THE EFFECT OF MECHANICAL WEED CULTIVATION ON CROP YIELD AND QUALITY, DISEASE INCIDENCE AND PHENOLOGY IN SNAP BEAN, CARROT AND LETTUCE CROPS.

by

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FOREWORD

This thesis comprises five sections. Section one is a general introduction and literature review. Section two to five are the body of the thesis. Section six is a general discussion. Section two (part I) and section three are presented as complete manuscripts. The thesis format has been approved by the Faculty of Graduate Studies and Research of McGill University and follows the conditions outlined in "Guidelines for Thesis Preparation," section three "Traditional and manuscript-based theses".

Faculty regulations

"Candidates have the option of including, as part of the thesis, the text of one or more papers submitted or to be submitted for publication, or the clearly-duplicated text of one or more published papers. These texts must be bound as an integral part of the thesis.
If this option is chosen, connecting texts that provide logical bridges between the different papers are mandatory. The thesis must be written in such a way that it is more than a mere collection of manuscripts; in other words, results of a series of papers must be integrated.
The thesis must still conform to all other requirements of the "Guidelines for Thesis Preparation". The thesis must include: A Table of Contents, an abstract in English and French, an introduction which clearly states the rationale and objectives of the study, a review of the literature, a final conclusion and summary, and a thorough bibliography or reference list.
Additional material must be provided where appropriate (e.g. in appendices) and in sufficient detail to allow a clear and precise judgement to be made of the importance and originality of the research reported in the thesis.
In the case of manuscripts co-authored by the candidate and others, the candidate is required to make an explicit statement in the thesis as to who contributed to such work and to what extent. Supervisors must attest to the accuracy of such statements at the doctoral oral defense. Since the task of the examiners is made more difficult in these cases, it is in the candidate's interest to make perfectly clear the responsibilities of all the authors of the co-authored papers."

Although all the work presented here was the responsibility of the candidate, the project was supervised by thesis committee members Dr. T. Paulitz, and Dr. K. Stewart, Department of Plant Sciences, Macdonald Campus of McGill University and Dr. D. Benoit, Agriculture et agroalimentaire Canada, Saint-Jean-sur-Richelieu. Dr. D. Cloutier, Agriculture et agroalimentaire Canada, Saint-Jean-sur-Richelieu, also supervised the project. For consistency and convenience, manuscripts are presented in a generic format.

ABSTRACT

M. Sc. Marcella L. Trembley Plant Science

THE EFFECT OF MECHANICAL WEED CULTIVATION ON CROP YIELD AND QUALITY, DISEASE INCIDENCE AND PHENOLOGY IN SNAP BEAN, CARROT AND LETTUCE CROPS

Inter-row mechanical cultivation was proposed as a supplement to or substitute for conventional weed control methods currently used in snap bean, carrot and lettuce production. Several types of cultivators were assessed and compared. The effect of mechanical cultivation on crop yield and quality was studied by counting, weighing and grading bean pods, carrot roots and lettuce heads. The effect of mechanical cultivation on disease incidence was studied by surveying fields during the season and by determining the number and weight of diseased pods, roots and heads at harvest. The relationship between the level of Cercospora blight on carrots and potential impacts on yield was also investigated by measuring plant characteristics and the amount of force needed to separate carrot foliage from root. The effect of mechanical cultivation on the phenology of snap bean flowering was studied by determining how long it took for a plant to produce 50% of its flowers and counting how many flowers and pods a plant produced. In general, mechanical cultivation did not affect normal crop production and may be used to replace or complement conventional weed control methods. There was little variation among different cultivators within one season, but cultivator effects differed among crops and from one year to the next.

RÉSUMÉ

M. Sc. Marcella L. Trembley Phytologie

LES EFFETS DU DÉSHERBAGE MÉCANIQUE SUR LE RENDEMENT, LA QUALITÉ, L'INCIDENCE DES MALADIES ET LA PHÉNOLOGIE DANS LES CULTURES DE FÈVES VERTES, DE CAROTTES ET DE LAITUES

Le désherbage mécanique entre les rangées a été proposé comme complément ou comme substitut aux méthodes conventionnelles de contrôle des mauvaises herbes couramment utilisées au niveau de la production de la fève verte, de la carotte et de la laitue. Plusieurs types de sarcleurs ont été évalués et comparés. L'effet du désherbage mécanique sur le rendement et la qualité des cultures a été étudié en comptant, pesant et calibrant les cosses de fève, les racines de carotte et les laitue. L'effet du désherbage mécanique sur l'incidence des maladies a été évalué en inspectant les champs durant la saison et en déterminant le nombre et le poids des cosses, des racines et des laitues malades au moment de la récolte. La relation entre le niveau de la brûlure cercosporéenne de la carotte et les impacts potentiels sur le rendement ont aussi été étudiés en mesurant les caractéristiques des plantes et la force requise pour séparer la racine du feuillage. Chez les fèves vertes, l'effet du sarclage mécanique sur la phénologie de la floraison a été étudié en déterminant combien de temps il fallait à la plante pour produire 50 % de ses fleurs et en comptant combien de fleurs et de cosses une plante produisait. En général, le désherbage mécanique n'a pas affecté la production normale des cultures et pourrait être utilisé pour remplacer ou complémenter les méthodes de contrôle des mauvaises herbes. Il y a eu peu de variation entre les différents sarcleurs à l'intérieur d'une même saison mais les effets de ces sarcleurs différaient entre les cultures et d'une année à l'autre.

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GENERAL INTRODUCTION

Green snap bean, carrot and lettuce are some of the most important vegetable crops produced in Quebec and across the country. Quebec was the largest Canadian producer of green beans (*Phaseolus vulgaris* L.) in 1994, with 3,274 hectares harvested (22,477 tonnes) at a value of 7,648,000 dollars (Statistics Canada 1995). Production of green beans in Quebec is highest on sandy loam soil (CPVQ 1982). Quebec was the second largest producer of carrots in Canada. Carrots are grown on many types of soils in Quebec, but the best results are achieved on sandy loam or deep organic muck soils with good drainage (CPVQ 1982). In 1994, 3,518 hectares of carrots (*Daucus carota* L. subspecies *Sativus* (Hoffm.) Arcang.) were harvested in Quebec, representing a total production of 121,817 tonnes with a value of more than 24,608,000 dollars (Statistics Canada 1995). Quebec was also the largest producer of lettuce (*Latuca sativa* L.) in Canada in 1994, with a total harvest of 1,741 hectares, (36,438 tonnes) valued at 19,364,000 dollars (Statistics Canada 1995). Lettuce is grown primarily on organic soils (CPVQ 1982).

One of the major challenges in the production of bean, carrot and lettuce crops is weed control. Weeds are commonly defined as plants that have undesirable features and grow in places where they are not wanted. Weeds are important elements in the agro-ecosystem because they may interfere with crop production, reduce crop yield or affect crop quality, and increase costs of production (Parish 1990). The percentage of lost crop production due to weeds in North and Central America is estimated at 8% (Altman 1993).

If weeds are not controlled, the consequences can be economically serious. In bean stands with natural weed infestations present for the growing season, 104 and 580 weeds per m^2 reduced yields 13 and 27% respectively, but in a very dry season, 400 weeds per m^2 reduced yield 80% (Hewson et al. 1973). Carrot stands exposed to severe weed competition experienced 30 to 60 % yield reduction (Shadbolt and Holm 1956). A study investigating natural weed infestation in lettuce stands demonstrated that a weed density as low as 65 weeds per m^2 caused complete yield loss (Roberts et al. 1977). Nutrient consumption by weeds and crops are very similar and in competitive situations, nutrients taken up by weeds are lost to crop plants (Zimdahl 1993). Crop plants have been shown to be especially sensitive to the presence of weeds during a critical period which occurs within the first few weeks after crop emergence (Weaver 1984).

Vector-borne plant viruses may be carried by weeds that remain symptomless while infected. For example, the virus causing carrot thin leaf and carrot motley dwarf may be transmitted by insects from wild growing *Daucus* species to cultivated carrots (Howell and Mink 1977). Virus diseases may be vector spread from weeds growing in or near a crop field. Direct evidence of virus transmission through seed or pollen is reported for 108 viruses (Mink 1993).

The first synthetic chemical developed for selective weed control was released in the early 1930's. Since that time, development and world wide use of herbicides has quickly increased. In 1978, 85 % of all pesticides used in Quebec were for agricultural purposes. Of this, 71 % (1,203,109 kg) were herbicides (MAPAQ 1991).

Herbicide use in itself has not solved the problem of weed control. Weeds may develop resistance to certain herbicides. More than 100 cases of weed resistance have been reported (Holt and LeBaron 1990). Also, shifts may occur in composition of weed communities towards species and genotypes that require more effort and expense to chemically control (Froud-Williams 1988). Cost of chemical weed control may increase at a faster rate than the unit price for certain crops. Herbicides may pose an environmental hazard in ground or surface waters, especially when applied to crusted bare soil or prior to heavy rains (Flury 1996). Herbicides are commonly detected in ground waters near agricultural activity even though their development has been directed towards less persistent herbicides that have lower soil mobility and higher target specificity (Lamoreaux 1994). The negative effects of herbicides on non-target and beneficial flora and fauna are also one of the primary concerns in agriculture (Ferguson et al. 1996). Herbicide and crop plant environment interactions are complex; positive and negative effects of herbicides on soil-borne pathogens, host susceptibility and the relationship between pathogen and soil microflora have been reported (Katan and Eshel 1973).

Modern agricultural production systems rely heavily on herbicides to control weeds. However, alternatives to herbicide use are increasingly being sought where economic costs are high, weed control is incomplete, herbicides are not permitted for use, weed resistance is observed and/or environmental impacts are of concern. In a recent survey of independent crop consultants, investigators found that the majority of agricultural producers desire to increase their use of non-chemical production practices (Ferguson et al. 1996). The primary limitation to integrating non-chemical practices was identified as a lack of viable non-chemical tactics.

The present research was motivated by a desire to investigate alternatives to conventional weed control methods. The study was designed to evaluate mechanical weed cultivation in particular. In bean and carrot production, chemical weed control is traditionally used. In lettuce, the objective was not directed towards replacing herbicides, but to find an alternative to a costly, time consuming and soil degrading weed control system which involves a combination of rototilling plus manual weeding. The study was designed to evaluate, in addition to solely weed control efficacy, other aspects of the agro-environment, such as soil and crop response. In an attempt to make the results of the study more accessible to producers, the cultivators that were chosen to be used in the study were ones that producers likely already owned and used in some capacity, or alternately could easily purchase.

Cultivation treatments were planned to replace herbicide use entirely in bean crops. In carrot production, cultivation was integrated with a reduced application of herbicide in which herbicide was band-applied on crop rows only and not on the inter-row. In lettuce production, mechanical cultivation was used as a replacement for conventional weed control which involves using a combination of rototilling and hand weeding, since no herbicides are registered for use in lettuce grown on organic soil. Four different types of cultivation treatments were used in each crop, in addition to weedy and weed-free checks and the conventional weed control method.

Several groups of investigators worked on this project and the focus of each can be roughly identified as weed, soil and crop response. The focus of the present study was on crop and disease response to mechanical weed cultivation. Mechanical weed cultivation may prove to be beneficial in crop production, above and beyond weed control, such as crop quality, disease control and/or phenology. For a similar or even lower level of weed control as conventional methods, mechanical cultivation may be preferred because of its positive influence on other aspects of crop production. Results of the weed and soil studies are not part of this particular investigation and are not reported here.

The objectives of this study were to determine if mechanical weed cultivation had any effects on specific aspects of crop production. This was accomplished by assessing amount and quality of marketable plant products, estimating disease levels and following developmental stages. Three broad domains of crop production were considered. Domain one involved evaluating crop yield and quality. Domain two involved evaluating levels of disease within each crop. One study in this domain focused on Cercospora blight of carrots and possible relationships between disease levels, yield and foliage vigor. Domain three involved a phenology study that consisted of collecting data on bean flowering. The study involved several types of cultivators, three different vegetable crops (snap beans, carrots and lettuce) and was conducted on two types of soils (clay loam and organic).

LITERATURE REVIEW

1. Mechanical cultivation in crop production

1.1 Mechanical cultivation

The mechanization of agriculture required that crops were grown in rows and mechanical cultivation for weed control in the inter-row soon developed (Parish 1990). Mechanical inter-row cultivation is used primarily as a method of weed control. Weeds are killed by desiccation of tissues, depletion of food reserves and/or smothering. The action of cultivation implements breaks or cuts weeds apart, tears them out of the soil and/or smothers them with soil (Ross and Lembi 1985). Most effective results are achieved if cultivation is done when soils are dry, in order to expose the damaged weed to desiccating conditions (Lovely et al. 1958).

Producers often cultivate on a regular basis for reasons other than weed control (Cardwell 1982). Cultivation of crusted soil improves soil aeration and water infiltration and a loosened surface layer may improve soil moisture by impeding the upward movement of capillary water (Blake and Aldrich 1955; Buhler et al. 1995; Prihar and van Doren 1967). Cultivation may also increase available soil nitrogen to varying degrees, depending on the type of soil (Lyon 1922). Soil temperatures in the cultivated layers are higher than below the cultivated layer (Chaudhary and Prihar 1974) and this may contribute to an increase in microfauna activity. Because mechanical cultivation is a physical process and requires that weeding machinery closely passes along the crop row, aspects of the crop environment maybe altered sufficiently to impact on crop yield and quality, disease incidence and severity. The usefulness of cultivation for purposes other than weed control and its impact on soil properties varies with crop type, weather, soil texture, soil water content, soil crusting and compaction and timing of cultivation and depth and action of the cultivator (Unger and Cassel 1991).

1.2 Crop yield and quality

Studies involving mechanical cultivation in crop production are primarily concerned with efficacy of weed control and subsequent impact on crop yield (Baumann and Slembrouck 1994; Burnside et al. 1994; Coote and Saidak 1984; Gunsolus 1990; Lovely et al. 1958; Mulder and Doll 1993; Peters et al. 1959). In most cases, increases in crop yield were attributed to a reduction in weed-crop competition, but other factors such as improved water conservation, increased water infiltration and soil aeration have also been identified (Blake and Aldrich 1955; Buhler et al. 1995; Perry 1983; Prihar and Van Doren 1967). Cultivation may offer unintentional secondary beneficial effects such as reduced disease incidence and/or severity of soilborne diseases (Shipton 1979; Perry 1983). On the other hand, some studies have detected no consistent benefit to soil physical properties and no increase in crop yield (van der Werf et al. 1991). However, mechanical cultivation may be of most benefit in integrated systems, where the advantages of both herbicide use and mechanical cultivation can be retained.

Herbicide use was reduced 50 to 70 % in an integrated corn system that combined a low concentration of herbicide with one or two cultivations and which gave good weed control and increased yield in corn without affecting cost of production, weed control or yield (Mulder and Doll 1993). Band application of herbicide combined with inter-row cultivation did not affect carrot yield or quality compared with broadcast herbicide application and herbicide inputs were reduced by 50% (Baumann and Slembrouck 1994). The potential reduction from full herbicide application is determined by the width of the band. In a study of carrots, minimization of the band width by cultivating very close to the row did not impact yield (Ascard and Mattsson 1994). In corn, a combination of herbicide at a reduced rate with two cultivations controlled weeds as effectively and increased yield compared with a full rate of herbicide (Buhler et al. 1995).

1.3 Soil physical properties

Cultivation is a physical process that disrupts the soil at the surface to a depth of approximately 15 cm. Cultivation of the soil is used most often in crops grown in rows and so it is the inter-row zone where the opportunity to influence surface water retention and infiltration takes place (Burwell et al. 1966). The random roughness of the soil surface is the measure of the surface microrelief or the irregular peaks and depressions created by aggregation of soil particles. The random roughness of cultivated soil is greater than uncultivated soils (Burwell et al. 1966; Unger 1984; Zobeck and Onstad 1987). Random roughness becomes important during rainfall since more water can collect on an irregular surface compared with a smoother one and this decreases the amount of rain lost to run-off and increases the amount which infiltrates the soil (Burwell et al. 1966; Unger 1984; Zobeck and Onstad 1987). An increase in soil random roughness also decreases water erosion of soil (Unger and Cassel 1991).

Soil bulk density which describes the total porosity and pore size distribution of a soil influences soil water relationships and root development and thus is important in crop growth and development and crop yield (Unger and Cassel 1991). Inter-row cultivation reduces bulk density of soil in the cultivated layer (Coote and Saidak 1984; Unger et al. 1973), but excessive cultivation tends to increase bulk density resulting in decreased soil air space which may limit nutrient uptake (Blake and Aldrich 1955).

There are effects of cultivation which must be considered in the decision whether to use cultivation as a primary method of weed control. Incorrect timing of cultivation may result in soil compaction (Blake and Aldrich 1955). A certain amount of soil compaction is desirable because it improves seed-soil contact, improves contact and penetration of the soil by roots, and reduces water evaporation (Allmaras et al. 1988). However, excessive soil compaction decreases soil porosity, degrades soil aggregation, restricts root penetration and decreases soil drainage, which reduces soil structure and may result in increased disease (Allmaras et al. 1988).

1.4 Crop pathology

Few weed control studies deal directly with the effect of weeding methods on disease incidence. This is a valid component to investigate, since many recent changes in techniques of crop and soil cultivation, introduced for economic reasons, may also have unintentional secondary effects on soil-borne diseases (Shipton 1979). The action of specific mechanical weed control implements that minimize contact between soil and carrot foliage may reduce mycelial infection by *Sclerotinia sclerotiorum* (Finlayson et al. 1989). Cultivation can potentially alter the plant canopy which may influence disease development and spread. In Nebraska, macroclimatic conditions are not conducive for the development of *S. sclerotiorum* on beans, but microclimatic conditions within the crop canopy have been shown to favour it (Blad et al. 1978; Steadman 1983). If cultivation takes place when crops are too large, roots and foliage may be damaged, possibly contributing to reduced growth, stress and/or providing wound sites through which pathogens may enter.

1.4.1 Inoculum potential

Cultivation may be a means to reduce inoculum levels of some pathogenic fungi that form sclerotia. Previous studies have focused on primary tillage, but some aspects of these studies may be applicable to cultivation practices.

Primary tillage studies have shown that fewer sclerotia of *Sclerotinia sclerotiorum* survive when buried under as little as 4 cm of soil compared with those at the soil surface (Merriman 1976; Merriman et al. 1979). The percent of apothecia-producing sclerotia was shown to decrease with increasing depth of burial and apothecial production was slower for sclerotia that had been deeper in the soil (Ben-Yephet et al. 1993). In general, cultivation works the soil deeper than 4 cm, but since the time interval between cultivations is short compared with primary tillage, it is likely that as many sclerotia would be brought to the surface as buried. Another tillage study demonstrated that while fungal sclerotia showed long term survival in both dry and wet soils, exposure to rapid fluctuations in moisture promoted a decline in overall numbers of propagules by retarding formation of secondary sclerotia (Williams and Western 1965). Soil moisture fluctuations occur up to 15 cm below the surface (Williams and Western 1965) and this may be promoted when soil is disturbed during cultivation.

The distribution of white mold (*S. sclerotiorum*) apothecia and disease has been shown to be correlated and spatially aggregated within a bean field (Boland and Hall 1988). Similar patterns of aggregation have been reported for lettuce drop sclerotia and disease incidence within a lettuce field (Subbarao et al. 1996). Deep plowing reduced the absolute numbers of sclerotia, but the distribution of sclerotia within the field became less aggregated and in consequence the disease incidence within the field increased (Subbarao et al. 1996). Sclerotia produce apothecia primarily under a well-developed plant canopy which restricts long-range dispersal (Steadman 1983) and promotes localized infection. Mechanical cultivation may potentially create a more uniform dispersal of infection propagules.

1.4.2 Dispersal mechanisms

Raindrops disperse inoculum from an initial infection source and redistribute it when more raindrops repeatedly strike already dispersed inoculum (Fitt et al. 1989; Reynolds et al. 1987). Plant canopies can reduce the distance rain-dispersed inoculum travels during rainfall. In weed-infested pigeon pea fields, the severity of Phytophthora blight was reduced compared with weed-free conditions, apparently because the dispersal of the pathogen was minimized (Chauhan and Singh 1991). Dispersal patterns of droplets in dense stands of field beans (*Vicia faba*) were substantially smaller compared with leafless stands (Stedman 1980). Soil under a dense canopy may be struck by fewer raindrops than a sparse canopy. Pathogenic propagules may also be wind dispersed. For example, conidia of *Cercospora carotae* can spread throughout crop plants by wind or water splash (Sherf and MacNab 1986). If mechanical cultivation disturbs or thins the plant canopy, it may have more impact on diseases that are typically splash drop dispersed.

1.5 Crop phenology

Agronomic yield is determined by patterns of growth and development that occur on an individual plant basis and at the field level. These patterns of growth can be broadly separated in to four stages: seedling growth, vegetative development, reproductive development and partitioning of dry matter (Sinha 1977). Total dry matter production is determined by basic vegetative development, economic yield potential is determined by reproductive development, and yield realization is determined by the partitioning of plant resources between the two (Sinha 1977).

In snap bean production, the economically important plant product is the pod, produced during reproductive development. In general, legume yields are limited by the number of flowers produced per plant and the proportion of pods set. The amount of vegetative biomass accumulated prior to flowering has also been implicated as a factor which may influence final yields (Egli and Legget 1973).

Cultivation may alter characteristics of the crop plant environment such that growth and developmental stages do not follow those observed in conventional production systems. This is of interest because it may have an impact on crop yield.

2. Description of cultivators

2.1 Rotary hoe. (Yetter Farm Equipment, Colchester, IL, USA).

The rotary hoe is made up of a series of disks with pointed digits. This cultivator uproots small weeds out of the soil and exposes them to desiccating conditions. It works best on firm, dry soil and on weeds just at or before their emergence. The rotary hoe should be used prior to crop emergence or when crop is well-rooted. Optimum operation speed is 7-14 km/h and soil disturbance occurs to a depth of 5 cm.

2.2 Tine harrow. (RabeWerk, Bad Essen, Germany).

Spring loaded tines disturb the soil at approximately 8 cm intervals, with tines raised over the rows and no goosefoot. Tines vibrate back and forth under tension, disturbing the soil and uprooting weeds. Tines can be adjusted independently and can be raised to accommodate crop rows. Operation speed is 2-8 km/h and soil disturbance occurs to a depth of 5-7 cm.

2.3 Torsion weeder. (Bezzerides Brothers Inc.).

The torsion weeder has two components, the "spyders" and the "torsion weeders." Free turning Spyder attachment has staggered teeth that mulch soil in an uneven pattern. Weeds are cut at the stem. The torsion weeders are arranged in pairs and their vibrating action loosens and smoothes the soil surface. The Spyder wheels reduce the formation of dirt clods. Operating speed is 1-3 km/h and soil disturbance occurs to a depth of 5-10 cm.

2.4 Danish tines. (Kongskilde, Denmark).

Cultivation with the Danish tine followed cultivation with the rotary hoe (described above). The Danish tines are 'S' shaped and vibrate over the soil surface. Tines cut and uproot weeds and then bury them. Shields on the row limit soil contact with the crop. Operating speed is 4.5 km/h and soil disturbance occurs to a depth of 10-15 cm.

2.5 Basket wheel hoe. (Buddingh Model K).

The basket wheel hoe has two sets of rolling metal cages that disturb soil along their length and act to break weed stems and strip leaves. The first set of cages are larger in diameter than the second set. The first set of cages turns more slowly than the second set. Cages of the same diameter are available in different widths and can be combined to accommodate different inter-row widths. Operating speed is 2-7 km/h and soil disturbance occurs to a depth of 3-6 cm.

2.6 Rototiller

Fast turning blades chop weeds into pieces. Covers protect the crop plants from blade action and possible soil contact. Operating speed 0.7-1 km/h and soil disturbance occurs to a depth of 9-11 cm.

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STUDIES ON CROP YIELD AND QUALITY

PREFACE TO STUDY I

Studies investigating mechanical weed cultivation effects on crop yield and quality have focused primarily on corn, soybean and potatoes, and recently a few studies have appeared on cultivation in carrots. Typically, only one or two cultivators are studied, but many cultivators are available to producers and their mode of action and effects may differ. The present study was undertaken to investigate if mechanical weed cultivation affects the yield and quality of green bean, carrot and lettuce crops. Four types of cultivators were used in each crop and were compared to weedy and weed-free checks and the standard weed control method. Comparisons were also made among cultivators.

Study I consists of two parts: Part I and Part II. Part I is presented as a complete manuscript, written in a generic format, and it will be rewritten in the format of a particular journal at submission, and references to Part II will be removed. Part II is not presented as a manuscript, but as a complement to the information provided in Part I. The difference between the two parts is that in Part I, the crops were grown using fungicide application programs typically used in Quebec, while in Part II, the crops were grown without fungicide use. The purpose of this was to grow crops under potentially low and high disease pressure, which becomes important in Studies III and IV. Since producers typically use fungicide programs in the production of bean, carrot and lettuce crops, the results from only those crops receiving fungicide applications were reported in the manuscript (Part I). Note, however, that in 1995, environmental conditions were unusually dry and producers utilizing fungicide spraying programs would not have applied fungicide in both bean and lettuce fields followed in this study. In these cases, for 1995 only, Part I thus includes results from bean and lettuce fields that were managed under fungicide programs but did not actually get treated with fungicide.

The "Abstract" pertains only to Part I. The "Introduction" and "Materials and Methods" sections are common to both Part I and Part II but separate "Results," "Discussion," and "References" sections are given for each. To avoid redundancy, the "Discussion" section of Part II outlines only similarities to and differences from the results observed in Part I.

STUDY I. THE EFFECT OF MECHANICAL WEED CULTIVATION ON CROP YIELD AND QUALITY IN SNAP BEAN, CARROT AND LETTUCE CROPS

PART I-CROPS GROWN WITH FUNGICIDE APPLICATION

PART II-CROPS GROWN WITHOUT FUNGICIDE APPLICATION

ABSTRACT: PART I

Several types of cultivators were used as a weed control method to replace or reduce the use of herbicide. For each bean, carrot or lettuce crop, four kinds of mechanical cultivators were tested for effects on crop yield and quality compared with weedy and weed-free checks and the typically used weed control method. Beans were grown on mineral soil without herbicide application and in both years yield, quality and stand in cultivated beans were similar to herbicide treated beans. Cultivated carrots were grown on organic soil with band application of herbicide on the row and in both years had yield, quality and stands similar to the overall surface application of herbicide. Lettuce were grown on organic soil without herbicide and cultivator treatments were compared with the conventional weed control method which involved rototilling and hand-weeding. In both years yield, quality and stands were similar to the conventional treatment. When results were compared among cultivators, effects were not always consistent from one year to the next or among different crops. In general, mechanical cultivation for weed control can be used in bean, carrot and lettuce to replace or complement conventional weed control methods without affecting crop yield and quality.

INTRODUCTION: PART I AND PART II

Mechanical cultivation is primarily used as a method of weed control in row crop production and is of increasing importance in integrated weed management strategies.

Alternatives to herbicides are sought where chemical costs are high, weed control is not complete, herbicides are not permitted for use and/or environmental issues are of concern. Inter-row cultivation may reduce the intensity and frequency of chemical herbicide applications and may also reduce the effort required for hand weeding. In integrated systems on corn crops, herbicide use could be reduced 50 to 70 % without impacting production costs, weed control or yield (Mulder and Doll 1993). Cultivation may help to prevent the establishment of herbicide-resistant weeds and perennial weeds.

Timeliness of cultivation is important in order to avoid negative effects on yield since it is not only the duration of weed competition which may affect crop yield but, perhaps more significantly, the time at which weed competition occurs in crop development. It has been shown that a critical period exists during which crop tolerance to weed competition is low enough to impact on crop yield (Weaver, 1984). Timeliness also refers to the soil conditions at time of cultivation. Soil water content at the time of cultivation is an important aspect of effects on soil physical properties, and improper timing may result in degraded soil properties (Unger and Cassel 1991). Wet soil conditions may also reduce the effectiveness of implements. Rotary hoeing when soil conditions were wet at the time of or after cultivation reduced weed control and soybean yields compared to timely hoeing (Lovely et al. 1958).

In most cultivation experiments, increases in crop yield are attributed to a reduction in weed-crop competition. However, some studies attribute the increase to other factors, such as improved soil water conservation or increased water infiltration. Blake and Aldrich (1955) attributed increased potato and corn yields to improved water conservation over and above the effects of weed competition. Yield increases in corn on soil susceptible to crusting were attributed to increased water infiltration and a reduction in short term water evaporation (Prihar and Van Doren 1967).

Producers often cultivate on a regular basis for reasons other than weed control (Cardwell 1982). Cultivation of crusted soil improves soil aeration and water infiltration which can significantly increase yield and a loosened surface layer may improve soil moisture by impeding the upward movement of capillary water (Blake and Aldrich 1955; Buhler et al. 1995; Prihar and van Doren 1967). Cultivation may also increase available soil nitrogen to varying degrees, depending on the type of soil (Lyon 1922). Soil temperatures in the cultivated layers are higher than below the cultivated layer (Chaudhary and Prihar 1974) and this may contribute to an increase in microfauna activity. The usefulness of cultivation for purposes other than weed control and its impact on soil physical properties varies with crop type, weather, soil texture, soil water content, soil crusting and compaction and timing of cultivation and depth and action of the cultivator (Unger and Cassel 1991).

While in some crop production systems, complete elimination of herbicide application may not be desired, substantial reductions from the current levels used may be achieved by combining inter-row cultivation with band applications of herbicides. When inter-row cultivation was combined with band application on the row, no decrease in carrot yield or quality compared to broadcast herbicide application was observed and yet herbicide inputs were reduced by 50% (Baumann and Slembrouck 1994). The width of the uncultivated strip on the row is the factor which determines the potential reduction in the amount of herbicide required. In a study designed to test if the width of the uncultivated strip could be minimized without an impact on carrot yield, no differences were found between normal cultivation and cultivation very close to the row in weed-free carrots (Ascard and Mattsson 1994). Also, no differences in yield were detected between the two types of mechanical cultivators used in the study. However, there was no consistent influence on yield in cultivated carrots compared to uncultivated, but carrots had been kept weed-free using not only herbicides but also hand-weeding, aspects of which may have had interaction with cultivation treatments. In another study of reduced herbicide input in a conservation tillage system, a combination of one application of herbicide at a reduced rate early in the season with up to two rotary hoe cultivations was shown to give similar weed control and corn yield was increased compared to a full rate of herbicide (Buhler et al. 1995). Few studies have compared the effects among several mechanical cultivators and in particular in vegetable crops such as bean, carrot and lettuce.

The objectives of the present study were firstly to use several types of mechanical weed cultivators in three types of crops to determine if there were effects on crop yield and quality compared to the conventional weed control regime. In bean and carrot crops, the conventional weed control method involves the use of herbicides while in lettuce it involves rototilling at thinning, followed by hand-weeding. We also wanted to compare one mechanical cultivation implement to the next, in order to determine if their affect on yield and quality differed.

Snap bean, carrot and lettuce crops used in this study were chosen in order to assess mechanical cultivation effects on crops characterized by the location of their marketable parts as above ground, at soil level or below ground. Weed control efficiency of treatments is not reported here.

MATERIALS AND METHODS: PART I AND PART II

Field Plan

The green bean field site was located at the Emile Lods Agronomy Research Centre on the Macdonald Campus of McGill University, Ste-Anne-de-Bellevue, Quebec. The soil is a Chateauguay clay loam mineral series. Carrots and lettuce were studied at the Agriculture Canada research substation in Sainte Clotilde, Quebec where the soil is organic muck.

The experimental design was a randomized complete block design with three blocks and seven treatments. In general, treatments included a weedy check which was not weeded, a weed-free check that was manually weeded, a typical chemical herbicide regime, and a selection of four mechanical cultivators chosen for suitability to the particular crop and soil. Cultivation was conducted as required for weed control only and so the number of cultivation events in each crop and year represents the minimum required for sufficient weed control (Table 1.1). No herbicides are registered for use on lettuce, but the limitations of the conventional weed control system involve the rototiller which limits production because of its slow working speed, the high effort required for manual weeding and its negative impact on soil properties.

Sites were fall plowed. Fertilization took place in the spring, in accordance with soil nutrient analyses. Crops were treated with the conventional fungicide regime (Part I only) and as necessary for insect outbreaks. Fields receiving fungicide applications were located down wind of fields not receiving fungicide, at approximately 20 - 50 m distant. Crops were inspected biweekly, to determine when to begin fungicide application.

Green beans, Macdonald site, mineral soil, 1995 and 1996

Bean (*Phaseolus vulgaris* L. cv Hialeah) seeds were sown in 1995 on June 7 and in 1996 on May 31, 25 seeds per meter with a precision seeder 25 to 30 mm deep. Rows were spaced at 65 cm intervals and each of the treatment plots was 6 rows wide. The total surface area for each block was 27.3 m by 11 m.

Bean treatments at Macdonald site

The following treatments were performed: 1. weedy check; 2. weed-free check using hand-pulling and hoeing; 3. conventional chemical: post-emergence 1.75 L/ha + 2.0 L/ha Bentazon + Assist (to enhance adhesion of herbicide to foliage) in 300 L water at first trifoliate. Bentazon controls certain broadleaf weeds and sedges; 4. rotary hoe (Yetter) 10-11 km/h, depth 5 cm; 5. tine harrow (RabeWerk) 8 km/h, depth 5 cm; 6. torsion weeder (Bezzerides torsion weeder with Spyders) 1 km/h, depth 5-10 cm; 7. rotary hoe (Yetter) to 4 true leaves, then Danish tines (Kongskilde) 4.5 km/h, depth 10-15 cm.

Beans were manually harvested on 2 m in the centre 2 rows of each plot. Harvest was conducted every 2-3 days until pod production finished. Only those pods deemed of market size were picked on any given harvest day. In 1995, beans were harvested on July 24, 26, 28, 31, August 1, 4, 7, 10, 14, 17 and 21 and in 1996 harvested on July 22, 24, 26, 29, August 1, 5, 8 and 12. Once picked, pods were classified by diameter, length, form and blemish or disease. Pods in each category were then counted and weighed. Canada A category included well formed beans in size class diameters 2 (5.7-7.3 mm), 3 (7.3-8.3 mm), or 4 (8.3-9.5 mm). Canada B category included curved beans or scarred beans and well formed beans in size classes 1 (4.7-5.7 mm), 5 (9.5-10.7 mm) or 6 (>10.7 mm) (LaFlamme et al. 1995). Cull category included beans that were diseased or insect damaged. One week after harvest, ten plants in each of the yield rows were randomly chosen, cut off at the soil line, placed in cloth bags and dried for 48 h at 75°C and average dry weight (g) was determined.

Fungicide application (Part I only)

In 1995, environmental conditions and crop appearance did not require fungicide application. In 1996, beans were sprayed on July 11 with Benlate (Benomyl 50%) at the rate of 1.75 kg/ha.

Carrots, Ste. Clotilde, organic soil, 1995 and 1996

Carrot (*Daucus carota* L. sativus cv. Six Pak II) seeds were sown in 1995 on May 31 and in 1996 on May 21, 12 to 20 mm deep at a density of 100 seeds per meter with a precision seeder that places three seeds across a band 75 mm wide. Rows were spaced at 60 cm and each treatment plot was 6 rows wide. The total surface area for each block was 25.2 m by 11 m. A 15 cm band of herbicide (linuron 3.25 kg/ha) was sprayed on the row post-emergence at the 4-5 leaf stage in 1995 and pre-emergence in 1996.

Carrot treatments at Ste. Clotilde

The following treatments were performed: 1. weedy check; 2. weed-free check using hand-pulling and hoeing; 3. conventional chemical: linuron pre-emergence at 3.25 kg/ha in 205 L water and post-emergence at 3.25 kg/ha in 205 L water when carrots 8 cm in height; 4. tine harrow (RabeWerk) 3-7 km/h, depth 3-7 cm; 5. basket wheel hoe

(Buddingh Model K) 2-7 km/h, depth 3 to 5 cm; 6. torsion weeder (Bezzerides Torsion weeder and Spyders) 2-3 km/h, depth 5-7 cm; and 7. rototiller 1 km/h, depth 9-11 cm.

Carrots were manually harvested in 1995 on Sept. 5-7 and in 1996 on Sept. 20-23, on two 2 m sections from the centre rows of each plot. Carrot roots from each row were classified by crown size and appearance into either Canada No. 1 (19.8 mm to 38.1 mm), Jumbo (>38.1 mm), Small (<19.8 mm or <114.8 mm long) or Cull (deformity, forking, disease or pest damage). Roots in each category were then counted and weighed and are presented as tonnes per hectare and number per hectare.

Fungicide application, (Part I only)

Starting in July, carrot crops were inspected biweekly to monitor foliage diseases. Five carrots from each treatment plot were inspected for symptoms of *Cercospora carotae* and if symptoms were present, fungicide spraying was initiated (Part I). In 1995, the fungicide Dithane DG at 2.25 kg/ha was applied seven times (July 21, 29, August 5, 10 17 and 25) and in 1996, eight times (July 18, 23, 28, and August 7, 17, 22, 30).

Lettuce, Ste. Clotilde, organic soil, 1995 and 1996

Lettuce (*Lactuca sativa* L. cv. Ithaca) seeds were sown in 1995 on May 19 and in 1996 on May 21, at 10 seeds per meter with a precision seeder 10 to 20 mm deep. Lettuce were later thinned to 5 per meter. Rows were spaced at 45 cm and each of the treatment plots was 8 rows wide. The total surface area for each block was 9 m by 31 m.

Lettuce treatments at Ste. Clotilde

The following treatments were performed: 1. weedy check; 2. weed-free check using hand-pulling and hoeing; 3. conventional: rototiller at thinning, followed by manual weeding; 4. tine harrow (RabeWerk) 2-6 km/h, depth 3-7 cm; 5. basket wheel hoe (Buddingh) 2-6 km/h, depth 4-6 cm; 6. torsion weeder (Bezzerides) 1-3 km/h, depth 7-8 cm; and 7. rototiller 1 km/h, depth 9 cm.

Lettuce were manually harvested in 1995 on July 13 and in 1996 on July 18, from 2 m sections on the 4 middle rows and then classified into either Canada No. 1 or Cull categories. Canada No. 1 category lettuce is firm, well shaped, of good color and free of blemish or disease and weighs >450 g. Cull lettuce is small (<450 g), deformed, diseased or blemished. For each classification lettuce number and fresh weight were recorded.

Fungicide application, (Part I only)

In 1995, environmental conditions and crop appearance did not require fungicide application. In 1996, Dithane DG was sprayed at 860 L/ha on June 29 and July 7.

Statistical Analyses

Analysis of variance was analyzed using the general linear model (GLM) of Statistical Analysis System (SAS Institute Inc., Cary, NC). Data were log or square root transformed when necessary to satisfy homogeneity of variance. Where treatment effects were significant ($P<0.05$) differences among means were detected using Duncan's least significant differences test.

RESULTS: PART I

Beans 1995. In the weedy check, yield, quality and number of pods per hectare were significantly decreased compared to all other treatments (Table 1.2). There were no statistically significant differences among the other six treatments, but cultivation with the torsion weeder and rotary hoe (+Danish) had the highest yields and highest Canada A yield compared to all other treatments, including the herbicide treatment. The mean dry weight per plant did not significantly differ among treatments (Table 1.3).

Beans 1996. Yield and number of pods per hectare were significantly reduced ($P<0.05$) by the weedy check compared to the weed-free, herbicide, tine and rotary (+Danish) treatments (Table 1.4). However, yield and number of pods in the rotary and torsion treatments did not differ from the weedy check. The weed-free check and cultivations with the tine harrow and rotary hoe (+ Danish) gave yields similar to the herbicide treatment. Canada A yield was increased in the weed-free, herbicide, tine harrow and rotary hoe (+Danish) treatments, but yields were decreased in the weedy check and cultivations with the rotary hoe and torsion weeder. The increased amount of cull in 1996 compared to 1995 was a result of high incidence of white mold (*S. sclerotiorum*).

The mean dry weight of plants in the weed-free treatment was significantly higher than all other treatments (Table 1.3). Cultivation implements that had significantly reduced bean stands also had the lowest mean biomass per plant.

Beans 1995 and 1996. Differences among mechanical implements did not differ significantly in 1995, but torsion and rotary (+Danish) treatments improved yield and quality. In 1996, the tine harrow significantly increased yield and quality and results were similar with the rotary hoe (+Danish). The torsion weeder and rotary hoe alone produced significantly lower yield and quality compared to the tine harrow.

Carrots 1995. The weedy treatment significantly decreased carrot yield and quality (Table 1.5). The weed-free treatment had the highest yield, but it did not significantly differ from other treatments except the tine harrow. The herbicide treatment increased Canada No. 1 yield, but this did not differ significantly from cultivation treatments except the tine harrow. The number of roots per hectare for all treatments were significantly low compared to the herbicide treatment.

Carrots 1996. The weedy treatment significantly decreased carrot yield and quality (Table 1.6). Total yields were higher with cultivation by basket hoe and torsion weeder, but these did not differ significantly from other treatments. Also, yield of Canada No. 1 carrots did not differ, but the herbicide treatment had a higher yield than mechanical cultivation treatments, of which basket hoe was the highest. The rototiller treatment significantly increased cull levels over that of the herbicide treatment. The total number of roots per hectare did not differ among treatments.

Carrots 1995 and 1996. Differences among treatments were not detected for most variables. Differences among mechanical implements did not differ significantly in either year, but best quality in both years was with basket hoe cultivation, while the rototiller gave highest total yields in 1995 and the torsion weeder gave highest total yield in 1996.

Lettuce 1995. The weedy check significantly decreased lettuce yield and quality (Table 1.7). Total yield was highest in the torsion and conventional treatments, but this was not significantly different from other treatments. The quality of the yield was significantly increased by cultivation with the torsion weeder compared to basket hoe, but other treatments were similar.

Lettuce 1996. The weedy check significantly decreased lettuce yield and quality (Table 1.8). Total yield was highest in the torsion treatment. Canada No.1 yield was highest in the standard treatment, but these were not statistically different from other treatments. High levels of cull in 1996 reflect the high incidence of downy mildew in the field.

Lettuce 1995 and 1996. Differences among mechanical implements did not differ significantly in either year, but for both years cultivation with the torsion weeder increased total yield and in 1995 increased quality compared to other mechanical treatments.

Cultivator actions on different crop types and soil types

Although data for the depth to which cultivation disturbed the soil were available for only the 1996 season and in general, few differences among yields and quality were detected, some generalizations can nevertheless be made about implement performance.

Cultivation in beans on mineral soil.

The rotary hoe disturbed soil to approximately 5 cm and the Danish tines 10-15 cm. The rotary hoe works by uprooting germinating weeds and exposing them to desiccating conditions while the Danish tine cuts, uproots and buries weeds that are more developed. Cultivation with the rotary hoe 2 or 3 times plus once with the Danish tines improved yield in both years, over rotary hoe alone. The torsion weeder with Spyders disturbed the soil surface to a depth of 5-10 cm. The free turning Spyder attachment had staggered teeth that mulched soil and cut weeds in an uneven pattern, while the torsion attachment loosened and smoothed the soil. In wetter conditions, uneven soil penetration and formation of dirt clumps were observed. Spring loaded tines on the tine harrow disturbed mineral soil to a depth of 5 cm. Tines vibrate back and forth under pressure and uproot weeds. In the drier year tines could not break the soil crust and may not have disturbed the crusted soil surface as efficiently as a soil with higher water content.

Cultivation in carrots and lettuce on organic soil

The basket wheel hoe implement has two sets of rolling metal cages that disturb soil to a depth of 3-5 cm. Weeds are killed by a lateral slicing motion. In the wetter year, some clumps of soil were observed turning with the cages, but were broken up as the second set of baskets passed by. Unlike results seen in beans on mineral soil, cultivation in carrots on organic soil with the torsion weeder (5-8 cm penetration) gave better yields in the wetter season, while in lettuce it gave similar results in both years. The rototiller has blades which slice and cut weeds into pieces and disturbs soil to a depth of 9-11 cm. Covers protect the crop plants from blade action and possible soil contact. Rototiller effects were beneficial to carrots in drier conditions and lettuce in wetter conditions.

Dominant Weed Species

At Macdonald Farm, mineral soil, dominant weed species included *Amaranthus retroflexus* L., *Chenopodium album* L., *Echinochloa crusgalli* (L.) Beauv., and *Panicum capillare* L. At Ste Clotilde, organic soil, dominant weed species included *Amaranthus retroflexus* L., *Chenopodium album* L. and *Galinsoga ciliata* (Raf.) Blake.

Table 1.1. Number of cultivation events per crop in 1995 and 1996. The total amount of precipitation occurring over the period of cultivation is also given.

IMPLEMENT	Bean		Carrot		Lettuce	
	1995	1996	1995	1996	1995	1996
Rotary hoe	3	3	-	-	-	-
Tine harrow	3	3	7	5	6	4
Torsion weeder	3	2	5	4	3	2
Rotary hoe + Danish tines	2 + 1	3 + 1	-	-	-	-
Basket hoe	-	-	5	5	4	3
Rototiller	-	-	3	2	1	1
Rainfall (mm)	0.0	75.7	75.9	187.1	29.0	83.0

Table 1.2. Bean harvest at Macdonald, 1995. Mineral soil. Tonnes per hectare and pod x 1000 per hectare. Numbers in brackets are percent Canada A of total harvest.

TREATMENT	Yield t/ha				#/ha x 10^3
	Canada A	Canada B	Cull	Total	Total
Weedy check	7.75 a (56.6)	5.53 a	0.43 ab	13.68 a	3019.2 a
Weed-free	12.35 b (61.8)	7.35 b	0.28 b	20.00 b	4187.5 b
Herbicide	11.55 b (61.2)	6.97 b	0.35 b	18.87 b	4214.42 b
Rotary hoe	11.50 b (60.4)	7.15 b	0.42 ab	19.05 b	3988.45 b
Tine harrow	11.10 b (59.3)	7.22 b	0.42 ab	18.73 b	3923.05 b
Torsion weeder	13.90 b (65.0)	6.87 b	0.63 a	21.37 b	4424.02 b
Rotary hoe + Danish tines	12.83 b (62.5)	7.40 b	0.27 b	20.52 b	4449.02 b

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 1.3. Mean aboveground biomass (g) of bean plants. Macdonald, 1995 (n=80) and 1996 (n=60). Mineral soil.

TREATMENT	**Biomass (g)**	
	1995	**1996**
Weedy check	15.11 a	12.00 a
Weed-free	20.57 a	18.64 b
Herbicide	18.11 a	14.37 a
Rotary hoe	22.80 a	11.77 a
Tine harrow	20.19 a	13.35 a
Torsion weeder	22.28 a	10.70 a
Rotary hoe + Danish tines	19.11 a	13.24 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 1.4. Bean harvest at Macdonald, 1996*. Mineral soil. Tonnes per hectare and pod per hectare x 1000. Numbers in brackets are percent Canada A of total harvest.

TREATMENT	Yield t/ha				#/ha x 10^3
	Canada A	Canada B	Cull	Total	Total
Weedy check	4.70 ab (39.9)	3.24 a	3.78 a	11.78 a	2990.00 a
Weed-free	7.36 c (35.2)	4.68 b	8.86 d	20.90 d	4951.33 e
Herbicide	6.35 bc (34.6)	4.19 ab	7.84 bd	18.37 bd	4279.33 be
Rotary hoe	4.16 a (32.0)	3.12 a	5.72 c	13.00 ac	3183.33 ad
Tine harrow	6.67 c (38.3)	3.78 ab	6.99 bc	17.43 b	4152.67 bce
Torsion weeder	4.66 ab (34.2)	3.28 a	5.69 c	13.63 ac	3400.00 acd
Rotary hoe + Danish tine	5.89 abc (36.4)	3.59 a	6.68 bc	16.17 bc	3897.33 bcd

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

*The ANOVA table for this analysis is shown in the appendix (A.I).

Table 1.5. Carrot harvest, Ste. Clotilde, 1995. Organic soil. Tonnes per hectare and number of roots x 1000 per hectare. Numbers in brackets are % Canada Number 1 of total harvest.

TREATMENT	Yield (t/ha)					#/ha x 10^3
	Can.#1 (%)	Small	Jumbo	Cull	Total	Total
Weedy check	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 c
Weed-free	37.47 b (60.7)	1.10 ab	12.22 c	10.90 b	61.69 c	715.27 b
Herbicide	45.13 c (73.8)	2.35 c	5.24 ab	8.46 b	61.18 c	926.37 a
Tine harrow	36.36 bc (67.7)	1.84 bc	5.88 ab	9.60 b	53.69 b	687.47 b
Basket hoe	41.66 bc (70.5)	0.94 ab	7.43 bc	9.06 b	59.10 bc	720.83 b
Torsion weeder	41.78 bc (73.3)	1.76 bc	5.14 ab	8.33 b	57.01 bc	776.37 b
Rototiller	38.94 bc (65.0)	0.89 ab	10.81 bc	9.24 b	59.88 bc	683.33 b

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 1.6. Carrot harvest at Ste. Clotilde, 1996*. Organic soil. Tonnes per hectare and number per hectare x 1000. Numbers in brackets are % Canada Number 1 of total harvest.

TREATMENT	Yield t/ha					#/ha x 10^3
	Can.#1 (%)	Small	Jumbo	Cull	Total	Total
Weedy check	14.17 a (50.6)	6.83 a	0.60 a	6.41 c	28.00 a	948.67 a
Weed-free	32.17 b (41.4)	2.63 b	18.63 b	24.17 ab	77.63 b	918.00 a
Herbicide	39.43 b (51.4)	2.48 b	17.57 b	17.13 b	76.67 b	979.00 a
Tine harrow	35.17 b (47.6)	2.29 b	14.07 b	22.43 ab	73.97 b	952.67 a
Basket hoe	37.23 b (47.4)	2.32 b	14.47 b	24.53 ab	78.50 b	941.67 a
Torsion weeder	32.33b (41.0)	2.81 b	19.70 b	24.10 ab	78.93 b	941.67 a
Rototiller	31.70 b (41.3)	2.97 b	14.13 b	27.87 a	76.67 b	1069.33a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

*The ANOVA output for this analysis is shown in the appendix (A.II).

Table 1.7. Lettuce harvest, Ste. Clotilde, 1995. Organic soil.
Numbers in brackets are % Canada No.1 of total harvest.

TREATMENT	Yield t/ha			#/ha x10^3
	Can.#1 (%)	Cull	Total	Total
Weedy check	0.00 c (0.00)	8.25 a	8.25 a	56.48 a
Weed-free	30.28 ab (76.7)	9.18 a	39.46 b	61.11 a
Rototiller + manual	31.40 ab (77.9)	8.90 a	40.30 b	62.96 a
Tine harrow	28.46 ab (84.0)	5.43 a	33.89 b	60.19 a
Basket hoe	24.35 b (65.2)	12.98 a	37.34 b	63.89 a
Torsion weeder	35.81 a (87.0)	5.32 a	41.13 b	61.11 a
Rototiller	28.67 ab (76.2)	8.94 a	37.61 b	61.11 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 1.8. Lettuce harvest, Ste. Clotilde, 1996*. Organic soil. Numbers in brackets are % Canada No.1 of total harvest.

TREATMENT	Yield t/ha			#/ha x10^3
	Can. #1 (%)	Cull	Total	Total
Weedy check	0.00 a (0.00)	23.79 a	23.79 a	64.82 a
Weed-free	19.58 b (46.7)	22.37 a	41.96 b	59.26 a
Rototiller + manual	24.70 b (61.3)	15.58 a	40.28 b	63.89 a
Tine harrow	20.19 b (53.7)	17.41 a	37.60 b	61.11 a
Basket hoe	20.44 b (53.6)	17.66 a	38.11 b	56.48 a
Torsion weeder	19.69 b (46.2)	25.26 a	42.66 b	61.11 a
Rototiller	19.64 b (48.6)	20.77 a	40.41 b	64.81 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

*The ANOVA output for this analysis is shown in the appendix (A.III).

DISCUSSION: PART I

Weed control is necessary in bean, carrot and lettuce production since significant decreases occur in crop yield and quality without weed control measures. In all cases, crop yield and quality were negatively affected by the presence of weeds. In general, when mechanical weed cultivation was used, crop yield and quality were similar to the conventional weed control methods. Also, mechanical cultivation results did not differ from those of the uncultivated weed-free check. However, it is difficult to interpret cultivated versus uncultivated effects since the hand-pulling and hoeing of the soil in the weed-free check may have mimicked the physical effects of cultivation on soil physical properties. In the weed-free checks, the hand-pulling and hoeing of weeds continued farther into the growing season than cultivation, and this may have alleviated surface crusting and allowed better water infiltration. In a study where potato and corn were maintained weed-free without soil scraping or hoeing, consistently higher yields were observed in the cultivated crops compared with uncultivated (Blake and Aldrich 1955).

Even though few differences were detected among cultivators, some trends could be identified. In general, the performance of cultivators from one year to the next were not consistent, the primary cause of which may be related to the differences in precipitation patterns between years. In 1995, total rainfall during the weeks in which cultivation occurred was less than half of that observed in 1996. However, performance of cultivators did not vary with precipitation alone, but also with crop type and/or soil type. In general, in beans on mineral soil, deeper penetrating cultivation tended to give better yields in the drier year, and in the wetter year, shallower cultivation was better as long as soil clumping did not occur. Large soil clumps may have caused damage to crop plants or increased contact between plant and soil which has been shown to affect crop quality by increasing the incidence of white mold (Bottenberg et al. 1997). However, in carrots on organic soil, a relatively shallow cultivation with the basket wheel hoe or torsion weeder gave better results in both dry and wet years compared to deeper cultivation with the rototiller. Deeper cultivation may be more aggressive on young, developing taproots which may fork or stub when cut or exposed to compacted soil (Olymbios and Schwabe 1977; White and Strandberg 1978). In lettuce, a relatively deeper cultivation (compared to others in lettuce) with the torsion weeder gave better results in both years. Cultivation may cause root pruning of shallow roots but may have no effect on over all root weight or may even increase it (Prihar and van Doren 1967). These variations may be the sum of cultivation physical effects directly on plants and differences in soil properties and types.

In only two cases did mechanical cultivation affect crop stands, compared to herbicide application. In 1995, the excessively high weed population in the carrots required the application of herbicide over the row. Stand loss in all plots but the one with standard preemergence herbicide application was observed when herbicide was applied postemergence directly on the row at the 4-5 leaf stage. Carrots were too young and the herbicide caused some thinning. Thus, mechanically cultivated carrots had a significantly lower number of roots per hectare but their weight was not similarly affected. In 1996, beans cultivated with the rotary hoe and torsion weeder had a significantly lower number of pods per hectare, which corresponded with their significantly lower crop yield and quality. It is difficult to know whether the lower number of pods per hectare is due to direct damage or thinning by cultivators. Bean plants growing under higher seeding densities have been shown to have a decreased mean number of pods per plant and an increased number of abscised pods (Malk et al. 1993). Inconsistencies in crop stand response to cultivation from one year to the next and one study to the next have been reported elsewhere (Burnside et al. 1993; Burnside et al. 1994).

Mechanical cultivators operate differently under wet and dry conditions, in different soil types and for different crops. Nevertheless, consistent reductions in herbicide usage can be achieved in carrot and bean crops without significant yield, quality or stand losses. Herbicide use can be reduced by 63% in carrots and by 100% in beans. In lettuce production, input costs can be reduced by using cultivators that operate at much higher speeds than the conventional implement, which may subsequently reduce the manual weed control effort. In most experiments cultivation yield and quality exceeded conventional production methods and while these increases were not statistically significant, they may nevertheless represent important economic benefits.

RESULTS: PART II

Beans 1995. Since beans did not receive fungicide application in 1995, and fields designated "with fungicide application" and "without fungicide application" did not statistically differ, results were combined and were presented in Part I above.

Beans 1996. Weeding treatments did not affect the tonnes of pods or number of pods per hectare (Table 1.9). Also, the mean dry weight of plants was not affected (Table 1.10).

Carrots 1995. The weedy treatment significantly decreased carrot yield and quality (Table 1.11). Cultivation with the basket wheel hoe and/or the rototiller had the highest yield, but it did not significantly differ from other cultivation treatments. It was higher compared to the herbicide treatment. Treatments did not affect the weight of carrot roots in the Canada No. 1 yield category, but the torsion weeder treatment was higher. The total number of roots per hectare did not differ among treatments.

Carrots 1996. The weedy treatment significantly decreased carrot yield and quality (Table 1.12). Total yields were higher with the herbicide treatment and cultivation by basket hoe, but these did not differ significantly from other treatments. Also, yield of Canada No. 1 carrots did not differ, but the herbicide treatment had a higher yield than mechanical cultivation treatments. The number of roots per hectare did not differ.

Carrots 1995 and 1996. Differences among treatments were not detected for most variables. Differences among mechanical implements did not differ significantly in either year. Cultivation with the basket hoe or rototiller were beneficial to total yield and quality in 1995 and in 1996 it was with the basket hoe.

Lettuce 1995. Lettuce did not receive fungicide application in 1995, but fields designated "with fungicide application" and "without fungicide application" statistically differed for the cull category (P>0.05) and so field results were presented separately (in Part I above and here in Part II). Differences in the thinning of lettuce between the two fields may have influenced the differences in cull lettuce.

The weedy check significantly decreased lettuce yield and quality (Table 1.13). Total yield was highest in the weed-free check and this significantly differed from cultivation with the tine harrow. All other treatments gave a similar total yield. The quality of the yield was not significantly affected by weeding treatments, but the weed-free treatment had higher Canada No. 1 lettuce.

Lettuce 1996. The weedy check significantly decreased lettuce yield (Table 1.14). Total yield was highest in the hand-weeded check, but this was not significantly different from the conventional treatment or cultivation with the torsion weeder. Significant differences were not detected in the Canada No. 1 yield, but the hand-weeded check was highest.

Lettuce 1995 and 1996. Differences among treatments were detected only in total yields and in both years, the hand-weeded check had the highest yields. Differences among implements did not differ significantly in either year, but in 1995 quality and yield were better with the basket hoe and in 1996, with the rototiller and torsion weeder respectively.

Table 1.9. Bean harvest at Macdonald, 1996. Mineral soil. Fungicide was not applied. Tonnes per hectare and pod per hectare x 1000. Numbers in brackets are percent Canada A of total harvest.

TREATMENT	**Yield t/ha**				**#/ha x 10^3**
	Canada A	**Canada B**	**Cull**	**Total**	**Total**
Weedy check	6.45	3.45	5.19	15.09	3742.67
Weed-free	8.51	4.40	6.95	19.85	4519.33
Herbicide	6.59	3.54	6.01	16.14	3576.67
Rotary hoe	5.53	3.34	4.84	13.71	3305.33
Tine harrow	8.60	4.85	7.48	20.93	4952.67
Torsion weeder	5.32	3.54	5.14	14.00	3460.33
Rotary hoe + Danish tine	5.20	3.04	5.96	14.19	3301.33

No significant differences (P>0.05) according to Duncan's multiple range test.

Table 1.10. Bean harvest at Macdonald Farm 1996. Mineral soil. Fungicide was not applied. Numbers represent the average dry weight (g) of one bean plant (n=30).

TREATMENT	Biomass (g)
Weedy check	11.98
Weed-free	13.79
Herbicide	12.88
Rotary hoe	10.50
Tine harrow	13.07
Torsion weeder	9.85
Rotary hoe + Danish tine	11.81

No significant differences (*P*>0.05) according to Duncan's multiple range test.

Table 1.11. Carrot harvest, Ste. Clotilde, 1995. Organic soil. Fungicide was not applied. Tonnes per hectare and number of roots x 1000 per hectare. Numbers in brackets are % Canada Number 1 of total harvest.

Treatment	**Yield t/ha**					**#/ha x 10^3**
	Can.#1 (%)	**Small**	**Jumbo**	**Cull**	**Total**	**Total**
Weedy check	0.00 a (00.0)	1.51 a	0.00 a	0.00 a	1.51 a	506.93 a
Weed-free	25.52 b (60.0)	0.45 a	5.25 a	11.32 b	42.54 c	594.43 a
Herbicide	23.83 b (68.7)	2.00 a	0.45 a	8.41 b	34.69 b	720.83 a
Tine harrow	26.14 b (63.9)	1.10 a	2.85 a	10.84 b	40.93 bc	598.60 a
Basket hoe	25.59 b (60.7)	1.42 a	4.85 a	10.26 b	42.13 c	663.90 a
Torsion weeder	27.78 b (67.7)	1.94 a	2.76 a	8.56 b	41.01 bc	745.80 a
Rototiller	27.42 b (65.8)	1.59 a	5.58 a	7.72 b	42.32 c	706.93 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 1.12. Carrot harvest at Ste. Clotilde, 1996. Organic soil. Fungicide was not applied. Tonnes per hectare and number per hectare x 1000. Numbers in brackets are % Canada Number 1 of total harvest.

TREATMENT	Can. #1 (%)	Yield t/ha				#/ha x 10^3
		Small	Jumbo	Cull	Total	Total
Weedy check	13.18 a (41.8)	7.75 a	0.38 d	10.15 a	31.50 a	959.67 a
Weed-free	20.47 a (36.4)	3.53 b	6.63 ab	25.63 a	56.27 b	863.67 a
Herbicide	31.77 a (52.3)	3.53 b	5.50 abc	19.93 a	60.73 b	1104.00 a
Tine harrow	21.87 a (40.9)	4.55 ab	4.58 bc	22.53 a	53.50 b	916.67 a
Basket hoe	24.10 a (39.7)	3.45 b	8.17 a	24.93 a	60.63 b	948.67 a
Torsion weeder	21.47 a (36.1)	4.61 ab	5.65 abc	27.80 a	59.53 b	1005.67 a
Rototiller	23.83 a (44.6)	6.42 ab	3.04 cd	20.13 a	53.40 b	948.33 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 1.13. Lettuce harvest, Ste. Clotilde, 1995. Fungicide was not applied. Organic soil. Numbers in brackets are % Canada No.1 of total harvest.

	Yield t/ha			#/ha x 10^3
TREATMENT	**Can. #1 (%)**	**Cull**	**Total**	**Total**
Weedy check	0.00 a (00.0)	12.32 a	12.32 c	55.56 a
Weed-free	39.00 b (75.6)	12.58 a	51.58 a	63.89 a
Rototiller + manual	28.58 b (69.9)	12.33 a	40.91 ab	61.11 a
Tine harrow	30.84 b (78.1)	8.64 a	39.47 b	59.73 a
Basket hoe	36.05 b (72.4)	13.72 a	49.77 ab	69.44 a
Torsion weeder	34.25 b (74.2)	11.88 a	46.13 ab	58.34 a
Rototiller	34.85 b (75.4)	11.35 a	46.21 ab	62.50 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 1.14. Lettuce harvest, Ste. Clotilde, 1996. Fungicide was not applied. Organic soil. Numbers in brackets are % Canada No.1 of total harvest.

	Yield t/ha			#/ha x 10^3
TREATMENT	**Can. #1 (%)**	**Cull**	**Total**	**Total**
Weedy check	7.89 a (32.4)	16.45 a	24.34 d	59.26 a
Weed-free	33.87 a (74.5)	11.57 a	45.45 a	60.19 a
Rototiller + manual	28.45 a (70.5)	11.89 a	40.33 ab	64.82 a
Tine harrow	20.67 a (61.5)	12.96 a	33.62 bc	58.33 a
Basket hoe	19.46 a (61.5)	12.20 a	31.66 c	53.70 a
Torsion weeder	22.77 a (58.2)	16.37 a	39.15 abc	63.89 a
Rototiller	25.72 a (72.7)	9.66 a	35.39 bc	61.11 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

DISCUSSION: PART II

Although crops were intentionally grown in a manner that producers would not normally follow, this study nevertheless provides valuable information about treatment effects at potentially higher disease pressures and it is useful for organic growers. Variability in disease levels occurs from one year to the next even when fungicidal applications take place (Hunter et al. 1978).

Weed control is a must in bean, carrot and lettuce production since significant decreases occur in crop yield and quality when no weed control measures are used. In carrot and lettuce crops where fungicide was not applied, yield and quality were reduced by the presence of weeds. In beans, weeds had no effect on bean yield, quality and biomass, but the weedy check was consistently lower than the herbicide treated check.

Mechanical weed cultivation treatments did not differ from those of the uncultivated herbicide treatment nor weed-free check, as observed in Part I. However, as explained earlier, soil surfaces of "uncultivated" weed-free checks may be disturbed in a similar manner during cultivation. Such weed-free checks are thus not necessarily uncultivated (Blake and Aldrich 1955).

There were no statistically significant differences among treatments that received cultivation with different machines, although some trends could be detected. Within each crop, performance of cultivators from one year to the next was not consistent, as seen in Part I. In general, cultivator performance in the bean and carrot crop was similar to that observed in Part I. In beans in the wetter year, the tine harrow gave better results. In carrot, overall for both years, the basket hoe gave better results. Cultivator performance in the lettuce crops was not similar to observation in Part I where the torsion weeder gave better results in both years. However, in this part of the study the torsion weeder's performance was second to the basket hoe in the dry year. In the wetter, year the torsion weeder had higher yields among cultivators, but in Canada No 1 lettuce it was lower than the rototiller because it was the treatment with the highest Cull. It is difficult to determine what might be the explanation for the inconsistencies among cultivator performance in lettuce between Part I and Part II of the study. Fields were located close to one another on the site. Fungicide application alone cannot account for the difference in these trends, since in the drier year fungicide was not even applied to lettuce, and furthermore, in beans and carrots, cultivator performance did not vary whether fungicide was or was not applied. None of the cultivation treatment effects were statistically different anyhow, but even small increases of one or two tonnes per hectare may represent a significant economic increase.

These results support the findings of Part I. Mechanical cultivation did not significantly affect crop yield and quality. Mechanical cultivators performed differently in dry and wet conditions, in different soil types and for different crops. In general, relative performance rankings of cultivators were similar to those observed in Part I, with the exception of lettuce. Mechanical weed cultivation performed just as well in the absence of fungicide. Cultivation treatments did not differ significantly from the conventional herbicide treatments and thus cultivation can be used as an opportunity to eliminate herbicide use in bean crops, decrease use in carrot crops and to provide alternatives to the conventional weed control method used in lettuce.

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STUDIES ON DISEASE INCIDENCE

PREFACE TO STUDY II

Mechanical cultivation is a physical process of weed control in the inter-row. In most studies, mechanical cultivation is assessed for efficacy of weed control and subsequent impacts on crop yield and quality, but there may be other valuable reasons to cultivate beyond agronomic aspects. There may be contact between crop foliage or roots and the cultivator which may impact on crop pathology (Finlayson et al. 1989; Vangessel et al. 1995; Prihar and van Doren 1967; van der Werf 1991). Cultivation alters soil physical properties in the inter-row and this may also influence disease levels (Perry 1983). Determining whether mechanical cultivation influences disease incidence might provide valuable reasons to cultivate even if weed control or crop yield and quality are not improved.

STUDY II. THE EFFECT OF MECHANICAL WEED CULTIVATION ON DISEASE INCIDENCE IN SNAP BEAN, CARROT AND LETTUCE CROPS

ABSTRACT

Several types of cultivators were used as a weed control method to replace or reduce the use of herbicide. Within each bean, carrot or lettuce crop, four kinds of mechanical cultivators were tested for effects on disease incidence in fields where disease pressure was potentially low (fungicide application programs were followed) or high (fungicide was not applied). In one year, which was unusually dry, bean and lettuce crops were virtually disease free. In the second year, beans were affected by white mold and lettuce by downy mildew. In both years, carrots were affected by Cercospora blight.

The tonnes per hectare of beans with white mold symptoms were significantly reduced by cultivation in one field and reduced, but not significantly in another. The increase in white mold was correlated to the number of days the treatment lasted. The level of Cercospora blight was not affected by weeding treatments in 1995, but in 1996 cultivation with the tine harrow significantly reduced the percent of leaf area affected by disease. In one case, increased disease was correlated to the number of days weeding lasted, but in another it was not. Cultivation increased the number of lettuce with basal rot in one field and decreased the severity in another.

INTRODUCTION

Incomplete control of some of the major diseases in green beans, carrot and lettuce often limit production and can seriously reduce crop yields. Cultural methods of disease control are often used as alternatives or supplements to chemical pesticides. Alternatives to pesticides are sought where chemical costs are high, disease control is incomplete, pesticides are not permitted for use and/or environmental issues are of concern. Chemical and cultural crop production methods introduced for reasons other than disease control may unintentionally influence soil-borne diseases (Shipton 1979).

Studies involving mechanical cultivation in crop production are primarily concerned with efficacy of weed control and subsequent impact on crop yield. In most cases, increases in crop yield are attributed to a reduction in weed-crop competition, but other factors such as improved water conservation and increased water infiltration have also been identified (Blake and Aldrich 1955; Prihar and Van Doren 1967). Inter-row cultivation has been shown to reduce the incidence of cavity spot lesions in carrots and improve the marketable proportion of the yield (Perry 1983). The effects were attributed to improved aeration of the soil by cultivation.

In addition to cultivation effects on soil physical properties, cultivation may damage crop foliage or roots, increase contact between soil and plants, or alter crop architecture all of which may influence disease incidence and severity, perhaps by predisposing plants to pathogenic agents. Carrot foliage that was in contact with mycelium of *Sclerotinia sclerotiorum* resulted in more diseased carrot roots at harvest and following three months of storage (Finlayson et al. 1989). Mechanical cultivation for weed control with a flex-tine harrow has been shown to cause injury to pinto bean hypocotyls and stems, but did not affect the severity of *Rhizoctonia* root rot (Vangessel et al. 1995). The effect of root pruning by cultivation in corn enhanced inter-row root growth (Prihar and van Doren 1967; van der Werf 1991).

Some of the primary diseases of bean, carrot and lettuce production in Quebec include white mold (causal agent *Sclerotinia sclerotiorum* (Lib.) de Bary) and common blight (causal agent *Xanthomonas campestris* pv. *phaseoli* (E.F.Sm.) Dye) of bean, Cercospora blight (causal agent *Cercospora carotae* (Pass.) Solheim) of carrot and downy mildew (causal agent *Bremia lactucae* Regel) and bottom rot (causal agent *Rhizoctonia solani* Kühn) of lettuce (Sherf and MacNab 1986). These were the major diseases observed during the years in which the present study was conducted.

White mold affects pods, stems, flowers and leaves of green beans and can cause severe yield losses. Chemical fungicides and cultural practices such as crop rotation often fail to control the disease (Hunter et al. 1978; Steadman 1983). Few bean cultivars are resistant to this disease and integration of several cultural practices are often required to control this and other bean diseases (Hall and Nasser 1996). Tillage is recommended in the control of several nematode, fungal and bacterial bean pathogens (Hall and Nasser 1996), but information about possible relationships between inter-row cultivation and disease control is limited.

In southern Quebec, Cercospora blight is a common disease of carrots and in fields in the organic farming region its incidence may be up to 99% in some years (Arcelin and Kushalappa 1991). Blighted foliage is covered with small necrotic lesions, reducing photosynthetic capacity and vigor. Yield losses occur during mechanical harvesting when blighted leaves break-off and roots remain in the ground. Control of Cercospora blight requires several applications of protectant fungicides and infection models have been developed to improve the timing and efficacy of fungicidal sprays (Carisse and Kushalappa 1990). Cercospora blight has been shown to reduce the weight of carrot roots (Bourgeois and Kushalappa 1992), but the threshold to which carrots can tolerate Cercospora blight without yield reductions is unknown.

Downy mildew of lettuce can cause serious crop losses since severely infected heads are unharvestable and at relatively low severity, its presence can decrease crop quality, require excess trimming at harvest and/or may promote rot during postharvest handling (Zink and Welch 1962). Fungicide applications and planting of resistant varieties help in the control of this disease (Sherf and MacNab 1986), but frequent irregular and unpredictable outbreaks limit the successful integration of other pest management strategies (Scherm and van Brugen 1994). Bottom rot lesions appear at maturity and may invade the entire head. Spread of the pathogen is favored by wet or humid microclimate conditions such as between bottom leaves and the soil surface (Sherf and MacNab 1986). Cultural methods of control involve crop rotation with non-susceptible hosts and deep tillage to bury sclerotia (Sherf and MacNab 1986).

The objectives of the present study were to determine whether several types of weeding treatments affected incidence and/or levels of disease in snap bean, carrot and lettuce crops. Also, we wanted to compare results among methods of weed control using mechanical cultivation and finally to compare cultivation treatments to the conventional methods of weed control.

MATERIALS AND METHODS

Field Plan

The green bean field site was located at the Emile Lods Agronomy Research Centre, Macdonald Campus of McGill University, Ste-Anne-de-Bellevue, Quebec. The soil is a Chateauguay clay loam mineral series. Carrots and lettuce were studied at the Agriculture Canada substation in Sainte Clotilde, Quebec. The soil is organic muck.

The experimental design was two randomized complete block designs with three blocks and 7 treatments. For each crop, three blocks were treated with the recommended rate and frequency of fungicide and three blocks remained untreated, in order to determine whether fungicide application affected disease incidence and to observe cultivation effects under potentially low and high disease pressure. Crops were inspected biweekly in order to determine when fungicide application was to begin. Cultivation was conducted as required for weed control only and so the number of cultivation events in each crop and year represents the minimum required for sufficient weed control (Table 1.1). No herbicides are registered for use in lettuce on muck soil, but the limitations of the conventional weed control system involve the rototiller which limits production because of its slow working speed and the high effort required for manual weeding. Sites were fall plowed. Fertilization took place in the spring, in accordance with soil nutrient analyses.

Green beans, Macdonald site, mineral soil, 1995 and 1996

Bean (*Phaseolus vulgaris* L. cv Hialeah) seeds were sown in 1995 on June 7 and in 1996 on May 31, 25 seeds to a metre with a precision seeder 25 to 30 mm deep. Hialeah is a medium upright to slightly open determinate type bush. Rows were spaced at 65 cm intervals and each of the treatment plots was 6 rows wide. The total surface area for each block was 27.3 m by 11 m. Fungicide application did not take place in 1995 since no diseases were observed.

Bean treatments at Macdonald

The following treatments were performed: 1. weedy check; 2. weed-free check using hand-pulling and hoeing; 3. conventional chemical: post-emergence 1.75 L/ha + 2.0 L/ha Bentazon + Assist in 300 L water at first trifoliate; 4. rotary hoe (Yetter) 10-11 km/h, depth 5 cm; 5. tine harrow (RabeWerk) 8.3-8.4 km/h, depth 5 cm; 6. torsion weeder (Bezzerides torsion weeder with Spyders) 0.9 km/h, depth 5-10 cm; 7. rotary hoe (Yetter) to 4 true leaves followed by Danish tines (Kongskilde) 4.5 km/h, depth 10-15 cm. The field treated with fungicide was sprayed with benlate at 1.75 kg/ha on July 11, 1996, 3 days after flowering was initiated.

Beans were manually harvested on 2 m in the centre 2 rows of each plot. Harvest was conducted every 2-3 days until pod production finished. Only those pods deemed of marketable size were picked on any given harvest day. In 1995, beans were harvested on July 24, 26, 28, 31, August 1, 4, 7, 10, 14, 17 and 21 and in 1996 harvested on July 22, 24, 26, 29, August 1, 5, 8 and 12. Once picked, pods were classified by disease. One week after harvest, ten plants in each of the yield rows were randomly chosen, cut off at the soil line, placed in cloth bags and dried for 48 h at 75° C and mean dry weight (g) was determined.

Carrots, Ste. Clotilde, organic soil, 1995 and 1996

Carrot (*Daucus carota* L. sativus cv. Six Pak II) seeds were sown in 1995 on May 31 and in 1996 on May 21, 12 to 20 mm deep at a density of 100 seeds per meter with a precision seeder that places three seeds across 75 mm wide band. Rows were spaced at

60 cm and each treatment plot was 6 rows wide. The total surface area for each block was 25.2 m by 11 m. A 15 cm band of herbicide (linuron 3.25 kg/ha) was sprayed on the rows post-emergence in 1995 and pre-emergence in 1996.

Carrot treatments at Ste. Clotilde

The following treatments were performed: 1. weedy check; 2. weed-free check using hand-pulling and hoeing; 3. conventional chemical: linuron pre-emergence at 3.25 kg/ha in 205 L water and post-emergence at 3.25 kg/ha in 205 L water when carrots 8 cm in height; 4. tine harrow (RabeWerk) 3-7 km/h, depth 3-7 cm; 5. basket wheel hoe (Buddingh Model K) 2-7 km/h, depth 3 to 5 cm; 6. torsion weeder (Bezzerides Torsion weeder and Spyders) 2-3 km/h, depth 5-7 cm; and 7. rototiller 1 km/h, depth 9-11 cm.

Starting in July, carrot crops were inspected biweekly to monitor foliage diseases. Five carrots from each treatment plot were inspected for symptoms of *Cercospora carotae* and if symptoms were present, fungicide spraying was initiated. In 1995, fungicide Dithane DG at 2.25 kg/ha was applied 7 times (July 21, 29, August 5, 10 17 and 25) and in 1996, 8 times (July 18, 23, 28, and August 7, 17, 22, 30).

Carrots were manually harvested in 1995 on Sept. 5-7 and in 1996 on Sept. 20-23, on two 2 m sections from the centre rows of each plot. Carrot roots from each row were classified by disease. Foliage disease evaluations were also conducted. This involved removing 10 carrots at random from each treatment, counting the number of leaves and recording the amount of surface area on each leaf that was affected by disease (*Cercospora carotae*). A key for measuring plant diseases was used to estimate % diseased tissue (Horsfall and Barratt 1945).

Disease evaluation for each treatment was also followed for carrot roots held in storage. Fifty Canada No. 1 carrots were randomly selected from each treatment, stored in plastic aerated bags and stored in a cooler at approximately 5° C. Ten carrots were removed monthly for 5 months (1995) and 1 month (1996), stored at room temperature for 2 weeks and then inspected for storage diseases.

Lettuce, Ste. Clotilde, organic soil, 1995 and 1996

Lettuce (*Lactuca sativa* L. cv. Ithaca) seeds were sown in 1995 on May 19 and in 1996 on May 21, at 10 seeds per metre with a precision seeder 10 to 20 mm deep. Lettuce were later thinned to 5 per metre. Rows were spaced at 45 cm and each of the treatment plots was 8 rows wide. The total surface area for each block was 9 m by 31 m.

Lettuce treatments at Ste. Clotilde

The following treatments were performed: 1. weedy check; 2. weed-free check using hand-pulling and hoeing; 3. conventional: rototiller at thinning, followed by manual weeding; 4. tine harrow (RabeWerk) 2-6 km/h, depth 3-7 cm; 5. basket wheel hoe (Buddingh) 2-6 km/h, depth 4-6 cm; 6. torsion weeder (Bezzerides) 1-3 km/h, depth 7-8 cm; and 7. rototiller 1 km/h, depth 9 cm.

Disease evaluation in the field was conducted at or near harvest time by randomly sampling and inspecting 15 (1995) or 12 (1996) lettuce plants per treatment. Basal rot, caused by *Rhizoctonia solani* or possibly Sclerotinia drop (*Sclerotinia sclerotiorum*) in the early stages was graded on a scale of 0 to 3, where 0 = no disease, 1 = rot present, on lower leaves only and is dry, 2 = rot present, on lower leaves only and wet, and 3 = rot present, advanced to inner leaves and wet. The incidence of other diseases, such as downy mildew was recorded by counting the number of leaves with at least one lesion.

Lettuce were manually harvested in 1995 on July 13 and in 1996 on July 18, from 2 m sections on the 4 middle rows. Basal leaves were trimmed in the field, then lettuce were classified. Type of disease was determined and number and fresh weight recorded.

Statistical Analyses

Analysis of variance was analyzed using the general linear model (GLM) of Statistical Analysis System (SAS Institute Inc., Cary, NC). Disease percent data were squareroot arcsin transformed prior to analysis, but the values reported are untransformed percentages. Where treatment effects were significant ($P<0.05$) differences between means were detected using Duncan's least significant differences test. Linear correlations were conducted using the robust straight line process with adjusted r^2 degrees of freedom TableCurve 2D (Jandel Scientific, San Raphael, CA).

RESULTS

Beans

Beans were virtually disease-free in 1995 (data not shown), but in 1996 white mold and bacterial blight were detected. Fungicide application did not significantly affect the total yield of rejected pods, number of rejected pods and pods with bacterial blight (Table 2.1). However, fungicide application increased the yield of pods with symptoms of white mold and decreased yield of scarred pods. The mean plant biomass was higher in the with fungicide field. The mean proportion of cull pods in total pod yield with fungicide application was 40.6% and without fungicide 36.6%.

Beans in field with fungicide application

The incidence of white mold symptoms on pods was significantly affected by weed control treatments (Table 2.2). Levels were lowest in the weedy check, likely because total yield was lowest in this treatment. The yield of pods with white mold was highest in the weed-free check. Differences among cultivated treatments were not significant, but disease levels in rotary hoe (+Danish) and tine harrow were higher. Herbicide increased white mold compared to cultivation with rotary hoe and torsion weeder. The incidence of bacterial spot was not affected by weeding treatments, nor was the incidence of scarred beans or beans with symptoms of viral infection.

When yield of white mold pods was compared to the number of times a weed control treatment was conducted, there was a strong correlation (Table 2.3), but yield was not correlated with the number of days between sowing and the end of treatment.

Beans in field without fungicide application

There were no significant differences among treatments for any of the variables (Table 2.4), but some of the same trends occur as seen in the field with fungicide application. The weed-free treatment had higher values for white mold and the weedy check had lower white mold values. Among cultivated treatments, the rotary hoe and torsion weeder had lower values.

Carrots 1995 and 1996

In both years, disease on harvested roots and roots held in storage was virtually nonexistent (data not shown). Levels of Cercospora blight on carrot foliage within fields where fungicide was applied were lower than the field where fungicide was not applied (Table 2.5). Mean root weight was not affected by fungicide, but in both, root weight was greater with fungicide application. The incidence of disease in 1995 did not statistically differ among treatments within crops that did or did not receive fungicide (Table 2.6), but differences were detected in 1996 and are presented below.

Carrots in field with fungicide application, 1996

In the field with fungicide application cultivation with the tine harrow reduced disease (Table 2.7). Mean % surface area affected by disease was not correlated (r^2=0.056) to the number of weeding passes (mechanical or manual) conducted during the season, nor were the % disease and length of time the weeding period extended past the sowing date (r^2=0.230) (Table 2.7).

Carrots in field without fungicide application, 1996

In the field without fungicide application cultivation with the tine harrow and rototiller significantly reduced disease compared to other weeding treatments (Table 2.8). The weed-free treatment had the highest level of disease. Mean % surface area affected by disease was not correlated (r^2=0.339) to the number of weeding passes (mechanical or manual) conducted during the season. However, the % disease was highly correlated to the length of time the weeding period extended past the sowing date (r^2=0.890) (Table 2.8).

Lettuce 1995 and 1996

Lettuce fields were virtually free of fungal diseases in 1995 (data not shown) but in 1996, downy mildew (*Bremia lactucae*) was prevalent. In 1996, in lettuce randomly sampled from the field, the incidence of having at least one leaf with downy mildew lesion(s) was 100% with or without fungicide applications. The incidence of lettuce having at least 5 basal and/or upright leaves with downy mildew lesion(s) was 71.4% in the fungicide-applied field and 90.5% in the field that was not sprayed. However, the incidence of downy mildew did not differ in a similar manner for lettuce graded at harvest (Table 2.9), likely because trimming prior to grading eliminated many leaves.

Lettuce in field with fungicide application

Weed control treatments affected the severity of basal rot in only 1995 in the field where fungicide was applied (Table 2.10). Cultivation did not affect severity of rot compared to the conventional method of weed control (rototiller and hand-weeding). However, among cultivators, the basket wheel hoe increased severity compared to the tine harrow and torsion weeder. Trends in 1996 did not follow those observed in 1995.

The weedy check increased the number of deformed lettuce and total number of rejected lettuce but there were no differences among treatments for downy mildew (Table 2.11). Basal rot of harvested lettuce was lowest in cultivation with the tine harrow compared to cultivation with either torsion weeder or rototiller (Table 2.11).

Lettuce in field without fungicide application

In both years, weed control treatments had no effect on basal rot severity (Table 2.10), but at harvest time, the number of lettuce with severe basal rot was increased by cultivation with the torsion weeder (Table 2.12). Differences were not detected for other disease categories.

Table 2.1. Comparison of total rejected pod number and yield, beans with scarring, mosaic, bacterial blight, white mold (1996) in fields where fungicide was applied or fungicide was not applied. Mean biomass per plant of aboveground vegetative tissues (n=180). Number of pods per hectare x 10^3. Numbers in brackets are the rejected pod yield percentage of the total yield.

Treatment	**#/ha x 10^3**	**t/ha**					
	Total	**Total**	**Scarred**	**Mosaic**	**Bact. blight**	**White mold**	**Biomass (g)**
Fungicide not applied	1300.2 a	5.94 a (36.6)	1.08 a	0.016 a	0.57 a	4.30 a	11.04 a
Fungicide was applied	1448.9 a	6.51 a (40.6)	0.82 b	0.003 a	0.53 a	5.15 b	13.07 b

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 2.2. Rejected bean pod yield in field in which fungicide was applied (1996). Yield of pods with scarring, symptoms of bean mosaic, bacterial blight or white mold and total yield of rejected pods. Numbers in brackets are the % of total yield that was rejected.

TREATMENT	t/ha				
	Scarred	**Mosaic**	**Bacterial**	**White mold**	**Total Cull**
Weedy check	0.44 a	0.00 a	0.58 a	2.76 d	3.78 d (32.1)
Weed-free	1.15 a	0.00 a	0.75 a	6.96 a	8.86 a (42.4)
Herbicide	1.31 a	0.00 a	0.49 a	6.04 ab	7.84 ab (42.7)
Rotary hoe	0.58 a	0.01 a	0.30 a	4.83 c	5.72 c (44.0)
Tine harrow	1.00 a	0.01 a	0.65 a	5.32 bc	6.99 bc (40.1)
Torsion weeder	0.58 a	0.01 a	0.46 a	4.64 c	5.69 c (41.7)
Rotary hoe + Danish tine	0.70 a	0.00 a	0.47 a	5.51 bc	6.68 bc (41.3)

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 2.3. Yield of pods with white mold, number of times weeding treatment was conducted and length of weeding period which was sprayed with fungicide (1996). Weight of diseased pods and number of passages were correlated (r^2=0.893) but weight and length of weeding period were not correlated (r^2=0.386).

Treatment	Pods with white mold (t/ha)	Number of Weeding passes	Weeding period*
Weedy check	2.76 d	--	--
Weed-free	6.96 a	6	63
Herbicide	6.04 ab	--	--
Rotary hoe	4.83 c	3	25
Tine harrow	5.32 bc	3	26
Torsion weeder	4.64 c	2	39
Rotary hoe + Danish tine	5.51 bc	3+ 1	40

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.
*The number of days following planting when weeding treatment was finished.

Table 2.4. Rejected bean pod yield in field which did not receive fungicide (1996). Yield of pods with scarring, symptoms of bean mosaic, bacterial blight or white mold and total yield of rejected pods. Numbers in brackets are the % of total yield that was rejected.

	t/ha*				
TREATMENT	**Scarred**	**Mosaic**	**Bacterial**	**White mold**	**Total Cull**
Weedy check	0.95	0.02	0.72	3.49	5.19 (34.4)
Weed-free	1.13	0.01	0.66	5.14	6.95 (35.0)
Herbicide	1.50	0.02	0.49	4.00	6.01 (37.2)
Rotary hoe	0.71	0.01	0.46	3.65	4.84 (35.3)
Tine harrow	1.45	0.00	0.68	5.34	7.48 (35.7)
Torsion weeder	0.78	0.04	0.32	4.01	5.14 (36.7)
Rotary hoe + Danish tine	1.04	0.01	0.66	4.25	5.96 (42.0)

*No significant differences (P>0.05) according to Duncan's multiple range test.

Table 2.5. Mean % foliage surface area affected by Cercospora blight of carrot (n=180) and mean fresh weight of carrot root (n=180) for 1995 and 1996 in fields with or without fungicide application.

Field	1995		1996	
	% disease	Root (g)	% disease	Root (g)
Fungicide not applied	21.22 a	10.79 a	23.88 a	10.82 a
Fungicide was applied	4.24 b	13.35 a	2.17 b	11.67 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 2.6. Mean percent surface area of leaf affected by Cercospora blight in fields with or without fungicide application (n=30), 1995.

Treatment	% surface area* No fungicide	% surface area* Fungicide
Weed-free	25.97	3.55
Herbicide	25.49	7.13
Tine harrow	24.62	3.88
Basket hoe	21.22	5.87
Torsion weeder	21.56	2.54
Rototiller	27.78	3.23

* No significant differences ($P>0.05$).

Table 2.7. Mean percent surface area of leaf affected by Cercospora blight, number of times weeding treatment conducted and length of weeding period in field sprayed with fungicide (n=30), 1996. Percentage of disease and number of passages were not correlated (r^2=0.056) and neither were % disease and length of weeding period (r^2=0.230).

TREATMENT	% DISEASE	Number of Weeding passes	Length of weeding period*
Weedy check	4.47 a	--	--
Torsion	2.83 a	4	43
Herbicide	2.76 a	-	--
Weed-free	2.32 a	6	58
Basket hoe	2.26 a	5	43
Rototiller	2.19 a	2	37
Tine harrow	0.71 b	5	36

Means within a column followed by the same letter are not significantly different at P<0.05 according to Duncan's multiple range test.
*The number of days following planting when weeding treatment was finished.

Table 2.8. Mean percent surface area of leaf affected by Cercospora blight, number of times weeding treatment conducted and length of weeding period in field not sprayed with fungicide (n=30), 1996. Percentage disease and number of passages were not correlated (r^2=0.339) but % disease and length of weeding period were (r^2=0.890).

Treatment	% DISEASE	Number of Weeding passes	Length of weeding period*
Weedy check	N/A	0	--
Weed-free	33.00 a	6	58
Herbicide	30.74 a	0	--
Torsion	28.38 a	4	43
Basket hoe	23.15 ab	5	43
Tine harrow	16.50 b	5	36
Rototiller	16.41 b	2	37

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.
*The number of days following planting when weeding treatment was finished.

Table 2.9. Mean number of rejected lettuce per 2 m at harvest (n=84) in fields with or without fungicide application, 1996. Total number of lettuce and number of heads that were deformed, affected by downy mildew or basal rot (severity = 3 on a scale of 0 to 3) or other blemishes.

TREATMENT	Number of lettuce				
	Total	Deformed	Mildew	Basal rot	Other
Fungicide not applied	2.35 a	1.59 a	0.10 a	0.58 a	0.08 a
Fungicide was applied	3.27 b	2.44 b	0.48 b	0.32 a	0.03 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 2.10. Severity of mean basal rot per lettuce in 1995 (n=15) and 1996 (n=12), where 0 = rot not present, 1 = rot present on lower leaves only and was dry, 2 = rot present on lower leaves only and wet, and 3 = rot present, advanced to inner leaves and wet.

TREATMENT	With fungicide		Without fungicide	
	Disease value			
	1995	1996	1995	1996
Weedy check	1.00 d	1.33	0.70	1.50
Weed-free	2.53 a	1.78	1.40	2.16
Rototiller + manual	1.87 abc	1.45	1.00	1.83
Tine harrow	1.33 cd	1.67	0.90	1.33
Basket hoe	2.33 a	1.33	0.90	1.83
Torsion weeder	1.53 bcd	1.44	1.00	1.83
Rototiller	2.07 ab	2.00	0.60	2.17

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 2.11. Mean number of rejected lettuce per 2 m at harvest (n=12) in field where fungicide was applied, 1996. Total number of lettuce and number of heads that were deformed, affected by downy mildew or basal rot (severity = 3 on a scale of 0 to 3) or other blemishes.

TREATMENT	Number of lettuce				
	Total	Deformed	Mildew	Basal rot	Other
Weedy check	5.83 a	5.92 a	0.00	0.00 d	0.00 a
Weed-free	2.92 b	1.50 b	0.75	0.50 ab	0.17 a
Roto + manual	2.42 b	1.92 b	0.33	0.17 bcd	0.00 a
Tine harrow	2.75 b	2.25 b	0.42	0.08 cd	0.00 a
Basket hoe	2.41 b	1.33 b	0.58	0.33 abc	0.08 a
Torsion weeder	3.33 b	2.17 b	0.75	0.42 ab	0.00 a
Rototiller	3.25 b	2.00 b	0.50	0.75 a	0.00 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 2.12. Mean number of rejected lettuce per 2 m at harvest (n=12) in field where fungicide was not applied, 1996. Total number of lettuce and number of heads that were deformed, affected by downy mildew or basal rot (severity = 3 on a scale of 0 to 3) or other blemishes.

TREATMENT	Number of lettuce				
	Total	Deformed	Mildew	Basal rot	Other
Weedy check	4.00	4.00	0.00	0.00 c	0.00
Weed-free	1.50	0.58	0.17	0.58 bc	0.17
Roto + manual	2.00	1.50	0.33	0.17 c	0.00
Tine harrow	2.33	1.33	0.17	0.50 bc	0.17
Basket hoe	2.17	1.08	0.00	1.00 ab	0.08
Torsion weeder	2.75	1.00	0.00	1.67 a	0.08
Rototiller	1.75	1.50	0.00	0.17 c	0.08

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

DISCUSSION

Beans

In 1995, beans were virtually free of disease, most likely because the season was dry and the field was previously cropped cereals. Bean debris left in the field in 1995 probably provided inoculum for the following year.

In 1996, white mold was observed on pods for all treatments and was the primary reason that pods were rejected at grading. Yield of bean pods affected by white mold were unexpectedly high where fungicide was applied. On average, aboveground plant biomass was greater in this field, which may have been a factor in the disease level. A greater biomass, which indicates a denser canopy and greater leaf area has been shown to contribute to a higher incidence of white mold (Haas and Bolwyn 1972; Weiss et al. 1980). Air flow is reduced and humidity levels are higher in a dense canopy, creating conditions conducive to white mold infection (Steadman 1983). A canopy structure that is open and permits air flow, such as the smaller plants in the non-fungicide applied field, is less prone to white mold infection (Schwartz et al. 1978). Among treatments, higher biomass was observed in the weed-free treatment, which also had higher yield of diseased pods. Another factor that may have contributed to incomplete control of white mold may have been the timing of fungicide application. It has been demonstrated that in order to sufficiently control white mold, fungicide application must take place 3-5 days prior to full bloom (Hunter et al. 1978) whereas in our study, the application took place at full bloom. Alternately, fungicide treated fields had a lower amount of scarred beans. Late in the harvest, when field conditions were dry, water soaked lesions on pods were observed to dry out and crust somewhat and these pods may have been mistakenly graded as scarred. On the other hand, many symptomless but infected pods may have been misgraded (Sherf and MacNab 1986).

Among treatments, herbicide application increased disease incidence compared to cultivation at similar plant biomass. Herbicide usage has previously been implicated in promoting disease caused by soilborne pathogens, by predisposing plants to infection, stimulating growth of pathogens, increased exudation of plant nutrients into the soil, negative effects on antagonistic soil microorganisms, etc., (Altman and Campbell 1977) and these may have been a factors here.

Where treatment effects were detected in the yield of pods with white mold, number of weeding events and disease levels were correlated. Treatment plots which were weeded a greater number of times had higher disease. The distribution of white mold apothecia and disease has been shown to be correlated and spatially aggregated within a bean field (Boland and Hall 1988). Sclerotia produce apothecia primarily under a well-developed plant canopy which restricts long-range dispersal (Steadman 1983) and promotes localized infection potential. Increased disturbance of the plant canopy by the action of hand-pulling and hoeing weeds may have aided in a more uniform dispersal of ascospores and thus contributed to an increase in overall disease levels.

Carrots

In both years, fungicide application reduced the level of Cercospora blight. Under conditions of higher disease, root weight was not affected, although weights were consistently lower in fields with higher disease, as has been observed elsewhere (Bourgeois and Kushalappa 1992). Weeding treatment effects on the foliar surface area affected by Cercospora blight were generally not consistent over the 2 year study, but effects in 1996 were consistent between fields where fungicide application was a factor. In both fields, cultivation with the tine harrow reduced the amount of diseased plant tissue, which was found to be correlated with the length of weeding period, rather than the number of times weeding treatments occurred. Disease levels were higher when weeding treatments continued longer into the season. However, this correlation was not well defined at lower disease levels, perhaps because plant response differences may not be detectable or useful measures at low disease levels (Gaunt 1995). Cultivation with the tine harrow ended earlier than any other treatment and it reduced the mean disease level compared to treatments such as the weed-free carrots which were weeded by hand relatively late into the season. Unlike the situation with white mold ascospore dispersal in bean fields, disturbance of the carrot canopy later in the season would not necessarily increase the dispersal of *C. carotae* conidia, which are wind dispersed over long ranges (Sherf and MacNab 1986). Damage to foliage by weeding later in the season may have increased the amount of foliage laying along the ground and thereby contributed to creating microclimates favorable for recurrent disease sporulation and infection. Infection and sporulation of conidia is promoted in warm weather by extended periods of leaf wetness and/or high humidity (Carisse and Kushalappa 1990, 1992; Carisse et al. 1993).

Information on the economic losses attributed to Cercospora blight are not well documented, but yield losses are thought to occur when more than 10-15% of the leaf area is blighted (Sutton and Gillespie 1979). In the present study, carrots were not mechanically harvested, so potential yield loss at the observed disease levels cannot be directly determined, although trends indicated that higher disease levels reduce root weight.

Lettuce

Except for basal rot, lettuce were disease free in one year and in the second year downy mildew was an additional factor. In general, weeding treatments did not affect the severity of basal rot or the incidence of disease such as downy mildew. A few differences were detected for measures of basal rot, but not consistently. A two year study may not be adequately long enough to detect effects of cultivation on soilborne sclerotia forming pathogens. Deep primary tillage has been shown to decrease survival of sclerotia (Merriman 1976; Merriman et al. 1979) and apothecial production over 4-8 years decreases with deeper soil burial (Ben-Yephet et al. 1993). These studies recommended avoiding cultivation events that may redistribute sclerotia closer to the soil surface, but an earlier study demonstrated that exposure to soil moisture fluctuations in the top 10-14 cm of soil decreased overall numbers of sclerotia by impeding formation of secondary sclerotia (Williams and Western 1965). Inter-row secondary cultivation may create adequate soil moisture fluctuations to achieve this, but the effect would have to be followed over several years.

The incidence of lettuce with downy mildew lesions was lower with fungicide application when sampling was done in the field, but at harvest, a greater number of lettuce with downy mildew lesions were observed for the fungicide treatment. When lettuce are harvested, excess basal leaves are trimmed and many infected leaves may thus be left behind, so lesion detection during grading at harvest would have only been on inner leaves. The apparent contradiction may have occurred because sampling size could have simply been too low. In a survey of lettuce fields at low incidence of downy mildew, Scherm and van Bruggen (1994) sampled several hundred lettuce.

Conclusions

In general, cultivation does not detrimentally impact aspects of diseases that arose in the course of bean, carrot and lettuce production over a two year period. In some cases, cultivation decreased disease levels, but results were not always consistent. Effects of cultivation varied with crop type and disease.

Disease development was unusually absent in one year, but higher levels in the following year enabled comparisons to be made among mechanical cultivators and conventional treatments, especially in fields not treated with fungicide where disease pressure was higher than typical production situations. However, when comparisons were made at the field level, unexpectedly higher levels of disease were found in bean and lettuce fields that had received fungicide applications.

Nevertheless, trends indicate potential benefits of incorporating mechanical cultivation into conventional weed control strategies. More studies of this type need to be conducted in order to elucidate patterns of crop and disease response. Under high disease pressure, correlation of disease levels to timing of cultivation indicate that crop canopy disturbance may be one of the major contributors to the detected differences among treatments, but this needs to be further explored.

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PREFACE TO STUDY III

Cercospora blight of carrot is one of the important diseases in carrots grown on organic soil in Quebec (Arcelin and Kushalappa 1991). Cercospora blight causes yield losses because blighted carrots are smaller and the foliage may break during mechanical harvesting, leaving roots behind. Disease models have been developed to minimize the number of fungicide applications used to control the disease (Carisse and Kushalappa 1990). Carrots are thought to tolerate a small percentage of disease without yield reduction, but exactly how much is not known. Determining whether there is a threshold at which a minimum level of disease can be tolerated without carrot size reductions would help reduce fungicide applications. Losses of carrots during mechanical harvesting is possibly related to the degree to which foliage has been weakened by blight and this may be a useful predictor when determining potential loss by roots remaining in the ground. Different types of weeding methods may influence potential losses.

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STUDY III. THE EFFECTS OF MECHANICAL WEED CULTIVATION AND CERCOSPORA BLIGHT IN CARROT PRODUCTION

INTRODUCTION

In southern Quebec, Cercospora blight (*Cercospora carotae*) is a common fungal disease of carrots. In crops grown in the organic farming region its incidence may be up to 99% in some years (Arcelin and Kushalappa 1991). Blighted foliage is covered with small necrotic lesions, which reduces photosynthetic capacity and vigor. Yield losses occur when blighted leaves break-off during mechanical harvesting and roots are left behind in the ground. Control of Cercospora blight requires several applications of protectant fungicides (Sutton and Gillespie 1979) and more recently, infection models have been developed to improve the timing and efficacy of fungicidal sprays (Carisse and Kushalappa 1990). Cercospora blight has been shown to reduce the weight of carrot roots (Bourgeois and Kushalappa 1992). Yield losses are thought to occur when more than 10-15% of the leaf area is blighted (Sutton and Gillespie 1979), but studies have not been conducted to test what the actual threshold might be and it is not known if this refers to a reduction in mean carrot weight or losses due to breakage.

In this study, carrots were grown with and without fungicide application in order to conduct the study with respectively low and high disease pressure. The objectives were 1) to determine if different levels of blight had an effect on root weight, root crown diameter, leaf weight, leaf number, petiole diameter and the amount of force required to separate roots from foliage; 2) to determine the effects of mechanical weed cultivation on these same variables.

MATERIALS AND METHODS

Carrot production methods and treatments were the same as those reported in Study III, except that at harvest time, in addition to the other measurements taken, an assessment of Cercospora blight was carried out. In 1995 the assessment took place 26-30 September and in 1996 11-14 September. Ten carrots were randomly chosen from each treatment in crops where fungicide was or was not applied. The amount of force (Newton per square meter = Pa) required to remove carrot tops from roots was determined by using a "carrot puller" apparatus (Appendix A.IV). Additional measurements taken on each individual carrot included: percent surface area of each leaf affected by Cercospora blight, root crown diameter, petiole diameter, number of leaves, root dry weight and total leaf dry weight (1996 only). The percentage of foliage surface area affected by disease was estimated using a scale (Horsfall and Barratt 1945). Only carrot leaves that were fully open were assessed and used to determine the mean disease level per plant. Roots were chopped into small pieces and then dried for 72 hr at 75° C and leaves were dried for 24 hr at 75° C.

Statistical Analyses

Data were analyzed using the general linear model (GLM) of the Statistical Analysis System (SAS Institute Inc., Cary, NC). Data were log or square root arcsin transformed when necessary to satisfy homogeneity of variance, but reported values are untransformed. Where treatment effects were significant (P<0.05) differences between means were detected using Duncan's multiple range test.

RESULTS

Crops with fungicide application versus crops without fungicide application

1995

Fungicide application significantly affected the force required to separate carrot root from leaves, the mean percent surface area of disease per leaf, the mean number of leaves per plant, and the diameter of all petioles together at attachment (Table 3.1). The mean diameter of the root at its crown and the mean weight of a root were not affected.

1996

Fungicide application significantly affected the mean percent surface area of disease per leaf, the mean leaf weight per carrot, and the diameter of all petioles together at attachment (Table 3.2). Fungicide application did not affect the mean force required to separate carrot root from its leaves, number of leaves, diameter of the root at its crown, nor mean root weight.

Weeding treatment effects

1995 Crops with and without fungicide application

There were no significant treatment effects (data not shown). Consistent trends in the data were not apparent either.

1996 Crops with fungicide application

Carrots cultivated with the tine harrow had the lowest disease level and the highest dry weight of leaves plus one of the highest measurements for the force needed to pull carrot leaves of the root (Table 3.3).

1996 Crops without fungicide application

Cultivation with the tine harrow had one of the lowest disease levels, but was similar to other treatments for the rest of the variables (Table 3.3).

Table 3.1. Carrot force experiment at Ste Clotilde, 1995, in crops where fungicide was applied or was not applied. Organic soil. Force is the mean Pascals required to separate carrot root from its leaves. Petiole diameter is the mean width of all leaf petioles together where they join the root. Crown diameter is the mean width of the carrot root at the widest part of its crown. Root is the mean dry weight of the root. Number of leaves is the mean number of leaves for each carrot. Percent disease is the mean percent of leaf surface area affected by Cercospora blight.

Crop treatment	Force (Pa x 10^5)	% Disease	Root (g)	# of Leaves	Petiole dia. (cm)	Crown dia. (cm)
Fungicide not applied	1.95 a	21.22 a	10.79 a	6.62 a	1.12 a	2.83 a
Fungicide was applied	2.75 b	4.24 b	13.35 a	8.72 b	1.31 b	3.08 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 3.2. Carrot force experiment at Ste Clotilde farm 1996, in crops where fungicide was applied or was not applied. Organic soil. Force is the mean Pascals required to separate carrot root from its leaves. Petiole diameter is the mean width of all leaf petioles together where they join the root. Crown diameter is the mean width of the carrot root at the widest part of its crown. Leaves is the mean dry weight of a carrot's leaves. Roots is the mean dry weight of the root. Number of leaves is the mean number of leaves for each carrot. Percent disease is the mean percent of leaf surface area affected by Cercospora blight.

Crop treatment	**Force (Pa x 10^5)**	**Disease (%)**	**Root (g)**	**Leaves (g)**	**# of Leaves**	**Petiole dia. (cm)**	**Crown dia. (cm)**
Fungicide not applied	1.67 a	23.88 a	10.82 a	3.54 a	5.38 a	1.10 a	2.92 a
Fungicide was applied	1.52 a	2.17 b	11.67 a	4.62 b	5.47 a	1.21 b	3.01 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

Table 3.3. Carrot force experiment at Ste Clotilde farm 1996. Muck soil. With and without fungicide application. Force is the mean Pascals required to separate carrot root from its leaves. Petiole diameter is the mean width of all leaf petioles together where they join the root. Crown diameter is the mean width of the carrot root at the widest part of its crown. Leaves is the mean dry weight of a carrot's leaves. Roots is the mean dry weight of the root. Number of leaves is the mean number of leaves for each carrot. Percent disease is the mean percent of leaf surface area affected by Cercospora blight.

TREATMENT	Force (Pa x 10^5)	Disease (%)	Root (g)	Leaf (g)	# of Leaves	Petiole dia. (cm)	Crown dia. (cm)
With fungicide							
Weedy check	0.85 c	4.47 a	5.05 a	2.55 d	4.50 a	1.02 a	2.35 a
Weed-free	1.14 c	2.32 a	10.83a	3.77 bc	4.90 a	1.13 a	3.24 a
Herbicide	1.67 ab	2.76 a	11.85 a	4.84 a	5.30 a	1.06 a	3.03 a
Tine harrow	1.67 ab	0.71 b	12.31 a	5.35 a	5.40 a	1.20 a	3.10 a
Basket hoe	1.19 bc	2.26 a	10.49 a	3.49 cd	5.10 a	1.18 a	2.87 a
Torsion	1.20 bc	2.83 a	12.71 a	4.63 ab	5.60 a	1.25 a	3.21 a
Rototiller	1.86 a	2.19 a	13.34 a	5.01 a	5.35 a	1.26 a	3.13 a
Without fungicide*							
Weed-free	1.56 a	33.00 a	11.52 a	3.94 a	5.60 a	1.12 a	3.11 a
Herbicide	1.48 a	30.74 a	10.92 a	3.26 a	5.30 a	1.09 a	3.02 a
Tine harrow	1.74 a	16.50 b	9.97 a	3.34 a	5.17 a	1.05 a	2.79 a
Basket hoe	1.75 a	23.15 ab	9.96 a	3.56 a	5.30 a	1.14 a	2.91 a
Torsion	1.83 a	28.39 a	12.72 a	3.71 a	5.50 a	1.12 a	3.02 a
Rototiller	1.67 a	16.41 b	9.81 a	3.45 a	5.40 a	1.04 a	2.67 a

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

*The data were not available for the weedy check

DISCUSSION

A significant increase in the percentage of foliage surface area affected by Cercospora blight tended to decrease carrot root weight and crown diameter. This is what was expected, since as the percentage of leaf area affected by blight increases, the mean photosynthetic capacity decreases because blighted tissue cannot photosynthesize. Thus, root growth becomes limited. Results also suggest that leaves themselves become nutrient limited. The diameter of all petioles as a unit where they join the root was decreased with increased disease levels and the dry weight of leaves was found to be lower.

The number of leaves per plant was lower with increased disease, but this measurement may not necessarily reflect disease effects because it was a measurement taken only at harvest time and does not consider total leaf production.

Cercospora blight thus may reduce yields because blighted carrots tend to have smaller roots that weigh less. However, losses can potentially exceed the sum of the difference in weights because entire roots of blighted carrots may remain in the ground when foliage breaks during mechanical harvesting. It is therefore of interest to determine if there is a correlation between breakage and level of blight.

The impact of disease levels on force values was not well defined and in one case, the results were unexpected. Increased disease levels significantly reduced the amount of force required to pull off carrot leaves in one year, as expected. However, in the second year, even with a greater margin between low and high disease means, force values were not different. In fact, the required amount of force was slightly higher in the carrot crop that had more disease. It is difficult to determine why this might have occurred. It is possible that other diseases may have contributed to the unexpected result. In the first year, Cercospora blight was essentially the only disease affecting carrots, but in the second year the presence of other diseases such as cottony soft rot (*Sclerotinia sclerotiorum*) were observed in patches in the field.

The force measurement in controlled conditions may not accurately represent what is happening in the field during mechanical harvesting. The carrot "puller" applies force in a uniform straight line motion from a fixed point whereas in the field the force motion is not uniform and the carrot is not held stationary by the soil. To obtain conditions more similar to mechanical harvesting, perhaps the carrot "puller" could be redesigned to pull carrots out of the soil.

If the disease threshold at which carrot foliage breakage occurs could be determined, producers could tolerate Cercospora blight to this level without yield loss during mechanical harvesting. However, irrespective of foliage breakage, trends indicated that individual carrot weights decreased as blight increased, so control of the disease at the levels observed in this study is necessary to minimize yield losses of carrot roots that do get harvested.

Detected differences among treatments were infrequent. In general, cultivation did not consistently affect force values, level of disease, root weight, leaf weight, leaf number, petiole diameter and crown diameter, but different Cercospora blight levels did. In most cases, differences among treatments occurred for one variable only and no conclusions could be made about possible relationships between disease level and foliage breakage . However, cultivation with the tine harrow affected aspects of several variables and this should be further investigated.

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STUDY ON PHENOLOGY

PREFACE TO STUDY IV

Mechanical weed cultivation may have no impact on yield, but may alter normal crop production by influencing aspects of plant growth and development. In snap bean cropping, pod production is of primary interest and in a determinate bean plant, uniformity of flowering and pod set is desired since mechanical harvesting can take place only once.

Legume yields are inherently limited by the number of flowers produced per plant and the proportion of pods set (Sinha 1977). The amount of vegetative biomass accumulated prior to flowering has also been implicated as a factor which may influence final yields (Egli and Legget 1973).

In snap bean production, different weed control techniques may affect reproductive development and ultimately yield realization. In order to investigate this, the following study was undertaken. Flowering and pod set in snap beans that received different weeding treatments were followed over two years.

Egli, D.B. and Legget, J.E. Dry matter accumulation pattern in determinate and indeterminate soybeans. Crop Science. 13: 220-222.

Sinha, S.K. 1977. Food Legumes: distribution, adaptability, and biology of yield. Food and Agriculture Organization of the United Nations, Rome, Italy. pp 124.

STUDY IV. THE EFFECT OF MECHANICAL WEED CULTIVATION ON FLOWERING AND POD SET IN SNAP BEANS

INTRODUCTION

Yield realization in snap bean production is influenced by vegetative and reproductive development and partitioning of plant resources between the two (Sinha 1977). Reproductive development in legumes encompasses the number of flowers produced per plant and the percentage of pods which are set from flowering. In general, beans demonstrate high percentages of flower abscission and pod abortion. Flowers that open first are more likely to produce marketable pods than flowers that open later (Binnie and Clifford 1981; Subhadrabandhu et al. 1978).

Flower and pod abscission

Flower abscission is one of the factors that limits the increase of legume yields worldwide (Sinha 1977). Flower abscission in 17 *Phaseolus vulgaris* dry bean cultivars ranged from 28-80% for greenhouse grown plants and 52-76% for field grown beans (Binnie and Clifford 1981; Subhadrabandhu et al. 1978) and similar percentages have also been reported in *Vicia faba* (Quagliotti et al. 1994; Soper 1952). Possible reasons for flower abscission include various aspects of the plant canopy microclimate such as light, temperature, gas exchange and humidity, and macroclimatic factors such as limitation of photosynthesis or nitrogen availability, soil aspects and water stress (Sinha 1977), but it is difficult to determine specifically what factors predominate (Quagliotti et al. 1994).

Pod abortion may be influenced by the same biotic and abiotic factors, but not necessarily in the same way or combinations of ways as for flower abscission. In general, earlier forming pods are larger than later forming ones (Sinha 1977). However, flower removal from bean plants for up to 15 days after anthesis did not affect yield because comparable pods were set from later forming flowers (Binnie and Clifford 1981). First forming pods inhibit the development of later forming pods (Binnie and Clifford 1981).

Vegetative matter accumulation

Vegetative and reproductive development patterns determine dry matter accumulation and yield potential respectively and it is the partitioning between the two which determines yield realization (Sinha 1977). Egli and Legget (1973) demonstrated that in soybeans with determinant growth the biomass accumulated prior to the onset of flowering accounted for 77-80% of total vegetative production and that vegetative accumulation increased only slightly afterwards. Once pod development begins, pods and seeds are thought to be the primary sink for photosynthates because at this time, vegetative growth was 88-92% of total accumulated (Egli and Legget 1973).

Mechanical cultivation

The influence of cultivation on factors in the field and within the developing plant canopy may impact on the vegetative and reproductive development of beans, in particular aspects of flowering. The objectives of the present study were to determine if mechanical weed control treatments had an effect on 1) the total number of flowers and pods produced on individual bean plants; 2) the number of days to 50% flowering; 3) the percentage of flowers and pods that were abscised and finally, to relate these observations to total pod production within the field.

MATERIALS AND METHODS

The field plan and weeding treatments are the same as those described in Study I, except that observations on bean flowering were also taken. These are described below.

Collection of flowering data

The developmental stage of beans was noted on a weekly basis. Once flowering had been initiated (>50% of plants with 1 flower open), 3 plants (1995) and 10 plants (1996) per plot were tagged and followed throughout the season. The number of newly opened flowers and developing pods were recorded every 2-3 days on each of the tagged plants. Pods were manually harvested every 2-3 days. Only those pods deemed of marketable size were picked on any given harvest day.

At the end of the flowering period the number of days up to 50% flowering was determined using cumulative flower counts. After harvest, each tagged plant was cut at the soil, placed in a cloth bag and dried for 48 h at 75°C and dry weight (g) was determined.

Statistical Analyses

Data were analyzed using the general linear model (GLM) of Statistical Analysis System (SAS Institute Inc., Cary, NC). Data were log or square root transformed when necessary to satisfy homogeneity of variance. Where treatment effects were significant ($P<0.05$) differences among means were detected using Duncan's multiple range test. The day of 50% flowering was determined by plotting day against cumulative flower count, fitting a linear equation of minimized sum of squares of the residuals with the software TableCurve 2D (Jandel Scientific, San Raphael, CA), and then plotting the 50% intercept. These values were then processed by ANOVA.

RESULTS

Flowering

In 1996, beans were sown one week later than in 1995 (Table 4.1). Initiation of the flowering stage occurred at approximately the same number of days after planting, but the flowering period lasted 8 days longer in 1996 (Table 4.1).

Within each year, weeding treatments had no significant effects on the number of days to the point of 50% flower production (Tables 4.2 and 4.3). Weeding treatments did not affect the number of flowers produced in 1995 (Table 4.2) but cultivation with the tine harrow increased flower production in 1996 compared to all other treatments except the weed-free check (Table 4.3).

The mean number of days to 50% flowering was longer in 1995 than in 1996 (Table 4.4) and the mean number of flowers produced was greater in 1995.

Pod production

The number of pods produced per plant was not affected by weeding treatments in either year (Tables 4.2 and 4.3). The fresh weight of the pods was not affected by weeding treatments, nor was the dry weight of aboveground vegetative parts.

The mean number of pods produced per plant was lower in 1995 than in 1996 and yet the total fresh weight was higher in 1995 than 1996 (Table 4.4). Mean dry weight accumulation was also higher in 1995.

Flower and pod abscission

The percentage of pods and flowers that were abscised was not affected by weeding treatments in either year (Tables 4.2 and 4.3), but the mean percentage abscission was higher in 1995 than 1996 (Table 4.4).

Table 4.1. Snap bean flowering pattern, Macdonald farm, mineral soil, 1995 and 1996. Sowing date, number of days after planting that initiation and end of flowering occurred and total days in flowering production.

Year	Sowing date	Flowering Start (DAP)	Flowering End (DAP)	Flowering period (days)
1995	June 7	35	56	21
1996	May 31	37	66	29

DAP = days after planting.

Table 4.2. Macdonald farm, mineral soil, 1995. Number of days after the first flower opened to the day when 50% of the total number of flowers had opened, total number of flowers and pods counted, percentage of flowers and pod abscised, total fresh weight of pods and mean plant dry weight.

TREATMENT	days to 50%	# flowers	# pods	% abscised	Yield (g)	Biomass (g)
Weedy check	9.65	25.22	13.00	49	115.84	29.75
Weed-free	8.06	33.44	10.11	70	117.68	27.64
Herbicide	10.26	36.11	13.00	63	124.62	31.57
Rotary hoe	10.06	33.78	8.89	75	106.31	29.66
Tine harrow	8.63	31.79	12.89	58	116.05	31.75
Torsion weeder	7.99	29.44	10.22	64	118.80	31.93
Rotary hoe + Danish tines	7.96	27.11	11.22	54	118.27	30.87

* No significant differences.

Table 4.3. Macdonald farm, mineral soil, 1996. Number of days after the first flower opened to the day when half of the total number of flowers had opened, total number of flowers and pods counted, percentage of flowers and pod abscised, total fresh weight of pods and mean plant dry weight.

TREATMENT	days to 50%*	# flowers	# pods*	% abscised	Yield* (g)	Biomass * (g)
Weedy check	4.63	19.43 b	12.80	35	60.28	8.63
Weed-free	4.88	23.73 ab	22.10	11	94.37	16.32
Herbicide	5.16	18.00 b	16.00	15	71.47	11.00
Rotary hoe	5.93	18.77 b	19.00	7	84.79	13.21
Tine harrow	5.77	27.43 a	22.97	20	105.39	17.39
Torsion weeder	4.67	18.37 b	16.30	15	68.70	10.77
Rotary hoe + Danish tine	5.95	20.13 b	20.00	11	98.69	14.71

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.
* No significant differences.

Table 4.4. Comparison of bean flowering and pod set in 1995 and 1996, Macdonald Farm, mineral soil. Number of days after the first flower opened to the day when half of the total number of flowers had opened, total number of flowers and pods counted, percentage of flowers and pod abscised, total fresh weight of pods and mean plant dry weight.

Year	**days to 50%**	**# flowers**	**# pods**	**% abscission**	**Yield (g)**	**Biomass (g)**
1995	8.94 a	32.41 a	11.33 a	62 a	116.84 a	30.45 a
1996	5.28 b	20.84 b	17.14 b	16 b	83.48 b	13.15 b

Means within a column followed by the same letter are not significantly different at $P<0.05$ according to Duncan's multiple range test.

DISCUSSION

Within years, weeding treatments did not affect variables of the reproductive development of snap beans, whereas year to year changes did. Within a given year, the number of days to 50% flowering, the number of pods produced, the amount of flowers and pods abscised and the biomass accumulation appeared unaffected by weeding treatments. In one year, cultivation with the tine harrow increased flower numbers, but there was no subsequent influence on the number of pods produced, and the difference was not realized at harvest. Previous studies have detected differences in flowering production that ultimately affected yield, but these studies compared among several types of bean cultivars, not just within one (Binnie and Clifford 1981; Subhadrabandhu et al. 1978). In addition, the differences in the number of flowers produced may have been affected when weather delayed one flower counting interval to 5 days instead of the usual 2-3. Patchy flower production was observed in the field and this five day period may have influenced the total flower count by including or omitting a flush of flowering.

Determinate bean cultivars, such as the one used in this experiment, are grown for mechanical harvesting and are bred for uniformity of pod set since harvesting can only take place once in the season. It is not surprising therefore that relatively little variability was observed among treatments versus between years. Individuals of a cultivar are expected to respond similarly to the same environmental conditions. Weeding therefore did not alter plant environmental factors within each treatment sufficiently enough to cause differential responses in flowering and pod set.

Plant dry weights were higher and the time to 50% flowering was longer in 1995. At flowering, bean plants have accumulated the majority of their biomass (Egli and Legget 1973), so presumably the plants in 1995 would have a comparatively larger photosynthate source to provide nutrients for developing flowers and pods, compared to 1996. However, the percentage of abscission in 1995 was greater and on average fewer pods were produced, but this did not impact the yield. The pods that were produced weighed more on average than the ones produced in 1996. The number of pods produced in 1996 was higher than 1995, but the vegetative dry weights were lower and pods developing on these smaller plants would presumably be more nutrient limited compared ot pods growing on larger plants.

Differences in the percentage of abscised flowers and pods was also compensated for at yield realization, as none of the differences seen in abscission percents appeared at harvest. The percent abscission observed in 1996 may be lower than actual, since one flower count interval was longer than ideal (explained above). Some flowers that were produced may not have been counted.

Conclusion

Patterns of flowering, pod set, abscission, yield and biomass were observed between years, but similar patterns were not detected at the treatment level. Environmental differences in temperature and precipitation between the years probably accounts for most of the differences. However, in a 5 year study on faba beans, no correlations could be detected between weather patterns and flowering and pod set patterns (Quagliotti et al. 1994). The biggest influence on yield realization may be the amount of biomass accumulated prior to flowering, but this hypothesis would need to be further tested.

Different methods of weed control used in this experiment did not affect the reproductive development of this bean cultivar and where they did, differences were not reflected in yield.

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GENERAL CONCLUSION

Modern farming practices depend upon chemical pesticides to maintain high crop yields and low disease levels. Increasing awareness and concern about the use of chemicals in agriculture, incomplete weed control and economic factors drive the investigation of non-chemical alternatives. Producers report that one of the major factors limiting the use of non-chemical methods is the lack of viable options. In a way, this study rediscovers some of the forgotten knowledge about cultural methods that farmers employed prior to the advent of chemical herbicides. Performance of technically engineered and improved cultivation machinery used for inter-row weed control no doubt vastly exceeds the performance of the original mechanized machinery. The present study found that mechanical weed cultivation is beneficial to the production of snap bean, carrot and lettuce crops in aspects of crop yield, crop quality, pathology and phenology.

Some form of weed control, whether chemical or non-chemical, is necessary to maintain yields in snap bean, carrot and lettuce production. Overall, when mechanical weed control was used, crop yields and quality were similar to or tended to be greater than that obtained with the standard chemical methods (bean and carrot) or standard non-chemical method (lettuce). Increases in yield and quality, even though statistically non-significant, may represent important economic benefits. Cultivator performances varied little within a crop or season, but differences were observed among crops and between years. Mechanical weed cultivation can be used to reduce or eliminate herbicide application without impacting bean and carrot yield and quality and can reduce production costs in lettuce without impacting yield and quality.

Mechanical weed cultivation reduced disease levels compared to herbicide treatments in beans and carrots, but did not seem to affect disease levels in lettuce. Disease levels were positively correlated with the length of the weeding period. Producers should therefore try to minimize working in the field late into the season. If late season weed control must take place, it should be done in dry conditions.

A possible relationship between Cercospora blight levels and carrot foliage breakage, of interest because roots may be left unharvested, was not found. Regardless of weeding treatment, increased blight tended to reduce root weight and leaf weight. Differences in Cercospora blight levels were not generally detected, but there were indications that the tine harrow had an influence on the disease.

Stages of flowering and pod set in bean were not affected by cultivation.

Results of these studies demonstrate that mechanical inter-row cultivation for weed control can be used as a substitute for or in combination with chemical methods to achieve similar yields, quality and disease levels as herbicide use alone. Mechanical cultivation provides an alternative to chemical weed control methods for bean and carrot producers who are concerned about the detrimental characteristics of herbicide use. In lettuce production, cultivation can be used to reduce costs of production.

Mechanical weed cultivation is of increasing importance as a viable alternative to chemical weed control, but research is far from complete. Effects of mechanical cultivation vary with the type of cultivation implement used, crop type, soil type and from year to year. Future studies should be conducted over several years in different crops and on different soils in order to better understand consistencies in how cultivation interacts with the crop plant environment. Producers could then choose the most appropriate mechanical cultivator for the crop and soil type of interest. Mechanical weed cultivation may also prove to be important as a non-chemical disease control strategy. More work needs to be conducted on this aspect, ideally in fields with a history of severe disease, in order to elucidate specifically how mechanical cultivation interacts with disease development and spread.

APPENDIX

A.I ANOVA output for the green bean harvest at Macdonald, 1996. Fungicide was applied. Variable CANAW = Canada A category pods weight, CANBW = Canada B category pods weight, REFW = refuse category pods weight, TOTN = total pods harvested number, TOTW = total pods harvested weight.

General Linear Models Procedure

Class	Levels	Values
BLK	3	1 2 3
TRT	7	1 2 3 4 5 6 7

Number of observations in data set = 21

Dependent Variable: CANAW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	29.2989524	3.6623690	3.49	0.0255
Error	12	12.5821714	1.0485143		
Corrected Total	20	41.8811238			

R/Square	C.V.	Root MSE	CANAW Mean
0.699574	18.01103	1.02397	5.6852381

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLK	2	3.4314952	1.7157476	1.64	0.2353
TRT	6	25.8674571	4.3112429	4.11	0.0179

Dependent Variable: CANBW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	7.27929524	0.90991190	2.95	0.0448
Error	12	3.70193333	0.30849444		

Corrected Total	20	10.98122857

R/Square	C.V.	Root MSE	CANBW Mean
0.662885	14.99984	0.55542	3.7028571

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	1.56140000	0.78070000	2.53	0.1211
TRT	6	5.71789524	0.95298254	3.09	0.0456

Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLK	2	1.56140000	0.78070000	2.53	0.1211
TRT	6	5.71789524	0.95298254	3.09	0.0456

Dependent Variable: REFW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	48.9618190	6.1202274	10.68	0.0002
Error	12	6.8737619	0.5728135		
Corrected Total	20	55.8355810			

R/Square	C.V.	Root MSE	REFW Mean
0.876893	11.62758	0.75684	6.5090476

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	0.0990381	0.0495190	0.09	0.9177
TRT	6	48.8627810	8.1437968	14.22	0.0001

Dependent Variable: TOTN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	9032832.10	1129104.01	5.49	0.0045
Error	12	2468000.19	205666.68		

Corrected Total	20	11500832.29			

R/Square	C.V.	Root MSE	TOTN Mean
0.785407	11.82146	453.505	3836.2857

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	403819.14	201909.57	0.98	0.4028
TRT	6	8629012.95	1438168.83	6.99	0.0022

Dependent Variable: TOTW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	198.809200	24.851150	7.39	0.0012
Error	12	40.375467	3.364622		
Corrected Total	20	239.184667			

R/Square	C.V.	Root MSE	TOTW Mean
0.831195	11.53884	1.83429	15.896667

Dependent Variable: TOTW

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	6.640467	3.320233	0.99	0.4011
TRT	6	192.168733	32.028122	9.52	0.0006

A.II ANOVA output for the carrot harvest at Ste Clotilde, 1996. Fungicide was applied. Variable SMAW = small category carrot weight, CANW = Canada #1 category carrots weight, JUMW = jumbo category carrots weight, REFW = refuse carrots weight, TOTN = total number carrots harvested, TOTW = total weight carrots harvested.

General Linear Models Procedure

Class Level Information

Class	Levels	Values
BLK	3	1 2 3
TRT	7	1 2 3 4 5 6 7

Number of observations in data set = 21

Dependent Variable: SMAW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	49.8959048	6.2369881	5.31	0.0051
Error	12	14.0972762	1.1747730		
Corrected Total	20	63.9931810			

R-Square	C.V.	Root MSE	SMAW Mean
0.779707	33.96696	1.08387	3.1909524

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	2.5277238	1.2638619	1.08	0.3717
TRT	6	47.3681810	7.8946968	6.72	0.0026

Dependent Variable: CANW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	1301.25143	162.65643	3.77	0.0194
Error	12	517.72000	43.14333		
Corrected Total	20	1818.97143			

R-Square	C.V.	Root MSE	CANW Mean
0.715378	20.69240	6.56836	31.742857

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	69.86000	34.93000	0.81	0.4679
TRT	6	1231.39143	205.23190	4.76	0.0105

Dependent Variable: JUMW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	805.429562	100.678695	4.22	0.0128
Error	12	286.570533	23.880878		
Corrected Total	20	1092.000095			

R-Square	C.V.	Root MSE	JUMW Mean
0.737573	34.49626	4.88681	14.166190

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	66.304867	33.152433	1.39	0.2869
TRT	6	739.124695	123.187449	5.16	0.0077

Dependent Variable: CULW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	950.557486	118.819686	4.25	0.0124
Error	12	335.372895	27.947741		
Corrected Total	20	1285.930381			

R-Square	C.V.	Root MSE	CULW Mean
0.739198	25.23533	5.28656	20.949048

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	23.171038	11.585519	0.41	0.6698
TRT	6	927.386448	154.564408	5.53	0.0059

Dependent Variable: TOTN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	113864.667	14233.083	0.69	0.6958
Error	12	248146.476	20678.873		
Corrected Total	20	362011.143			

R-Square	C.V.	Root MSE	TOTN Mean
0.314534	14.91054	143.802	964.42857

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	69476.8571	34738.4286	1.68	0.2274
TRT	6	44387.8095	7397.9683	0.36	0.8919

Dependent Variable: TOTW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	6329.90571	791.23821	45.57	0.0001
Error	12	208.34667	17.36222		
Corrected Total	20	6538.25238			

R-Square	C.V.	Root MSE	TOTW Mean
0.968134	5.948120	4.16680	70.052381

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	93.12667	46.56333	2.68	0.1089
TRT	6	6236.77905	1039.46317	59.87	0.0001

A.III ANOVA output for lettuce harvest at Ste Clotilde, 1996. Variable CAN = Canada A category lettuce weight, REFW = refuse category lettuce weight, TOTN = total harvest number of lettuce, TOTW = total harvest lettuce weight.

General Linear Models Procedure
Class Level Information

Class	Levels	Values
BLK	3	1 2 3
TRT	7	1 2 3 4 5 6 7

Number of observations in data set = 21

Dependent Variable: CAN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	2910.25405	363.78176	3.48	0.0259
Error	12	1255.34281	104.61190		
Corrected Total	20	4165.59686			

R-Square	C.V.	Root MSE	CAN Mean
0.698640	39.85747	10.2280	25.661429

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	391.08526	195.54263	1.87	0.1965
TRT	6	2519.16879	419.86147	4.01	0.0194

Dependent Variable: REFW

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	674.159324	84.269915	1.79	0.1742
Error	12	563.594400	46.966200		
Corrected Total	20	1237.753724			

R-Square	C.V.	Root MSE	REFW Mean
0.544664	33.58074	6.85319	20.408095

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	437.611267	218.805633	4.66	0.0318
TRT	6	236.548057	39.424676	0.84	0.5629

Dependent Variable: TOTN

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	188.073838	23.509230	1.27	0.3435
Error	12	222.728543	18.560712		
Corrected Total	20	410.802381			

R-Square	C.V.	Root MSE	TOTN Mean
0.457821	6.989208	4.30821	61.640952

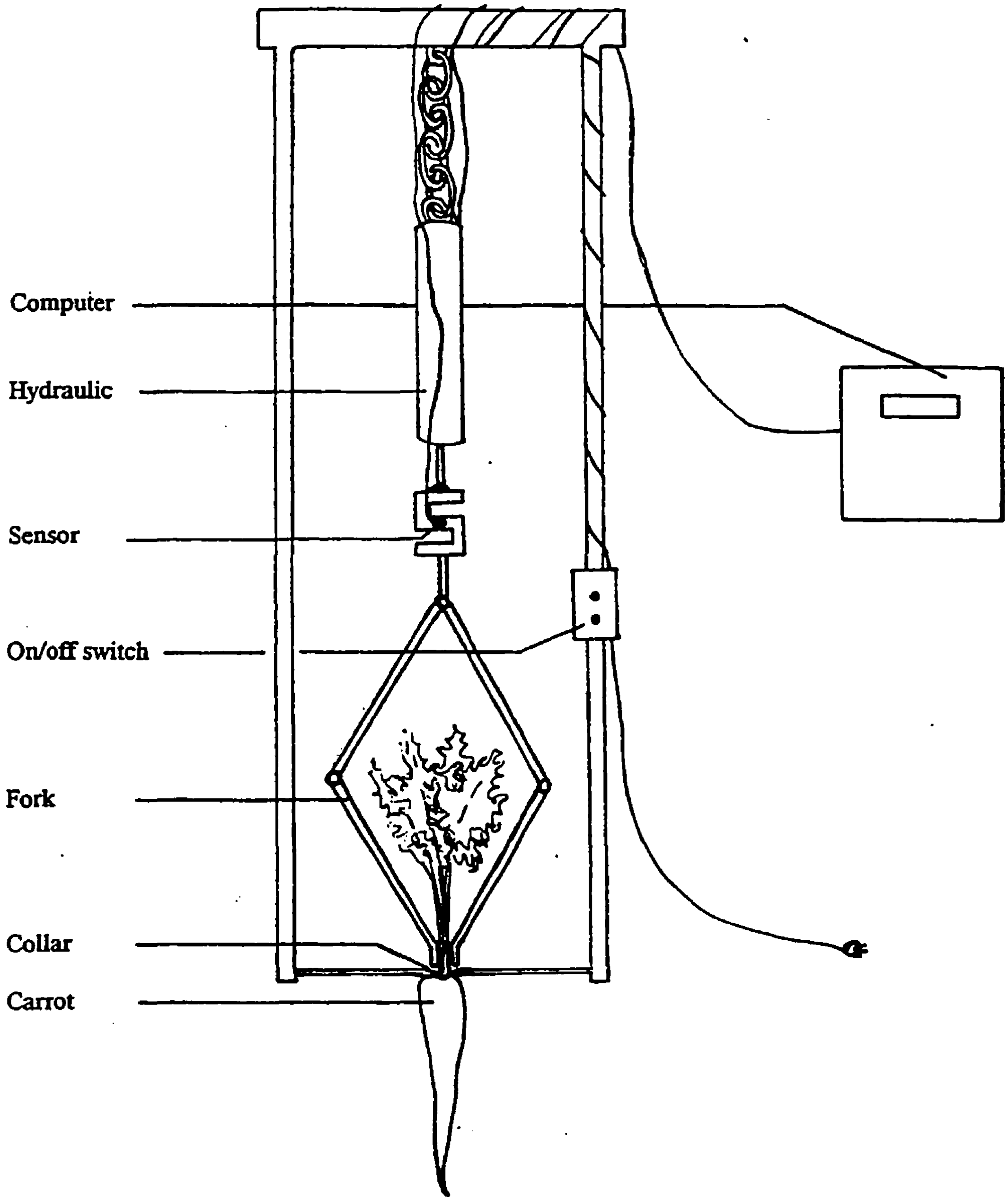
Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	13.960924	6.980462	0.38	0.6944
TRT	6	174.112914	29.018819	1.56	0.2399

Dependent Variable: TOTW

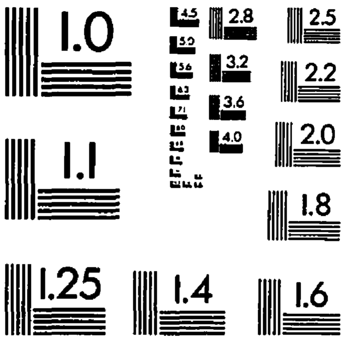
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	893.347581	111.668448	12.39	0.0001
Error	12	108.160876	9.013406		
Corrected Total	20	1001.508457			

R-Square	C.V.	Root MSE	TOTW Mean
0.892002	7.936418	3.00223	37.828571

Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLK	2	142.915657	71.457829	7.93	0.0064
TRT	6	750.431924	125.071987	13.88	0.0001



A.IV. Carrot pulling apparatus. Carrot is placed in stationary collar at the junction of petiole and crown. A fork attached to a hydraulic is clamped onto petioles as close to the crown as possible. The hydraulic is turned on and pulls the fork upwards. A sensor on the "s" shaped metal object records to a computer the amount of force (Newton per square meter = Pa) required to pull petioles from the root.



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