b] in 1987 and 1988.

Density x weed species	Potato height			
	1987		1988	
	Hilling time	Canopy closure	Hilling time	Canopy closure
	(cm/plant)			
1 AMARE/m	31	55	30	52
2 AMARE/m	36	57	30	54
4 AMARE/m	31	56	33	57
1 ECHCG/m	33	57	31	55
2 ECHCG/m	32	58	34	53
4 ECHCG/m	36	57	34	53
LSD (0.05)[c]	3	NS	NS	NS

[a]Measurements at hilling time only include treatments with weeds seeded in the crop row.

[b]Measurements at canopy closure are combined over hilling time.

[c]Comparisons between columns are not valid.

of the individual plant species could be a competitive factor. Weeds with similar dry weights, one growing erect and the other growing more prostrate due to injury or insect damage, may differ in competitiveness in potatoes, where the crop is not erect. Potatoes adjacent to both types of weed architecture, showed poorer growth when weeds were prostrate.

The canopy temperature was measured August 12, 1988 at 3:30 pm in the weed free plot and in plots containing barnyardgrass and redroot pigweed seeded within the row at 1 and 4 weeds/m. Canopy temperature was significantly higher in the weed free plot compared to the pigweed and barnyardgrass plots, and no difference was noted between weed species (data not presented). Weeds in the crop row appeared to absorb radiation due to their height advantage, thus reducing the potato canopy temperature.

PAR. As the potato plants emerged and developed foliage, the plants were erect and maximum shading occurred in the crop row. The potato plants assumed a more prostrate growth habit shortly after canopy closure with fewer leaves in the crop row. In addition, the older leaves of the potato plant began to senesce, resulting in further reduction of PAR absorption in the crop row. In 1987, the potato canopy in the row with or without weeds absorbed at least 56% of the PAR at the time of hilling (40 DAP) and PAR absorption did not vary among treatments. By canopy closure (54 DAP), the canopy absorbed 96% of the PAR in the row with no difference between treatments, and as the plants began to senesce (109 DAP), the potato canopy alone absorbed 46% of the available PAR and potato plus weed canopy absorbed 47% to 62% of PAR (Table 7). At senescence when the weed free check was included in the analysis, there was no difference between treatments. However there were differences

Table 7. PAR absorption by the potato canopy and potato plus weed canopy measured at crop senescence in 1987. PAR absorption data was combined over weed species and densities.

Weed location	PAR absorption
	------(%)------
Weeds between rows	47
Weeds within rows	62
Significant[a]	*
Weed free[b]	41

[a]-* designates significant differences between means.

[b]-weed free mean not used in analysis of variance.

among the weed treatments, with weeds seeded in the row absorbing 62% of PAR, while weeds between the crop row absorbed only 47%. PAR absorption measured between the crop row was 50% at canopy closure and 45% at senescence for potatoes alone, and 60% and 76% at canopy closure and senescence, respectively, for potatoes plus weed plot.

There was no correlation between PAR absorption and weed biomass, potato height, or aboveground potato biomass. Light is a resource required for growth (1, 10, 11), and PAR was available for weeds to grow from planting until sometime past the time of hilling when PAR absorption reached 95%. Weeds between the row had little time for growth with PAR below 90%, and thus could only increase growth after senescence. It was noted that weeds were mature at the time of senescence when seeded in the row, but not for those between the row. Thus growth for these weeds could occur after senescence, as in 1988.

Leaf area. Selected plants of potato and weed species were harvested in August to correlate plant size with total leaf area. Height, fresh weight, and dry weight of each species were regressed on leaf area to determine which parameter had the greater correlation with leaf area (Table 8). Plant fresh weight had the highest correlation with plant leaf area for barnyardgrass, redroot pigweed, and potatoes in 1987 and 1988. The height of redroot pigweed in 1987 and the dry weight of redroot pigweed in 1988 also explained 96% of 98% of the variability in pigweed leaf area.

Tuber yield. Weeds germinating between the crop row after hilling (40-49 DAP) had no impact upon total or marketable yield when compared to the weed free plot in 1987 or 1988 (Table 9). Yield of oversized tubers (greater than 8 cm in diameter) doubled when weeds were seeded between

Table 8. Measured growth parameter for each species that had the greatest correlation with leaf area in 1987 and 1988.

	1987			1988		
Plant	Parameter	r^2	Equation line	Parameter	r^2	Equation line
Potato	fresh weight	0.71[a]	y=129.1 + 0.1x	fresh weight	0.98	y=32.3 + 0.1x
AMARE	height	0.96	y=17.5 + 0.0x	dry weight	0.98	y=-12.4 + 0.0x
ECHCG	fresh weight	0.99	y=-46.3 + 0.2x	fresh weight	0.99	y=41.0 + 0.1x

Comparisons between years are not valid.

[a]Significant at alpha = 0.10 level.

Table 9. Yield of graded tubers and the percent reduction of marketable yield combined over weed species in 1987 and 1988.

Density x location	Yield 1987 Total yield	Marketable yield	Reduction marketable tuber yield	Tuber diameter 5-8 cm[c]	+8 cm[d]	Off type	Yield 1988 Total yield	Marketable yield	Reduction marketable tuber yield	Tuber diameter 5-8 cm[d]	+8 cm	Off type
	---(metric t/ha)--		---(%)---				--(metric t/ha)--		---(%)---			
1 weed/m between row	50	47	2	87	6	0	39	37	9	85	9	1
2 weeds/m between row	49	46	5	88	5	0	37	34	12	86	7	1
4 weeds/m between row	50	46	5	85	6	2	39	36	8	85	9	1
1 weed/m within row	42	38	20	86	4	0	30	28	26	86	8	0
2 weeds/m within row	38	33	32	84	3	0	29	28	28	87	7	1
4 weeds/m within row	35	29	40	80	3	1	25	23	40	91	2	0
Weed free	51	48	--	87	6	1	40	39	--	83	12	0
LSD (0.05)[ab]	4	4	7	--	--	NS	3	3	6	--	3	NS

[a]Comparisons between years is not valid.
[b]LSD values are from factorial analysis, omitting the weed free treatment.
[c]Weed placement and weed density main effects are significant.
[d]Weed placement main effect is significant.

Weeds within the crop row reduced total and marketable yield in 1987 and 1988. One weed/m of either species within the crop row was sufficient to cause a reduction of 18% and 17% in marketable yield, as well as a 22% and 26% reduction in total yield, in 1987 and 1988, respectively. Redroot pigweed was more competitive (7%) than barnyardgrass in 1988, but not in 1987 (Table 10).

In previous research, redroot pigweed seeded 1.25 m apart caused a 39% yield reduction in sugarbeets (24), and a 45% reduction in cotton when seeded at a 0.5 m spacing (3). When spaced at 0.25 m, redroot pigweed reduced soybean yield 60% (12), and corn yield 15% (12), compared to the 20% reduction found in our research. This is not in agreement with VanHeemst (30), who ranked potatoes as a more competitive crop than corn.

In both years, there was no relationship between total yield and either weed density, total weed weight per plot, percentage of weeds in total dry biomass, or potato aboveground biomass for plots with weeds seeded between the row (data not presented). When weeds were seeded within the row, the percentage of redroot pigweed biomass in the total dry biomass explained 66% of the yield variation in 1987, and 56% in 1988 (Table 11). The percentage of barnyardgrass biomass in the total plot biomass when seeded in the row, explained 62% of the total yield variation in 1987 and 44% in 1988. Weed biomass increased as weed density increased, with density explaining 69% to 74% of the variation in weed biomass/total biomass per plot when seeded in the row (Table 5). The weight of the individual weeds did not change as weed density increased. Therefore, either weed biomass/total biomass or weed density could serve as predictor of yield with a similar degree of reliability.

Table 10. Yield of tubers in 1988, averaged across weed densities and location.

	Yield				
			Diameter		
Weed species	Total	Marketable	5-8 cm	8 cm	Off type
	---(metric t/ha)--		--------(%)----------		
AMARE	32	30	86	8	1
ECHCG	34	32	87	7	1
Significant[a]	*	*	*	*	NS

[a]*-designates significant difference between means.

Table 11. Yield regressed on percent weeds in total plant biomass, for weeds seeded within the crop row, 1987 and 1988.[a]

	1987		1988	
Species	r^2	Equation line	r^2	Equation line
AMARE	62	y = 52 - 18x	56	y = 39 - 17x
ECHCG	66	y = 51 - 21x	44	y = 39 - 14x

[a]Comparisons between years are not valid.

the row, compared to plots with weeds in the row. Weeds in the row were more competitive, and thus reduced the size of individual tubers. This data concurs with Indian research where potatoes required a weed free period of 6-7 weeks prior to weed germination or a yield reduction occurred (26, 29). This data is also consistent with research by Nelson et al. (15) and Saghir et al. (23) who found as total yield decreased, the yield of marketable tubers also increased, resulting in an increase in tubers with a diameter less than 5 cm. None of our treatments affected specific gravity (data not presented).

Absorption of PAR between the crop row, beginning at or prior to canopy closure, reduced the growth of weeds seeded between the crop row until the potato plants began to senesce. As potatoes began to senesce, the weeds between the crop row were able to receive increased PAR, and in 1988 weed dry weight increased from the time of senescence to desiccation. However this late season weed growth in 1988 did not reduce yield. In field observations outside the research plots, redroot pigweed germinating 2 weeks after our seeded pigweed reached or surpassed the height of these seeded weeds after 5 weeks. Irradiance in plots with weeds between the crop row measured 787 $\mu E\ cm^{-2}\ sec^{-1}$ at the soil surface in 1988 at canopy closure. Irradiance in 1987 measured 1018 $\mu E\ cm^{-2}\ sec^{-1}$ at the soil surface at canopy closure, and 921 $\mu E\ cm^{-2}\ sec^{-1}$ as the plants began to senesce in 1987. Weaver and McWilliams reported that the relative growth of redroot pigweed decreased as irradiance decreased from 750 to 90 $\mu E\ cm^{-2}\ sec^{-1}$ (32), but they did not speculate as to whether relative growth rate would continue to increase as irradiance increased above 750 $\mu E\ cm^{-2}\ sec^{-1}$. Growth of weeds below the potato canopy after canopy closure in 1987 and 1988 does not appear to be an important factor since yield was not affected.

Nelson and Thoreson (15) found weed biomass/total biomass explained 83% of the variation in total yield. However, their research involved weeds broadcast seeded at potato planting with no cultivation or hilling. Therefore, weeds between the potato row were allowed to compete for the full season. This study also noted that as the weed free period prior to weed emergence lengthened, yield increased. Similarly, Vitolo[7] reported that barnyardgrass emerging 2 weeks after potato planting reduced yield 10%, while grasses competing the full season caused a 44 to 56% yield reduction.

Tuber quality. Weed density did not influence the degree of internal defects in U. S. # 1 tubers (5 cm to 8 cm in diameter) either year. Weed species influenced the degree of hollow heart, internal brown spot, and vascular discoloration yet the treatments did not differ from the weed free treatment (data not presented).

The impact of weeds on harvest was eliminated by mowing the plots. However, mowing weeds prior to harvest is not practical in commercial situations. Weeds within crop rows have developed extensive root systems which hinder harvest and other field operations, while weeds between the crop row that emerge after hilling are smaller and their impact on harvest could be eliminated by use of a desiccant. Upon desiccation, the thick stems and massive root systems of large weeds in the row would still be present.

Weeds emerging later in the season between the potato row due to soil disturbance by cultivation or loss of herbicide efficacy can increase in size after the potato canopy senesces, as in 1988, but the

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[7]Vitolo, D. B. 1985. Grass competition in white potatoes. PhD. dissertation. Rutgers University, New Brunswick, NJ. p. 58.

control of these weeds was not necessary since they did not reduce tuber yield or tuber quality. In 1987, redroot pigweed had greater biomass yet barnyardgrass reduced aboveground potato biomass more than redroot pigweed. However, neither weed species had an impact on tuber yield in 1987. In 1988, weed species did not influence weed biomass/plot or aboveground p tato biomass, yet redroot pigweed reduced total yield 7% more than barnyardgrass. Soil moisture may influence the competitiveness of weeds, with pigweed being more sensitive to soil moisture levels than barnyardgrass.

Previous research on weed interference in potato examined weeds at densities well above those established in this research, yet the influence of 1 weed/m within the crop row significantly reduced yield. Weed density was as reliable predictor of yield as total weed biomass and weed biomass/plot. Therefore, the presence of one barnyardgrass or pigweed/m of row weed require control to avoid a yield reduction. With a better understanding of the impact of weed species, weed density, and weed emergence time on potato yield and quality, coupled with the availability of postemergence herbicides labeled for application in potatoes, a grower can develop a more comprehensive weed management program.

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EFFECT OF SOIL TYPE, HILLING TIME, AND POTATO VARIETY ON WEED INTERFERENCE IN POTATOES[1]

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ABSTRACT. Two potato varieties ('Atlantic' and 'Russet Burbank') were grown with and without weeds and hilled at two different stages of potato growth (potato cracking and when potatoes are 30 cm tall) on both mineral and muck soils. Weed pressure was greater on the mineral soils in both 1987 and 1988. In general, aboveground biomass and total yield of 'Atlantic' were impacted less by weed interference on both soils. However, total tyield of 'Russet Burbank' was not reduced by weeds as much as the tuber yield of 'Atlantic' in both years on muck soil. Hilling at potato cracking caused the greatest reduction in weed dry weight at both locations in 1987 and 1988, and therefore reduced the influence of weeds on yield. Early hilling also resulted in the greatest amount of potato biomass in 1988 at both locations, yet a single hilling procedure was not adequate to provide season long weed control. Early hilling provided better weed suppression than conventional hilling, and increased the relative biomass of C_4 weeds compared to C_3 weeds. Weed pressure did not have a consistent effect on specific gravity. Internal brown spots were greatest in weed free 'Atlantic' plots on mineral

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soils in both years and on muck soil in 1987 only. Vascular discoloration was greater on mineral soil when weeds were absent both years, and greatest in 'Russet Burbank' plots. Hollow heart increased in weed free 'Russet Burbank' plots both years on the muck soil.

Nomenclature: Potato, Solanum tuberosum L.

Additional index words. Aboveground biomass, canopy closure, competitiveness, hilling time, interference, tuber quality, varieties, AMARE, CHEAL, ECHCG, POLPE.

INTRODUCTION

Potatoes (Solanum tuberosum L.) are an intensely managed crop, and research has lead to improved crop management techniques that increase yield and quality. These techniques, such as irrigation scheduling, optimum nutrient application and timing, and improved insect control and disease monitoring have also led to increased weed growth (10). Poor weed control can reduce tuber yield. Nelson and Thoreson (15) reported that a 10% increase in weed dry weight reduced tuber yield 12%. These researchers found a strong correlation (-0.87 and -0.97) between weed dry weight and potato yield (15). In other research (27), no yield reduction occurred when barnyardgrass was allowed to infest and compete with potatoes (var. 'Superior') after a 2 to 4 week weed free period, but grasses that infested potato plots all season, reduced tuber yield

40%[3]. Nelson and Thoreson (15) and Saghir and Markoullis (21) concluded that weeds reduced yield due to a decrease in both the number of tubers and the average size. Weeds did not alter the specific gravity of the potatoes (10, 15), although Nelson et al. reported a trend towards higher specific gravity when weeds were present (15). The harvested potato tuber is not visible all season, therefore a grower must determine the impact of pests on yield by previous experience or using reported pest threshold data.

Research has been conducted examining the ability of many crop varieties, including corn (Zea mays L.), cotton (Gossypium hirsutum L.), soybeans (Glycine max (L.) Merr.), and potatoes, to suppress weed interference (5, 6, 23, 25, 29). More erect growth and increased shading provide better weed suppression as well as increased light interception and photosynthesis. Potato varieties that emerge quickly, exhibit rapid early growth and have an upright, dense canopy, provide the greatest weed suppression (29). Studies of weed suppression by potato varieties generally have compared long season varieties with short season varieties (18, 22). No research has been published comparing differences in the competetiveness of the potato varieties 'Atlantic' and 'Russet Burbank'. 'Atlantic' is a medium to late maturing variety while 'Russet Burbank' is a late maturing variety (9, 27). Both varieties have large leaves, are classified as having large amounts of aboveground biomass, and are grown under similar cultural practices.

[3] Vitolo, D. B. 1985. Grass competition in white potatoes. Ph.D. dissertation. Rutgers University, New Brunswick, NJ. Pages 58.

Hilling potatoes serves as a cultivation to control weeds emerging between the crop rows (4, 14). Cultivation had no advantageous effect on yield when weeds were not present, and researchers concluded that potatoes should be cultivated for weed control purposes only (7, 10, 13, 19). Hilling potatoes just prior to potato emergence provided the greatest weed control because weeds were smallest at that time, but later germinating weeds were not controlled (19). The time of hilling did not alter herbicide efficacy, and therefore Rioux et al. (19) recommended that a single hilling operation should be timed to maximize vegetative growth of the potato, and not used as an additional weed control method.

Mechanical tillage and hilling disrupt the layer of soil containing the herbicide, thus bringing new weed seeds to the surface, and increasing the opportunity for delayed weed germination (12, 19, 20). Numerous studies have examined weed emergence throughout the summer, and many species of annual weeds continue to emerge well into late summer (1, 11, 12, 20). C_4 and C_3 plants have different environmental conditions optimal for growth, and although the photosynthetic pathway may or may not be a substantial competitive characteristic (2, 3), it may dictate which species have a competitive advantage due to climatic conditions present at the time of germination (2). C_4 plants optimumize growth at higher temperatures and have a greater moisture efficiency than C_3 plants (3). Weed emergence and competitive ability at various times during the growing season may vary as environmental conditions change during the course of the season.

Potato production in Michigan is predominantly on coarse textured mineral soils, however, approximately 10% of the potato acreage is planted on muck (high organic matter) soils. Weed research and published literature for potato production on high organic matter soils is limited.

Research was initiated to determine the competitiveness of two potato varieties, 'Atlantic' and 'Russet Burbank' on mineral and organic soils. The influence of hilling time on weed species composition, abundance, and weed interference was evaluated. The effect of early and mid-season photosynthetically active radiation (PAR) absorption by the potato plant canopy on the growth and competitiveness of both potatoes and weeds was also studied.

MATERIALS AND METHODS

Research was conducted in 1987 and 1988 at the Montcalm and Rose Lake Research Farms representing two diverse soils on which Michigan potatoes are produced. The study at the Montcalm Farm was conducted on a sandy loam soil complex of Montcalm (sandy, mixed, frigid Alfic Haplorthod) and McBride (coarse-loamy, mixed, frigid Alfic Fragiorthod) soil series with an organic matter content of 1.8% and 1.6%, and a pH of 6.2 and 5.2, in 1987 and 1988, respectively. The Rose Lake Farm soil was a Houghton Muck (euic, mesic, Typic Medisaprist) with an organic matter content of 92.4% and 81.3%, and a soil pH of 6.9 and 6.5, in 1987 and 1988, respectively.

Both locations were planted with two varieties of potatoes, 'Atlantic' and 'Russet Burbank', using standard grower practices and Michigan State University (MSU) soil test recommendations for field preparation and fertilization. The plots were monitored for insects and diseases and treated accordingly. Both sites were irrigated with solid set irrigation according to MSU potato irrigation scheduling.

The previous year's crop for both years of research at the Montcalm Farm was alfalfa (Medicago sativa L.). Prior to spring plowing in 1987, muriate of potash (0-0-60) at 224 kg/ha was applied. The research site was tilled, and planted with a 18 cm band application of 560 kg/ha of 20-10-10 (N-P-K) fertilizer. The planting dates were April 30, 1987 and April 27, 1988. 'Atlantic' was planted with a 21 cm plant spacing in the row and 'Russet Burbank' at 31 cm. Subsequent applications of nitrogen (28% liquid ammonium nitrate at 84 kg/ha) were applied through the irrigation system 48, 67 and 89 days after planting (DAP) in 1987. In 1988, 26 kg/ha of 28% liquid ammonium nitrate was applied through the irrigation system at 62 and 86 DAP.

The plots at the Rose Lake Farm in 1987 had been fallow in 1986, and 1988 research plots were in celery (Apium graveolens L.) production in 1987. The plots received a broadcast application of 784 kg/ha of 8-16-32 (N-P-K) fertilizer in 1987 and 896 kg/ha in 1988, which was incorporated. Planting dates were May 14, 1987 and May 19, 1988. Both varieties were planted with a 25 cm spacing in the row. Eighty-four kg/ha of urea (45-0-0) were sidedressed 42 DAP in 1987 and 32 DAP in 1988.

The experiment consisted of 8 treatments with 4 replications arranged in a randomized complete block design. The design was a three factor factorial with two levels for each factor. The three factors were: 1) variety, 'Atlantic' or 'Russet Burbank'; 2) hilling time, hilling at potato cracking (early hilling), or when the potatoes were 30 cm tall (conventional hilling); and 3) weeds, either weed free, or a natural infestation of weeds. The hilling times at Montcalm were May 15, 1987 and May 19, 1988 for early hilling, and June 9, 1987 and June 16, 1988 for conventional hilling. At Rose Lake the early hilling was conducted on June 1, 1987 and June 7, 1988, and conventional hilling on June 15, 1987 and June 21, 1988. Each plot at both locations consisted of 3 potato rows 6.1 m in length, on an 86 cm row spacing.

At Montcalm, potato height and photosynthetically active radiation (PAR) were measured at the time of conventional hilling (40 DAP in 1987 and 49 DAP in 1988) and canopy closure (54 DAP in 1987 and 67 DAP in 1988). At the Rose Lake farm, potato height and PAR were measured at the time of conventional hilling (32 DAP in 1987 and 33 DAP in 1988) and at canopy closure in 1987 (50 DAP). Only potato height was measured in 1988 at canopy closure (51 DAP). PAR was measured with a photometer[4] which measures quantum flux density between 400 and 700 nm. Measurements were taken above the canopy and at soil level both within and between the crop row. The values are reported as percent absorption = Sa-Sb/Sa, where Sa is the reading above the canopy and Sb is the reading at the soil surface.

Potato dry weight, weed dry weight by species, and the number of weeds/species were determined at potato senescence (109 and 92 DAP in 1987, and 107 and 111 DAP in 1988 at Montcalm and Rose Lake, respectively). Weed samples were harvested from one meter of row (0.86 m^2) at one location in each border row of each plot.

Aboveground biomass of two potato plants was also measured at each of these sites. Plant tissue was dried to a constant weight and recorded

[4]Li-cor LI-185B Quantum radiometer/photometer, Lincoln, NE 68504.

for each plant. For data analysis, measurements of the 4 potato plants/plot and 2 weed measurements/plot were averaged.

Vines were desiccated on September 14, 1987 and September 8, 1988 at the Montcalm Farm, and September 12, 1987 and September 16, 1988 at the Rose Lake Farm. Diquat (6,7-dihydrodipyrido 1,2-2:2',1'-c pyrazinediium ion) plus a non-ionic surfactant[5] were applied at 0.38 kg/ha plus 0.5% (v/v). Plots at the Montcalm Farm were mowed 14 days later and beaten with a mechanical beater to ease harvesting. Weeds at the Rose Lake farm were removed by hand to eliminate their effect on harvest.

The center row of each plot was harvested, graded and weighed. 'Atlantic' tubers were graded as follows: less than 5 cm in diameter; 5 to 8 cm; over 8 cm in diameter; and off types. The 'Russet Burbank' were graded as follows: less than 115 g; 115 to 285 g; over 285 g; and off types. Tuber weights were taken for each grade and reported as metric tons per hectare. Marketable tubers for 'Atlantic' were all tubers over 5 cm, and for 'Russet Burbank', all tubers over 115 g. Specific gravity was determined for each plot. Fifteen tubers ('Atlantic', 5 to 8 cm in diameter and 'Russet Burbank' at 115 to 285 g) from each plot were cut stem end to distal end and examined for internal defects.

All data was subjected to analyses of variance, and main effects and interactions tested for significance. Treatment means were compared using least significant differences (LSD) test at $P \leq 0.05$ based on significant main effects and interactions. Data was not combined over years or locations because of significant year by treatment and location by treatment interactions.

[5]X-77 Spreader (alkylarylpolyoxethylene, glycols, free fatty acids, and isopropanol). Chevron Chem. Co., San Francisco, CA 94119.

RESULTS AND DISCUSSION

Montcalm-mineral soil. Weed growth. In 1987, potato variety and hilling time did not affect weed number by species, individual weed dry weight, or total weed dry weight (Table 1). Barnyardgrass (Echinochloa crus-galli L. Beauv.) (ECHCG), redroot pigweed (Amaranthus retroflexus L.) (AMARE), and common lambsquarters (Chenopodium album L.) (CHEAL) were the predominant species with dry weight/plant of 186 g, 152 g, and 164 g, respectively, averaged across hilling time and varieties.

In 1988, the time of hilling significantly influenced weed biomass (Table 1). The population of common lambsquarters in 1988 was greater in conventionally hilled plots, and thus total weed dry weight/plot was greater in 1988 in conventionally hilled plots compared to 1987. Total dry weight of weeds/m^2 when harvested in August 1988, was also greater for all treatments that were conventionally hilled compared to early hilled treatments, and the time of hilling influenced the weed species composition. In conventionally hilled plots, the number of common lambsquarters plants increased to 27 plants/m^2 with a dry weight/m^2 of 748 g, compared to only 7 plants/m^2 and 237 g/m^2 in early hilled plots. Common lambsquarters emerged earlier than the other weeds, and by the time of conventional hilling lambsquarters were well established and hilling did not remove them. Conventional hilling only destroyed the small, less established weeds, and also allowed for another flush of seed germination. When measured in August, some conventionally hilled plots contained large weeds that were not destroyed by hilling, while other

Table 1. Weed dry weight/m^2 for early and conventionally hilled treatments, Montcalm, combined over potato varieties.

	Annual[a] Grasses		AMARE		CHEAL		POLPE		Total
Hilling time	No.	Dry wt.	No.	Dry wt.	No.	Dry wt.	No.	Dry wt.	Dry wt.
	(g/m^2)								
1987									
Early hill	-	254	6	179	5	147	1	22	602
Conventional hill	-	170	3	169	2	221	1	26	568
Significant	-	NS	NS	NS	NS	NS	NS	NS	NS
1988									
Early hill	3	123	2	121	7	237	1	26	507
Conventional hill	1	19	5	76	27	748	1	13	856
Significant[b]	NS	*	*	*	*	*	NS	NS	*

[a]Annual grass is predominantly barnyardgrass.

[b]*-designates significant difference between means of the main effect.

Number of annual grasses not recorded in 1987.

plots contained numerous weeds with smaller biomass that emerged after hilling. The number of redroot pigweed increased by 1 plant/m^2 when conventionally hilled, but the dry weight/m^2 did not change. The number of annual grasses did not change with hilling time, but when early hilled, the dry weight/m^2 of grasses in early hilled plots increased over 650% compared to conventionally hilled plots. Ogg and Dawson (16) also reported that barnyardgrass emergence was not affected by cultivation.

Early hilling provided timely mechanical control of emerged weeds, but a single cultivation was inadequate for complete season long weed control, particularly for annual grasses. Rioux et al. (19) found hilling at potato emergence provided greater weed control. Rioux et al. explained the difficulty in timing the hilling operation with weed emergence, and therefore a single hilling operation provided inadequate weed control for the entire growing season. In both years, the least amount of weed dry weight was in early hilled plots, however, in 1987 this was not significant ($P \leq 0.05$). Hilling at potato cracking provided timely control of emerged weeds, but also brought new weed seed to the surface which increased later season germination. Plots were early hilled 16 and 22 DAP, in 1987 and 1988, respectively, when the soil was warm. Warmer temperatures may provide a competitive advantage for C_4 plants (2, 3). Annual grasses and redroot pigweed, both C_4 plants, may have produced more biomass in plots that were early hilled because the environmental conditions for C_4 plant growth were more optimal in June than in May. Pearcy et al. (17) reported redroot pigweed at high temperatures (28-34^{o}C) was more competitive than common lambsquarters, whereas at low temperatures (14-18^{o}C) the opposite occurred. Wiese and Davis (28) found redroot pigweed had the best emergence in the 18 to 27^{o}C range. Furthermore, Baskins and Baskins (1) found peak common lambsquarters emergence in early to mid spring, while redroot pigweed emergence peaked in late spring to early summer. Cultivation/hilling moves the seeds closer to the soil surface and may expose them to warmer temperatures.

Aboveground potato biomass. Aboveground potato biomass in 1987 was greater in weed free plots with 'Russet Burbank' producing more 'Atlantic' (Table 2). In 1988, both hilling time and weed presence influenced aboveground potato biomass. Weeds reduced aboveground potato biomass both years. Potato biomass of early and conventionally hilled plots without weeds averaged 102 g/plant. Conventionally hilled treatments with weeds had the lowest potato dry weight biomass. Conventionally hilled plots with weeds had a greater reduction in potato biomass in 1988 because weeds were well established at the time of hilling and resulted in inadequate weed removal, resulting in greater interference with potato growth than early hilled plots with weeds.

There was no relationship between potato height and PAR measured either within or between the crop row or potato height and total weed dry weight/m^2 for either year. This data suggests that leaf and stem distribution of the potato is more critical to PAR absorption and weed suppression than the height of the potato.

Tuber yield. The potato variety and presence of weeds influenced both total and marketable yield in 1987 (Table 3). Total yield for 'Atlantic' (35 t/ha) was 1.6 times greater than the yield of 'Russet Burbank' (22 t/ha). Weeds reduced total yield 62% in comparison with weed free potatoes, when averaged across hilling times and potato varieties.

Total yield in 1988 was 1.5 times greater for 'Atlantic' than

Table 2. Aboveground biomass of individual potato plants, Montcalm, August 17, 1987 and August 12, 1988.

Variety x hilling x weeds	Potato biomass (g/plant) 1987[a]	1988[b]
	--(dry	weight)--
'Atlantic' early hilled, weed free	44	104
'Atlantic' early hilled, weedy	14	72
'Atlantic' conventionally hilled, weed free	53	88
'Atlantic' conventionally hilled, weedy	20	32
'Russet Burbank' early hilled, weed free	118	109
'Russet Burbank' early hilled, weedy	22	97
'Russet Burbank' conventionally hilled, weed free	94	106
'Russet Burbank' conventionally hilled, weedy	36	30
LSD (0.05)[c]	27	29

[a]Data can be combined over hilling time.

[b]Data can be combined over potato variety.

[c]Comparisons between years not valid.

Table 3. Yield and specific gravity, averaged over hilling time, Montcalm, 1987.[a]

Weeds x variety	Total[b] yield	Marketable[c] yield	Grade B[d] yield	Specific[b] gravity
	----------(metric t/ha)---------			
Weed free 'Atlantic'	48	43	5	1.080
Weedy 'Atlantic'	21	14	7	1.076
Weed free 'Russet Burbank'	34	19	10	1.065
Weedy 'Russet Burbank'	10	3	7	1.062
LSD (0.05)[e]	*	7	3	*

[a]Yield of off type tubers not reported.

[b]Potato variety and presence of weeds main effects are significant.

[c]Marketable tubers: 'Atlantic' = tubers greater than 5 cm in diameter; and 'Russet Burbank' = tubers greater than 115 g.

[d]Grade B tubers: 'Atlantic' = tubers less than 5 cm in diameter; and 'Russet Burbank' = tubers less than 115 g.

[e]-*designates significant differences between means of the main effects.

'Russet Burbank' (Table 4). Weed free plots, whether early or conventionally hilled, yielded 32 t/ha of total tubers, early hilled plots with weeds present yielded 20 t/ha, and conventionally hilled plots with weeds present yielded only 7 t/ha of total tubers. Marketable yield was greatest in weed free 'Atlantic', yielding 34 t/ha while 'Atlantic' with weeds and weed free 'Russet Burbank' yielded an average of 15 t/ha. Potato yield was greater in weedy early hilled plots compared to conventionally hilled plots because of the increased weed control provided by early hilling and not because of a change in potato development. This increased weed control was noted by the reduced aboveground potato biomass and increased weed dry weight in weedy conventionally hilled plots (Tables 1 and 2).

Yield of marketable 'Atlantic' was reduced 57% in the presence of weeds, while 'Russet Burbank' was reduced at least 70% for both years. Aboveground dry biomass of 'Atlantic' was reduced 64% in the presence of weeds whereas 'Russet Burbank' biomass was reduced at least 73% in 1987 and 1988. Marketable yield and aboveground biomass measurements in both years indicate that 'Atlantic' was a better competitor with weeds than 'Russet Burbank' except in early hilled treatments in 1988. Previous greenhouse research by VanGessel and Renner (26), does not support this conclusion, as 'Atlantic' and 'Russet Burbank' were equally competitive in a greenhouse replacement studies. However, in the greenhouse experiment the potatoes were equally spaced, while in this field research, 'Atlantic' were planted on a 21 cm spacing, and 'Russet Burbank', on a 31 cm seed spacing. Closer plant spacing may increase potato competitiveness with weed species.

Specific gravity. The specific gravity of 'Atlantic' was greater than 'Russet Burbank' when averaged across hilling times and weed presence in

Table 4. Yield and specific gravity, Montcalm, 1988.[a]

Weeds x variety	Total[bc] yield	Marketable[d] yield	Grade B[e] yield	Specific[b] gravity
	(metric t/ha)			
'Atlantic' early hilled, weed free	39	37	2	1.087
'Atlantic' early hilled, weedy	25	24	1	1.087
'Atlantic' conventionally hilled, weed free	34	32	2	1.084
'Atlantic' conventionally hilled, weedy	10	8	2	1.087
'Russet Burbank' early hilled, weed free	28	17	4	1.073
'Russet Burbank' early hilled, weedy	16	9	6	1.075
'Russet Burbank' conventionally hilled, weed free	26	13	7	1.070
'Russet Burbank' conventionally hilled, weedy	3	1	2	1.079
LSD (0.05)	4	3	2	0.003

[a]Yield of off type tubers are not reported.

[b]Potato variety main effect is significant.

[c]Data can be combined over hilling time.

[d]Marketable tubers: 'Atlantic' = tubers greater than 5 cm in diameter; and 'Russet Burbank' = tubers greater than 115 g.

[e]Grade B tubers: 'Atlantic' = tubers less than 5 cm in diameter; and 'Russet Burbank' = tubers less than 115 g.

1987 (Table 3). In 1988, the presence of weeds impacted specific gravity, dependent on hilling time and potato variety (Table 4). The specific gravity of weed free 'Russet Burbank' was less than weed free 'Atlantic' plots, and the specific gravity of weedy 'Russet Burbank' plots was less than the specific gravity of weedy 'Atlantic' plots. Therefore, in both 1987 and 1988 'Atlantic' had higher specific gravity than 'Russet Burbank', which supports previous published reports (8). Potatoes in weed free, conventionally hilled plots had a lower specific gravity than potatoes in all other treatments in 1988, while in 1987 potatoes in weed free plots had a higher specific gravity than potatoes in weedy plots when combined across hilling time and varieties. Therefore, research results were contrasting in 1987 and 1988, and contrary to research by Saghir and Markoullis (21) who reported that weeds had no effect on specific gravity. Nelson and Thoreson found weed presence had a tendency to increase specific gravity (15).

Potato Quality. Internal brown spots (IBS) was greatest both years in weed free 'Atlantic' plots (Table 5). IBS is thought to occur with rapid growth and/or calcium deficiencies. IBS susceptibility is variety dependent, and 'Atlantic' is classified as a susceptible variety (8). The presence of weeds may have reduced rapid tuber growth in 'Atlantic', and therefore reduced the incidence of IBS.

Absence of weeds increased vascular discoloration in 1987 and 1988 (Table 5). 'Russet Burbank' is reported to be susceptible to Verticillium wilt, which can cause of vascular discoloration while 'Atlantic' is resistant (24). Vascular discoloration can also occur if the soil moisture is below 50% of field capacity when the vines are desiccated (24). Potato plants in weedy plots were dead at the time of

Table 5. Internal defects in 15 Grade A[a] tubers, averaged over hilling times, Montcalm.

	1987		1988	
Weeds x variety	IBS[b]	VD[de]	IBS[b]	VD[d]
	(% tubers affected)			
Weed free 'Atlantic'	9	16	5	8
Weedy 'Atlantic'	2	3	0	3
Weed free 'Russett Burbank'	0	26	0	9
Weedy 'Russett Burbank'	0	21	2	3
LSD (0.05)[ef]	4	*	4	*

[a]Grade A tubers: 'Atlantic' = tubers 5 cm to 8 cm in diameter; 'Russet Burbank' = tubers 115 g to 285 g.

[b]IBS = internal brown spots.

[c]VD = vascular discoloration.

[d]Weed presence main effect is significant.

[e]Potato variety main effect is significant.

[f]*-designates significant difference between main effects.

[g]Comparisons between years are not valid.

desiccation, and therefore, low soil moisture should not have been a factor in weedy plots. But increased vascular discoloration in weed free plots may have resulted from the vine killing operation.

ROSE LAKE-muck soil. Weed growth. Weed biomass was greatest in conventionally hilled plots in 1987 (Table 6) which is in agreement with results reported by Rioux et al. (19), and our observations on mineral soils noted above. Weeds were established by the time of conventional hilling on muck soils, and inadequate control by hilling resulted in increased biomass compared to early hilled plots when sampled in August.

Common purslane (Portulaca oleraceae L.), large and smooth crabgrass (Digitaria sp.), and barnyardgrass were the most common weed species in 1987. The weed pressure was variable across the plots, therefore weed biomass was summed for broadleaves and grasses. The percentage of total weed dry weight consisting of grass species was greater in early hilled plots, while the percentage of total dry weight composed of broadleaves was greater in conventionally hilled plots. Early hilling provided timely control of the broadleaves and may have allowed annual C_4 grasses an opportunity to germinate and be more competitive than common purslane, common lambsquarters, and wild mustard under warm environmental conditions (2, 3). In 1988, the weed pressure was lower than in 1987 and total dry weight of weeds and the percentage of grass versus broadleaf weeds did not vary between treatments (Table 6). Temperature may have been the environmental factor determining which weed species would be most competitive. Hilling exposed the weed seeds to the light required to induce germination and irrigation provided adequate moisture. In previous research barnyardgrass had peak emergence in the 18 to 27^{o}C range (27), whereas, common lambsquarters was more competitive than redroot pigweed at 14 to 18^{o} C (17).

Table 6. Weed dry weight/m^2 for early and conventionally hilled treatments, combined over potato variety, Rose Lake.

	1987			1988		
Hilling	Total weed dry weight	% grass[a]	% broad-leaves[b]	Total weed dry weight	% grass[c]	% broad-leaves[b]
	--(g/m^2)--	-------(%)------		---(g/m^2)-	------(%)------	
Early hilling	97	49	51	59	31	69
Conventional hilling	279	17	83	169	25	75
Significant[d]	*	*	*	NS	NS	NS

[a]Annual grasses in 1987 were predominantly barnyardgrass and crabgrass.

[b]Predominant broadleaf weeds in 1987 and 1988 were common purslane, common lambsquarters, and pigweed spp.

[c]Annual grasses in 1988 were predominantly barnyardgrass and witchgrass.

[d]*-Designates significant difference between means of the main effect.

Aboveground potato biomass. Biomass of the early hilled potatoes was greater than the conventionally hilled potatoes when measured 92 DAP in 1987 (Table 7). Early hilling reduced weed interference more than conventional hilling which resulted in greater potato biomass. Potato biomass was greatest for weed free 'Russet Burbank'. This is similar to results noted above on mineral soil in 1987.

In 1988, 'Russet Burbank' had greater biomass than 'Atlantic' potatoes across all treatments (Table 7). Conventionally hilled, weed free plots had greater biomass then conventionally hilled, weedy plots. Early hilling did not affect potato growth since there was no difference in aboveground potato biomass between weedy and weed free, early hilled plots when measured 111 DAP. Weed pressure on the muck location was lower in 1988 compared to 1987. Early hilling destroyed the existing weeds between the rows and the number of weed seeds germinating after hilling was not great enough to influence potato growth in 1988.

Aboveground biomass of 'Atlantic' was not reduced as much the biomass of 'Russet Burbank', although both varieties are classified as having a 'large' amount of biomass (9, 27). The distribution of the plant material and type of growth appears to be more critical to competitive ability than total aboveground biomass. The correlation between potato height and potato biomass for each variety was not significant for either year at either location.

Tuber yield. Total yield and marketable yield were greatest in both weedy and weed free early hilled plots, and weed free conventionally hilled plots in 1987 (Table 8). Marketable yield of each variety was also affected by weed presence. Weed free 'Atlantic' had a greater yield of marketable tubers compared to weed free 'Russet Burbank'.

Table 7. Aboveground biomass of individual potato plants, Rose Lake, August 14, 1987 and September 7, 1988.

	Potato biomass	
Variety x hilling x weeds	1987[a]	1988[b]
	---(dry weight (g/plant)--	
'Atlantic' early hilled, weed free	76	112
'Atlantic' early hilled, weedy	108	112
'Atlantic' conventionally hilled, weed free	46	105
'Atlantic' conventionally hilled, weedy	48	76
'Russet Burbank' early hilled, weed free	97	168
'Russet Burbank' early hilled, weedy	87	148
'Russet Burbank' conventionally hilled, weed free	87	234
'Russet Burbank' conventionally hilled, weedy	53	116
LSD (0.05)[c]	21	41

[a]Hilling time main effect is significant.

[b]Potato variety main effect is significant.

[c]Comparisons between years are not valid.

Table 8. Yield at Rose Lake, 1987.[a]

Variety x hilling x weeds	Total yield	Marketable[b] yield	Grade B[cd] yield
	----------(metric t/ha)-------		
'Atlantic' early hilled, weed free	47	41	3
'Atlantic' early hilled, weedy	45	38	3
'Atlantic' conventionally hilled, weed free	56	51	3
'Atlantic' conventionally hilled, weedy	26	23	2
'Russet Burbank' early hilled, weed free	54	38	5
'Russet Burbank' early hilled, weedy	51	39	4
'Russet Burbank' conventionally hilled weed free	51	36	6
'Russet Burbank' conventionally hilled weedy	33	22	7
LSD (0.05)[e]	6	6	*

[a]Yield of off type tubers not reported.

[b]Marketable tuber: 'Atlantic' = tubers greater than 5 cm in diameter; and 'Russet Burbank' = tubers greater than 115 g.

[c]Grade B tuber: 'Atlantic' = tubers less than 5 cm in diameter; and 'Russet Burbank' = tubers less than 115 g.

[d]Potato variety main effect is significant.

[e]*-designates significant difference between means of the main effect.

In 1988, the total yield of early or conventionally hilled 'Atlantic', and early hilled 'Russet Burbank' were greater than conventionally hilled 'Russet Burbank' (Table 9). Marketable yield was 15% greater with 'Atlantic' compared to 'Russet Burbank' in 1988. Weed pressure was quite low in 1988, and did not impact yield. Hilling time indirectly influenced potato growth through the effect on weed suppression. Early hilling destroyed the existing weeds between the crop row and the new flush of weed seed germination did not provide sufficient weed pressure to impact yield or aboveground potato biomass, whereas conventional hilling did not control the established weeds and the weed population was able to reduce yield and aboveground potato biomass.

Although 'Russet Burbank' produced more aboveground biomass, 'Atlantic' was more competitive when aboveground potato biomass measurements in weed free plots were compared to weedy plots for both years. This is similar to results on mineral soils noted above.

If competitiveness on muck soil is viewed in terms of marketable yield, 'Russet Burbank' was more competitive than 'Atlantic'. The marketable yield of 'Atlantic' was reduced 34% in 1987 and 18% in 1988 in the presence of weeds, while 'Russet Burbank' was reduced only 16% in 1987 and 3% in 1988 (1988 was nonsignificant at $P \leq 0.05$). This is contrary to the results on mineral soils, where 'Atlantic' was more competitive than 'Russet Burbank'.

At Montcalm, 'Atlantic' was planted with a 21 cm spacing in the row and 'Russet Burbank' at 31 cm, while at Rose Lake, both varieties were planted at 25 cm. Plant spacing may not be a critical factor in the greater competitiveness of 'Atlantic' noted on the mineral soils. The closer seed spacing for 'Russet Burbank' at Rose Lake should have increased the number of smaller individual tubers, yet this did not

Table 9. Yield and specific gravity, Rose Lake, 1988.[a]

Variety x hilling x weeds	Total yield	Marketable[bd] yield	Grade B[c] yield	Specific[d] gravity
	------------(metric t/ha)------------			
'Atlantic' early hilled, weed free	37	34	3	1.067
'Atlantic' early hilled, weedy	36	31	3	1.068
'Atlantic' conventionally hilled, weed free	43	39	3	1.071
'Atlantic' conventionally hilled, weedy	31	29	2	1.067
'Russet Burbank' early hilled, weed free	38	31	4	1.063
'Russet Burbank' early hilled, weedy	41	33	5	1.062
'Russet Burbank' conventionally hilled, weed free	31	25	2	1.062
'Russet Burbank' conventionally hilled, weedy	25	21	3	1.062
LSD (0.05)[e]	8	*	1	*

[a]Yield of off type tubers not reported.

[b]Marketable tuber: 'Atlantic' = tubers greater than 5 cm in diameter, and 'Russet Burbank' = tubers greater than 115 g.

[c]Grade B tuber: 'Atlantic' = tubers less than 5 cm in diameter, and 'Russet Burbank' = tubers less than 115 g.

[d]Potato variety main effect is significant.

[e]*-designates significant difference between means of the main effect.

occur. The wider spacing for 'Atlantic' at Rose Lake did increase the percentage of oversized tubers as expected, but these were included in the marketable yield, and did not explain the greater competitiveness of 'Russet Burbank' compared to 'Atlantic'.

Different soil types may alter partitioning of potato photosynthate in the presence of weeds. 'Russet Burbank' in both years at both locations produced greater aboveground biomass than 'Atlantic' when measured at senescence, yet this greater biomass was reflected in increased yield of 'Russet Burbank' compared to 'Atlantic' on the Rose Lake muck soil only. The competitiveness of 'Russet Burbank' with weeds was greater than 'Atlantic' only in 1988 on the muck soils, and when the plots were early hilled on the mineral soils in 1988.

There was no correlation for either weed dry weight or aboveground potato biomass with yield on muck soils either year. Previous research by Nelson and Thoreson (15) found high negative correlations between the weed dry weight portion of the total dry weight per plot and yield. However, weed density in their research ranged form 59 to 311 weeds/m^2, while weed density in these studies ranged from 0 to 31/m^2. These low weed densities did not reduce yield compared to weed free plots in 1988, and in 1987, only weedy conventionally hilled plots reduced yield. Therefore no correlation between weed dry weight and yield would be expected.

Specific gravity. Specific gravity was measured in 1988 only (Table 9). 'Atlantic' had a higher specific gravity than 'Russet Burbank', 1.068 and 1.063, respectively, when averaged across weed presence and hilling time. Weed presence did not influence specific gravity on muck, possibly due to the low density of weeds both years of the studies. 'Atlantic' had higher specific gravity than 'Russet Burbank' on mineral soils in 1987 and 1988, confirming previous reports (8).

Potato Quality. Weed free 'Russet Burbank' had a greater percentage of tubers with hollow heart in 1987 and 1988 (Table 10). Hollow heart is associated with periods of rapid growth, and the presence of weeds may reduce the rapid nutrient and moisture uptake required for rapid growth to occur. 'Atlantic' is reported to be susceptible to hollow heart (8), yet this was not observed. Internal brown spots (IBS) were found in 11% of the tubers in weed free 'Atlantic' plots in 1987. Although IBS was not significant ($P \leq 0.05$) in 1988, no IBS was found in any treatments containing 'Russet Burbank' in 1987 and 1988. The susceptibility of 'Atlantic' to IBS was noted on mineral soils as well.

Early hilling provided better weed control than conventional hilling, however it resulted in later weed germination, increasing the proportion of C_4 to C_3 weeds compared to the conventionally hilled plots. Environmental conditions at early hilling, such as warmer soil and air temperature, may be better suited for C_4 weed growth than at the time of planting. Hilling brought additional weed seeds closer to the soil surface and exposed them to red light, and irrigation maintained adequate soil moisture for seed germination. Changing weed species and abundance after early hilling may require applications of postemergence herbicides able to control late emerging annual grasses.

Previous research showed weed dry weight to be a good predictor of tuber yield reduction when weed density was high (7, 15), but low weed densities and biomass were unreliable predictors of tuber yield. Reduction of marketable yield due to weeds ranged form 11 to 73%, therefore weeds must be controlled prior to establishment by either chemical or cultural methods (hilling). Adequate control of weeds

Table 10. Internal defects in 15 Grade A tubers,[a] averaged over hilling times, Rose Lake.

	1987		1988	
Weeds x variety	HH[b]	IBS[c]	HH[b]	IBS[c]
	------------(% tubers affected)----------			
Weed free 'Atlantic'	5	11	1	2
Weedy 'Atlantic'	7	2	4	0
Weed free 'Russet Burbank'	35	0	13	0
Weedy 'Russet Burbank'	12	0	3	0
LSD (0.05)[d]	11	6	7	NS

[a]Grade A tubers: 'Atlantic' = tubers 5 cm to 8 cm in diameter; 'Russet Burbank' = tubers 115 g to 285 g.

[b]HH = Hollow heart.

[c]IBS = Internal brown spots.

[d]Comparisons between years are not valid.

germinating after early hilling, particularly annual grasses may be necessary. To delay the control of weeds until conventional hilling is not practical because established weeds cannot be controlled by chemical or mechanical means. Therefore, two weed control options appear feasible on both mineral and muck soils. Early hilling for weed control followed by herbicide applications to control germinating weed seeds (particularly grasses) after hilling is one option. Alternatively, herbicides could be applied at planting to control germinating weeds, and then the potatoes hilled at the conventional time. If dry weather or other reasons caused a failure in herbicide performance, potatoes should then be early hilled and a second herbicide application made, since delaying hilling to the conventional time would result in inadequate control of established weeds, and yield reductions.

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INFLUENCE OF WEEDS ON INSECT DIVERSITY AND POPULATION DYNAMICS IN POTATOES (Solanum tubersum L.)[1]

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Abstract. Larval Colorado potato beetle (CPB) were found most often in early hilled and weed free potatoes when totaled for the entire season in both 1987 and 1988. Weed free potatoes provided a concentration of resources for CPB. Emergence of early hilled potatoes was delayed and the plants were at a preferable developmental stage for CPB. In 1988, the presence of adult CPB was followed in sequence by egg masses, larva, and again adults in the same treatment for a generation of beetles. In 1987, flea beetle, aphid, and tarnished plant bug counts were greatest in weed free plots, but not in 1988. Ladybugs in 1987 and lacewings in 1988 were erratic, but showed preference for weed free plots, while stinkbug counts in 1988 were higher in weedy plots.

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INTRODUCTION

Agroecosystems in agriculture today tend to be vegetatively homogeneous as a result of monoculture crop production. Plant homogeneity reduces diversity which may affect the abundance and diversity of insect populations. There is much speculation as to the impact reduced plant diversity may have on insect populations, and research has been conducted to determine the interactions between plant diversity and insect populations (2, 3, 5).

Companion crops, intercrops, trap crops, and weed infested crops have been mentioned as cultural practices that can increase plant diversity in food production (3). Companion cropping and intercropping increase plant diversification through the use of two or more agriculturally productive species. Plants used as trap crops may or may not have intrinsic agricultural value. Weed infested crops add to the diversity of agroecosystems, and weeds may be beneficial or detrimental, dependent on the specific crop/weed/pest interaction (2, 4, 5).

Agroecosystems can be manipulated in various ways to influence weed species and weed density. Methods to manipulate weed population include the use of selective herbicides, amending soil fertility and soil pH to alter soil chemical properties, changing crop rotations, seeding cover crops to suppress weeds, direct seeding of desirable weeds, and soil disturbances by primary and secondary tillage and cultivation (2). Hilling is a mechanical cultivation procedure in potato production that shields potato tubers from light, aids in mechanical harvest, and destroys weeds present at the time of hilling. However, hilling can also bring about a flush of new weed seed germination (6).

The presence of weeds may affect both pest and beneficial insects (2, 3). Weeds provide pollen, nectar and fluid from which insects obtain carbohydrates, amino acids, and other dietary requirements. Weeds provide shelter and a substrate for egg deposition. Alternate prey may inhabit weed infested crops, and provide a substitute to the beneficial insect if a preferred pest is unavailable. However, weeds may hinder an insect's ability to locate the crop using visual interference, olfactory or chemical interference, preferred hosts and decoy interference, and/or physical interference (8).

Increased vegetative complexity can adversely affect herbivore insect populations (3). Both Andow (3) and Perrin (5) concluded that the dilution of required or preferred host plants by plant diversity may account for decreased pest populations and reduced insect damage in diverse agroecosystems. Predators and parasites increased with greater plant diversity due to improved microhabitats and an abundance of food sources (3).

The presence of nonhost plants reduced specialized herbivore pest population, but the mechanisms have not been determined (4). Weeds may alter crop quality and reduce pest attacks, chemical or visual stimuli may be altered thus reducing a pest's ability to locate a host, there may be dilution of host to nonhost ratio, or weeds may alter the cropping system microclimate. Weeds can reduce the immigration rate of insects into weedy crop plots, but had varying results on the insect emigration rate (4).

Two theories have been proposed to explain the effect of plant diversification on insect populations (3). The 'enemies hypothesis' predicts that diversified systems will increase the number of predators and parasites, which in turn will reduce levels of insect pests (3). The 'resource concentration hypothesis' suggests that a specific habitat is best suited for a particular pest (3). Any deviation from that habitat results in difficulty by the pest in locating host plants, a propensity for the host plant, or a reduced insect reproductive rate. This 'resource concentration hypothesis' may account for the decreased pest populations noted in diversified agroecosystems (4).

Research with dry beans (*Phaseolus vulgaris* L.), wild mustard (*Sinapis arvensis* L. or *Brassica kaber* (DC.) Wheeler.), and Mexican bean beetle larva (*Epilachna varivestis* (Mulsant)) found that low levels of weed infestation (no weed density reported) had a beneficial effect in controlling bean beetle population. This compensated for the competition occurring between the dry bean and wild mustard plants (3).

Research was initiated to determine if the presence of a natural infestation of weeds would influence the presence and reinfestation of insect populations in potatoes after insecticide treatments. Hilling at either potato cracking or when the potato plant was 30 cm tall was included in the study to determine the impact of hilling on weeds species abundance and diversity, and subsequent effects on beneficial and detrimental insect populations.

MATERIALS AND METHODS

Variety and hilling study. Field research was conducted at the Montcalm Potato Research Farm, Entrican MI, in 1987 and 1988. The soil was a complex of Montcalm and McBride sandy loam, soil pH was 6.2 and 5.2, and organic matter content was 1.8% and 1.6%, in 1987 and 1988, respectively. The previous crop for both years of research was alfalfa (*Medicago sativa* L.). Potato plots were 6.1 m long, and 3 rows (86 cm spacing) in width. Plots were fertilized according to Michigan State University (MSU) soil test recommendations and irrigated in accordance with MSU irrigation scheduling for potatoes with solid set irrigation. Potato planting occurred April 30, 1987 and April 27, 1988.

The experiment consisted of 8 treatments (2 x 2 x 2 factorial) with 4 replications arranged in a randomized complete block design. The three factors were: 1) variety, 'Atlantic' or 'Russet Burbank'; 2) hilling time, at potato cracking (early hilling) or when the plants were 30 cm tall (conventional hilling); and 3) weeds, hand weeded or a natural infestation of weeds. Hilling times were May 15, 1987 and May 18, 1988 for early hilling and June 9, 1987 and June 16, 1988 for conventional hilling.

Barnyardgrass and redroot pigweed study. In 1988, three treatments from an adjoining study of barnyardgrass and redroot pigweed interference in potatoes (var. 'Atlantic') were included as a comparison. One barnyardgrass or redroot pigweed was seeded every 0.5 m in the crop row within one day of potato planting. This weed pressure was maintained throughout the season by removing undesirable weeds by hand. A weed free plot was the third treatment. The three treatments were hilled once when the potatoes were 30 cm tall. These treatments had 2.2 kg active ingredient (ai)/ha of aldicarb (2-methyl-2-(methylthio) propionaldehyde 0-(methylcarbamoyl) oxime), applied at the time of planting each year.

The research plots were monitored and sprayed when the population of insects or disease level had reached damaging levels. Carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate) was applied at 1.1 kg ai/ha on June 13, June 23, and July 1, 1987 for control of Colorado potato beetle (CPB) (Leptinotarsa decemilineata (Say)), and flea beetle (Epitrix cucumeris (Harris)). In 1988, phosmet (N-(mercaptomethyl) phthalimide,S-(0,0-dimethyl phosphorodithioate) was applied on June 29 and July 12 at 1.1 kg ai/ha for control of CPB, and fenvalerate (cyano (3-phenoxy phenyl) methyl-4-chloro-alpha-(1-methylethyl) benzeneacetate) was applied at 0.22 kg ai/ha on July 15 to control CPB, flea beetle.

Measurements. Insects were counted four times in 1987 and six times in 1988. All potato plants from 1.5 m of the middle row of each plot were examined. In 1987, all insects considered pests in Michigan potato production ladybeetles (coccinellids) were counted. In 1988 insect counting was expanded to include other beneficial insects. Insects counts in each plot were totaled across all observation dates to evaluate the full season effect of a particular treatment.

Data analysis. Insect counts were transformed by the equation log (x + 1) prior to analysis (7). Transformed data was subjected to analyses of variance. Treatment means were compared using a least significant difference (LSD) test at $P \leq 0.05$. Data in tables is presented as actual insect counts. Data was not combined over years because of significant year by treatment interactions.

RESULTS AND DISCUSSION

Variety and hilling study. The predominant weed species in 1987 were common lambsquarters (Chenopodium album L.) (3 plants/m^2), redroot pigweed (Amaranthus retroflexus L.) (5 plants/m^2), and annual grasses (predominately Echinochloa crus-galli (L.) Beauv.) (counts not recorded in 1987). Common lambsquarters was the predominant weed in 1988 (17 plants/m^2).

Colorado potato beetle (CPB) egg masses were most abundant in the weed free plots on June 10 and when counts were totaled for the season (Table 1). This concurs with previous research where the presence of weeds reduced the population of specialized herbivores due to dilution of host plants and/or alteration of host finding mechanisms (4).

On June 10 and when counts for CPB egg masses were totaled over the season, there was an interaction between potato variety and hilling time. The greatest number of CPB egg masses were in early hilled 'Atlantic' and conventionally hilled 'Russet Burbank' (Table 1). The fewest CPB egg masses were found in conventionally hilled 'Atlantic' plots. 'Atlantic' emerged earlier than 'Russet Burbank', and therefore the emergence of early hilled 'Atlantic' and conventionally hilled 'Russet Burbank' was within days of each other and plants in these treatments may have been at

Table 1. Treatment preference of various stages of CPB when totaled for four measurement times, in 1987.

Variety x hilling x weeds	Colorado potato beetle: Egg masses[a]	Hatched egg masses	Larvae[ab]
	-------(no./1.5 m)---		
'Atlantic', early hilled, weed free	10	1	5
'Atlantic', early hilled, weedy	6	2	2
'Atlantic', conventional hill, weed free	5	4	5
'Atlantic', conventional hill, weedy	1	1	1
'Russet Burbank', early hill, weed free	8	1	17
'Russet Burbank', early hill, weedy	3	1	12
'Russet Burbank', conventional hill, weed free	6	1	2
'Russet Burbank', conventional hill, weedy	3	1	5
LSD (0.05)[cd]	4	2	*

[a]Weed presence main effect is significant.

[b]Hilling time main effect is significant.

[c]LSD value for CPB egg masses represents significant potato variety by hilling time interaction.

[d]*-designates significant difference between means of the main effect.

a stage that attracted CPB.

The greatest number of hatched egg masses on June 10 and when combined over the season were found in weed free, conventionally hilled 'Atlantic' plots (Table 1). The htached egg masses were not separated by hatched egg masses and eggs fed upon by predators. The conventionally hilled 'Atlantic' were the first plants to emerge and the absence of weeds offered CPB a weed free area of potato plants for egg deposition. Larval CPB were also most abundant in 'Atlantic' plots on June 10 (data not presented). The totaled number of CPB larva for the season were most numerous in both weed free and early hilled plots (Table 1).

In 1988, all stages of CPB were most numerous in early hilled plots early in the season and in the weed free plots later in the season. On June 15, CPB egg masses, hatched egg masses, larvae, and adults were found in greater numbers in early hilled plots compared to the conventional hilled treatments (Table 2). CPB egg masses and larvae counted on June 20 (4 days after conventional hilling), and larva on July 4, were present in greater numbers in early hilled treatments. The early hilled plots emerged 3-7 days after the conventionally hilled plots and this delayed emergence may have allowed early hilled potato plants to be more easily located by the adult CPB.

CPB egg masses will hatch in 4 to 7 days, therefore, the presence of egg masses indicated adult activity 4-7 days prior to observations. Hatched egg masses are a result of adult activity 10-14 days prior to observations. CPB may have favored the delayed potato emergence in early hilled plots because these potatoes were at an earlier stage that attracted emerging adult CPBs which began to feed, oviposit, and successive stages remained throughout the summer.

Table 2. Influence of hilling time on CPB at successive stages of development, in 1988. Data combined over potato variety and weed presence.

	Colorado potato beetle					
	June 15		June 20		July 4	July 18
Hilling time	Adults	Egg masses	Egg masses	Larvae	Larvae	Adult
	(no./1.5 m)					
Early hill	1	6	4	4	2	1
Conventional hill	0	1	1	1	1	0
Significance (0.05)[ab]	*	*	*	*	*	*

[a]*-Designates significant differences between means.

[b]Comparisons between columns are not valid.

On July 4, more hatched CPB egg masses were found in weedy, early hilled treatments than weedy, conventionally hilled treatments (data not presented). Early hilling in 1988 reduced the amount of weed biomass in the plot compared to the conventional hilling and resulted in a higher percentage of annual grasses. The shift in the weed spectrum in early hilled plots may have altered the stimuli to attract CPB adults and favored CPB egg deposition.

On July 21, adult CPB were found in greater numbers in early hilled, weed free treatments than other treatments (data not presented). By this date, weed biomass was greater than potato biomass and weed interference had reduced the growth of the potato plant, thus serving as a physical barrier to the potato plant, and diluting the amount of potato biomass available to CPB for feeding. By August 1, adult CPB and egg masses were most evident in weed free plots, and larval CPB were in greater numbers in weed free 'Russet Burbank'. No CPB larvae were found in either variety when weeds were present. The weeds appear to have reduced the immigration rate of CPB as predicted by Andow (4).

CPB egg masses totaled for 1988 were more numerous in early hilled weedy and weed free treatments, and conventional hilled weed free treatments (Table 3). CPB larvae, adults, and hatched egg masses were also more abundant in early hilled plots. CPB larvae numbers were greater in weed free plots, which was similar to totaled larval results in 1987.

There were more flea beetles, tarnished plant bugs (Lygus sp.), and combined aphid counts (green peach aphid (Myzus perisicae (Sulzer) and potato aphid (Macrosiphum euphoribae (Thomas)) in weed free plots than in weedy plots in 1987, possibly due to the dilution of desirable hosts in the weedy plots (Table 4). However, in 1988, the presence of weeds had

Table 3. CPB counts totaled for the six observation times in 1988. Data combined over potato variety.

Hilling x weeds	Colorado potato beetle			
	Egg masses	Hatched egg masses[a]	Larvae[ab]	Adults[a]
	-------------(no./1.5 m)--------------			
Early hill, weed free	12	4	19	4
Early hill, weedy	10	4	6	2
Conventional hill, weed free	5	2	20	8
Conventional hill, weedy	1	0	1	0
LSD (0.05)[c]	7	*	*	*

[a]Hilling time main effect is significant.

[b]Presence of weeds main effect is significant.

[c]*-Designates significant differences between means of main effects.

Table 4. Flea beetle, tarnished plant bug, and aphid population counts totaled for the entire growing season, in 1987 and 1988.

Variety x hilling x weeds	Flea beetle 1987[a]	Flea beetle 1988[bc]	Tarnished plant bug 1987	Tarnished plant bug 1988[a]	Total aphids 1987[a]	1988 Green peach aphid	1988 Potato aphid[b]
	(no./1.5 m)						
'Atlantic', early hilled, weed free	11	11	0	1	90	1	1
'Atlantic', early hilled, weedy	2	9	4	2	107	2	1
'Atlantic', conventional hill, weed free	3	10	1	2	115	2	0
'Atlantic', conventional hill, weedy	1	5	5	1	66	1	1
'Russet Burbank', early hill, weed free	4	8	1	2	138	1	4
'Russet Burbank', early hill, weedy	0	10	1	2	115	3	1
'Russet Burbank', conventional hill, weed free	4	5	0	4	250	1	1
'Russet Burbank', conventional hill, weedy	1	1	3	2	85	3	1
LSD (0.05)[d]	*	*	NS	*	*	NS	*

[a]Weed presence main effect is significant.

[b]Potato variety main effect is significant.

[c]Hilling time main effect is significant.

[d]*-Designates significant differences between means of main effects.

no effect on insect treatment preferences. Flea beetles were more numerous in plots containing 'Atlantic' and early hilled treatments, potato aphids were more abundant in 'Russet Burbank' than 'Atlantic' plots, and numbers of both tarnished plant bug and green peach aphid did not differ among treatments. The greater total number of insects for the season in weed free plots in 1987 may be due to the diversity of plant species in weedy treatments, and was consistent with the 'concentrated resource hypothesis' (3). High weed pressure in 1988 from common lambsquarters may have increased the weed influence on insect preference for plants in the weedy treatments.

Ladybeetles and lacewings had a low total number for both years, but ladybeetles tended to be most numerous in weed free, early hilled, 'Atlantic' and weed free, conventionally hilled 'Russet Burbank' plots in 1987 (Table 5). No ladybeetles were counted in weed free, conventionally hilled 'Atlantic' plots.

In 1988, ladybeetle numbers did not differ between treatments. Lacewing (*Chrysopa* sp.) counts on July 18,1988 were more abundant in early hilled plots. Ladybeetle and lacewing counts were contrary to reports of vegetative diversity increasing beneficial insects (2, 3). However, in 1988, stinkbugs (*Perillus* sp.) were only in weedy plots when combined over the season.

Redroot pigweed and barnyardgrass study. Insect counts in this study were low, but some consistency in insect counts were observed. On June 15, 1988, barnyardgrass plots had the greatest number of flea beetles compared to the weed free plots or the plots containing redroot pigweed (Table 6). By July 4, 1988, more flea beetles were present in the weed free plots compared to the barnyardgrass plots. By July 4, barnyardgrass

Table 5. Beneficial insect counts in 1987[a] and 1988, totaled for the entire growing season.

Variety x hilling x weeds	Ladybeetles 1987	Ladybeetles 1988	1988 Lacewings	1988 Stinkbugs[b]
	----------(no./1.5 m)---------			
'Atlantic', early hilled, weed free	1	0	2	0
'Atlantic', early hilled, weedy	0	0	2	1
'Atlantic', conventional hill, weed free	0	0	4	0
'Atlantic', conventional hill, weedy	1	0	1	1
'Russet Burbank', early hill, weed free	0	0	1	0
'Russet Burbank', early hill, weedy	1	0	2	1
'Russet Burbank', conventional hill, weed free	1	0	2	0
'Russet Burbank', conventional hill, weedy	0	0	1	1
LSD (0.05)[cd]	1	NS	NS	*

[a]Ladybeetles were only beneficial insect counted in 1987.

[b]Weed presence main effect is significant.

[c]Comarisons between years are not valid.

[d]*-Designates significant differences between means of main effects.

Table 6. Beneficial insect counts in the redroot pigweed and barnyardgrass study, in 1987.

Weeds	Ladybeetles[a]	Lacewings[b]
	-------(no./1.5 m)---------	
Redroot pigweed	0	1
Barnyardgrass	0	0
No weeds	1	0
LSD (0.05)	1	1

[a]Insect counts totaled for entire season.

[b]Measurements taken on June 20, 1988.

was the tallest plant and had begun to tiller which resulted in a lower percentage of potato biomass to weed biomass, thus discouraging the presence of the flea beetle.

On June 20, lacewings were most numerous in redroot pigweed treatments, while barnyardgrass and weed free treatments did not differ from each other (Table 6).

When insect counts were combined over the season, ladybeetles were only seen in weed free plots (Table 6). This is similar to the data reported above, yet contrary to earlier findings and hypotheses (2, 3, 5).

The weed density in all weedy treatment resulted in a significant yield reduction. Weeds emerged prior to the potatoes, and the potato plants in weedy plots had begun to senesce earlier than the weedfree potato plots. Late emerging weeds would be maturing later in the season and could add a new dimension to agroecosystems. Insecticide treatments both years lowered the level of insect populations, yet the trend of CPB in early hilled plots and later emigrating to weed free plots was consistent across most insecticide applications. Weeds may have reduced the efficacy of the insecticides, thus leaving a small pool of fertile adults to replenish the population.

Total number of larval CPB, were greatest in early hilled and weed free plots in both 1987 and 1988. In 1988, CPB were more abundant in the early hilled plots. As the season progressed and weed interference occurred, CPB became more evident in weed free plots. The method by which insects locate the host or desired plant is poorly understood (3), and until it has been determined, crop/weed/insect interactions cannot be fully understood.

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