INFLUENCE OF A ROW COVER AND COVERING DURATION ON GROWTH AND DEVELOPMENT OF EARLY MINI CARROT AND CRISPHEAD LETTUCE IN SOUTHERN QUEBEC.

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INFLUENCE OF A ROW COVER
AND COVERING DURATION

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OPTIMUM ROW COVERING DURATION

FOR MINI CARROT AND ICEBERG LETTUCE

ABSTRACT

M.Sc. Sylvie Jenni Plant Science

Influence of a row cover and covering duration on growth and development of early mini carrot and crisphead lettuce in Southern Quebec

Field experiments were established in muck soil to determine optimal removal time of a floating row cover for early crops of crisphead lettuce and mini carrot.

Covering mini carrot reduced the time to harvest by 7 days in 1987 and 1988. The row cover reduced mean emergence time and increased plant uniformity at harvest. Highest yields were obtained when the row cover was left on the crop at least 39 days. Root/shoot partitioning was affected by the use of the row cover.

Covered crisphead lettuce plants were harvested 4 and 7 days earlier than the control in 1987 and 1988, respectively. Growth of both covered and uncovered plants fitted a common logistic relationship when growing degree-days were used as a time scale. Head formation started earlier for covered lettuce as indicated by a higher width to length ratio of the 13^{th} leaf and a higher rate of leaf production. The critical stage for cover removal occurred at "soil cover". Although firmer and larger heads were harvested with longer covering periods, plants showed increased symptoms of tipburn, sunscald and disease.

RESUME

M.Sc Sylvie Jenni Phytotechnie

Influence d'une couverture flottante et de sa période de recouvrement sur la croissance et le développement des cultures hâtives de la mini carotte et de la laitue pommée

Des essais en terre noire ont été établis afin de déterminer la période optimale de recouvrement d'une couverture flottante pour les cultures hâtives de la laitue pommée et de la mini carotte.

La couverture flottante a produit des gains de hâtivité de 7 jours pour la mini carotte en 1987 et en 1988. On a observé une réduction du temps de germination ainsi qu'une plus grande uniformité des racines à la récolte. De meilleurs rendements ont été obtenus quand la couverture restait sur les plantes pendant au moins 39 jours après la germination. On rapporte aussi un effet de la couverture flottante sur la répartition racine:feuillage.

La récolte des laitues pommées recouvertes s'est effectuée 4 et 7 jours avant le témoin en 1987 et 1988, respectivement. La croissance des laitues couvertes et non couvertes était reliée par une équation logistique commune quand l'accumulation de degré-jours était utilisée comme échelle de temps. Un ratio largeur/longueur de la 13ème feuille plus élevé et une production de feuilles accrue étaient les indices de la formation avancée de la pomme des laitues couvertes. Le stade de croissance "couverture du sol" en était un critique pour l'enlèvement des couvertures flottantes. Car même si on obtenait des laitues plus fermes et plus grosses avec de plus longues périodes de recouvrement, des symptômes de brûlure marginale, d'échaudure et de maladie augmentaient.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS USED

Abbreviation	Term represented
AGR	absolute growth rate
CV	coefficient of variability
EPP	extruded polypropylene
GDD	growing degree-day
max	maximum
min	minimum
P	probability
PA	polyamid
PAR	photosynthetically active radiation
PE	polyethylene
PI	photosynthetic irradiance
PPFD	photosynthetic photon flux density
PVC	polyvinyl chloride
RGR	relative growth rate
SAS	statistical analysis system
SPE	spunbonded polyester
SPP	spunbonded polypropylene
UV	ultra violet

1. INTRODUCTION

Early spring vegetables in Quebec often display poor germination, transplant shock, reduced vigor and ultimately irregular maturity. These problems are a direct result of the poor environmental conditions (wind, temperature, moisture stress) during the planting period. One method which can be used to successfully modify the microclimate under field conditions is the row cover. Row covering offers a compromise between expensive greenhouses, which provide an ultimate in environment control, and mulches which act exclusively on the root system. Wells and Loy (1985) described row covers as "flexible, transparent coverings which are installed over single or multiple rows of vegetables for the purpose of enhancing growth and yield". These include tunnels, which are supported by hoops, and floating row covers, which are directly laid on the crop.

In general and in particular in Quebec, most of the work on row covers has been done on members of the Curcubitaceae and Solanaceae using combinations of mulches and tunnels (Wells and Loy, 1985; Argall and Stewart, 1987, 1988). One reason is that the most widely used row cover material, polyethylene, generates high temperatures to which these are well adapted. It can, however, produce a problem for cool season crops because temperatures found under these cover are well above their optimal range. However, cool season crops are of major economical importance in term of vegetable production in Quebec, particularly in the muck soil area. Carrot and lettuce were the first and the fourth most important vegetable crops grown in Quebec with farm values of 14 and 10 million dollars, respectively (Bureau de la statistique du Quebec, 1986). Quebec accounted for 47 % of the lettuce and 34 % of the carrot produced in Canada (Statistics Canada, 1988).

Recently, new types of plastics have arrived on the market, called Agrotextiles. These are made of polyester, polypropylene and polyamid and seem particularly suited for use as row covers. They are extremely light and do not need support and have a high uniform porosity to air and water which prevents excessively high temperatures from building under the floating row cover. Furthermore, most agrotextiles are available in width up to 12.8 meters, which substancially reduces installation costs.

The objectives of the present study were:

1) to evaluate the potential benefit of a 12.8 meter wide floating row cover on yield of two cool season crops, a leafy crop, iceberg lettuce and a root crop, mini carrot in the muck soil area of Southern Quebec.

2) to determine the optimal growth stage or time for the removal of the floating row cover on these two crops.

3) to study the effect of row cover microclimate modifications on growth and development of iceberg lettuce and mini carrot.

2 LITERATURE REVIEW

2.1 Floating row covers

2.1.1 Historical perspective

The environment in which a plant grows is not always ideal. Horticulturalists have for centuries attempted to protect their plantings from the hazards of the natural environment. Garnaud (1984) stated that, initially, there were windbreaks of reeds and straw, mulches of stones, paper or various organic materials, these in turn lead to the use of glass and plastics. Growers began to make full use of glass mainly in the form of cloches, hot and cold frames, and glasshouses. The discovery of plastics brought about a new era in the horticultural industry. Polyethylene originated in Britain in 1937, but was classed as strategic material and was not released until 1946-47 following the end of the war (Garnaud, 1984). Emmert (1955), considered by many as the 'father of plastics' (Hall and Besemer,1972), developed many principles of the technology with his research on mulches, row covers and greenhouses. In 1960, Shadbolt and McCoy, working with cantaloupe, established the superiority of plastic row covers over the widely used paper hot tents. Wells and Loy (1985) considered the hot tents as the forerunners of row covers. In California during the sixties, Hall and Besemer (1972) established the practical and commercial uses of row covers for cucumbers, tomatoes and peppers. The first type of row cover used in California consisted of two-pieces of 0.9 meter wide solid plastic laid on wire hoops, secured along the edges with soil, reinforced with additional wires or strings and joined at the center of the row with special clothespins (Hall and Besemer, 1972). The system provided both a shelter and, with the central opening, ventilation for the plants. The two-piece system had problems in that it was very laborious to maintain and subject to wind damage (Wells and Loy, 1985). Perforated or slitted plastic films were introduced to overcome the problem of manual ventilation of these low tunnels. This self ventilating system reduced manual labour and installation costs, the latter by eliminating all fixing other by soil. The wire hoops were still present (Wells and Loy, 1985). Although research had been conducted, perforated row covers were not commercialized in the United States to the same extend that they were in Europe and the Middle East. Indeed, it was only in 1980 that "slitted row covers" were commercially available.

Since 1964, Seitz, in West Germany, has carried out a series of experiments using perforated films for low tunnels and direct soil covering to hasten germination (CTIFL, 1987). His research led in the late sixties to a technique called "Flachfolie" which involved the use of unsupported film coverings. The use of this system became wide spread through Western and Central Europe (Garnaud, 1984). This technique has been referred to as floating row cover in the United States and floating mulch in the United Kingdom. Originally, the covering materials were composed of either polyethylene (PE) or polyvinyl chloride (PVC) (Baudonnel and Sotton, 1985). Initially, a problem arose since the PE film was degraded by ultraviolet (UV) radiation. This was later corrected and the first form of UV stabilized

PE film was marketed around 1960 (Bloom and Ingratta, 1985). PVC manufacture showed extrusion problems which affected quality and life of the product. Although PVC was slightly more effective in retaining heat, it was more costly than PE (Hall and Besemer, 1972).

Recently, several new row cover materials have been developed as offshoots from the fiber industry. These non-woven textiles are commonly referred to as agrotextiles (Baudonnel and Sotton, 1985). They first appeared in 1976-1977 in Eastern France and have become widely adopted since 1980 (Baubonnel and Sotton, 1985; Wells and Loy, 1986).

Agrotextiles have several advantages over plastic films. They are very light, thin and flexible, not requiring hoops for support. They are generally very homogeneous, having a high porosity (to air and water) which is not localized as in the case of perforated films, but rather distributed on the scale of fiber interlinks (Baudonnel and Sotton, 1985). A significant advantage of agrotextiles is the ease of application, limited by anchoring the edges of the cover with soil. This also reduces the cost of labour as compared to the wire hoop installation of perforated or slitted tunnels (Loy and Wells, 1982). This became especially significant with the introduction of wide-width row covers, first in Europe in 1979, and recently (1986) in North America. In 1987, over 50 % of agrotextiles covers used in Europe were over 10 meters wide (Christensen, 1987). Cost savings in installation and removal of the row covers make them practical and manageable on larger scales.

2.1.2 The Agrotextiles: definition and terminology

In agriculture, two types of plastic material are used. The films are perforated or slit mechanically after manufacture by extrusion blowing (CTIFL, 1987). The most common films include polyethylene (PE) and polyvinyl chloride (PVC). Secondly, the agrotextiles are manufactured by several different methods but always from fibers or filaments distributed in an isotropic manner to form a voile (Baudonnel and Sotton, 1985). They include polyester, polypropylene and polyamid (nylon).

Plastics are based on polymers which are long chains of the monomer ethylene $CH_2=CH_2$ (Dubois, 1978). The agrotextiles are manufactured with direct production of filaments and thermo-welding (Baudonnel and Sotton, 1985; CTIFL,1987). The first stage corresponds to the plastic processing and consists of the fusion and homogenization of the polymer and any possible additives (pigments, mineral fillers, UV stabilisers, anti-oxidants and colourants). The second or 'fibre' stage starts with the production of filaments passing the molten polymer through holes in a die. The filaments are then cooled and stretched to align the polymer molecules. Finally, the filaments are formed into a mat or voile with the greatest possible isotropy and homogeneity and then 'hot calendered' by being pressed between two heated rollers. Non woven fabrics of this type can be produced with widths of 2 to 4 meters. These, in turn, can be joined together by welding or stitching to obtain widths to a maximum of 12.5 meters (Baudonnel and Sotton, 1985).

Another type of agrotextile, referred to as extruded, are

Table 2.1: Agrotextile row covers sold commercially in North America (a).

TRADE NAME	MANUFACTURER OR DISTRIBUTOR	TYPE (b)	WEIGHT (in g/m^2)	WIDTH (in meters)
AGRONET	Beghin Say CDK International	95 % EP 5 % PA	15.9	1.1-12.8
AGRYL P17	Sodoca American Agrifabrics	SP	17.4	1.8-10.4
KIMBERLY FARMS	Kimberly Clark	SP	17 43 57	1.6-14.6
REEMAY	Reemay, Inc. (U.S.) Dupont (Canada)	SE	17 34.6	1.7-2.4

(a) sources: Wells and Loy (1986), Hochmuth et al. (1986), Regan (1987).
(b) (EP)= extruded polypropylene
(PA)= polyamid
(SP)= spunbonded polypropylene
(SE)= spunbonded polyester

manufactured with a different technique (Baudonnel and Sotton, 1985; CTIFL, 1987). It involves a two-way stretching of a flat film obtained by co-extrusion of the filaments to produce a fibrous network.

The most common agrotextiles presently found on the market are presented in table 2.1 with key features.

2.1.3 Environmental modification

2.1.3.1 Effects on temperature

Row cover are effective in increasing daytime and nightime, soil and air temperatures as a result of reduced radiant and convective heat loss below the cover (Tanner, 1974). Numerous field experiments have shown increased temperatures with perforated or slitted polyethylene (PE) (Shmueli and Goldberg, 1971; Loy and Wells, 1982; Tan, Papadopoulos and Liptay, 1984; Wells and Loy, 1985; McCraw, 1986; Perry and Sanders, 1986; Wolfe, Wyland, Albright and Novak, 1986; Mansour and Hemphill, 1987), spunbonded polyester (SPE) (Loy and Wells, 1982; Wells and Loy, 1985; Hassel,1986; Abbes, Hemphill and Mansour, 1987; Mansour and Hemphill, 1987; Pollard, Loy and Wells, 1987; Sanders, Giacomelli and Ginger, 1987), extruded polypropylene (EPP) (Wells and Loy, 1985; Pollard et al., 1987; Sanders et al, 1987) and spunbonded polypropylene (SPP) (Hassel, 1986; Pollard, 1987; Sanders et al, 1987).

While field testing is indispensable for an accurate assessment of specific crop responses under a variety of environmental conditions, controlled environments provide a rapid and efficient method for evaluating a large number of row covers without relying on the vagaries of natural conditions. Sanders, Turlington and Perry (1987) tested the temperature response of different row cover materials placed on wet and dry soils in a controlled environment. Lights (262 W/m^2 fluorescent-incandescent) were on for 9 hours and air temperature was lowered from 10 ^oC at a rate of 0.9 ^oC per 1/2 hour. Greatest warming was found under clear PE which exceeded outside air temperature by 13 ^oC during the light period, followed by EPP 9 ^oC, SPP 8 ^oC and SPE 5 ^oC. The differences in air temperatures under and over the cover at the end of the cooling period over dry and wet soils were respectively as follows: clear PE 3 ^oC, 5.1 ^oC; SPP 1.5 ^oC, 0.8 ^oC; SPE 1.9 ^oC, 0.9 ^oC; EPP 0.8 ^oC, 0.9 ^oC.

Pollard, Loy and Wells (1987) studied thermal transmission of several row cover materials. Styrofoam ice boxes (2.5cm by 35cm by 30cm) containing one liter of water were fitted with 3 meters heating coils as a heat source, and thermocouples. Test materials were sealed across 100 cm^2 openings at the tops of the chambers. These boxes were placed in a refrigerated room at 7.2^{o}C and the water in the test chamber was heated to 27.2^{o}C. After the heat source in the water of the test chambers was switched off, water temperature in the control chamber (no cover) dropped 8.3^{o}C in a linear fashion over a 30 minute time period. Row cover treatments slowed down the rate of decrease in water temperature, with SPE and SPP being the most and EPP the least effective.

Although controlled environment studies provide rapid evaluation about the thermal properties of row cover materials, actual temperature effect of these covers under field conditions is much more complex. The degree of frost protection or the increase in temperature over outside air temperature varies considerably depending on several factors. These include not only thermal properties of the covering material but also degree of perforation, width, condensation on the material, heat input from previous days, thermal properties of the soil, cloud cover, wind and others (Shadbolt, McCoy and Whiting, 1962).

Perforation in floating row covers seems necessary to prevent excessively high temperatures under the cover. Shadbolt et al. (1962) studied the effect of perforation on low plastic tunnel temperatures. During the night, when heat was being radiated from the soil, the temperature diminished slightly under the perforated covering material because of convection of warm air upward through the perforations. During the day, due to rapid heating and expansion of air under the covers, this convection proceeded at a more rapid rate. In addition, winds occured more during the day than the night, caused further movement of air through the perforations.

Guttormsen (1972) concluded that a marked reduction in cumulative day-time heat and in extremes of day-time temperatures resulting from perforation was far more important than the slight reduction in protection against frost.

For Wells and Loy (1985), the currently available agrotextiles, which are relatively porous, offered a compromise in providing frost control and increased night-time temperatures, while not increasing day-time temperatures which are excessive for plant growth and fruiting.

Most heat retention and frost protection afforded by PE covers are due to condensation of moisture on the inside surface of the covers (Delwiche and Willis, 1984). Unlike glass covering which typically have thermal transmissivities less than 5 % (Walker and Slack, 1970), PE films have relatively high transmissivities resulting in increased radiant heat loss and a reduced greenhouse effect. The transmittance of water, even for a thin layer (<1mm) has a zero value in the far infrared wavebands (Nijsken, de Halleux, Deltour, Coutisse and Nisen, 1984). Nijskens et al. (1985) found that transmittance in the far infrared range of a dry PE cover drops from 77 % to 0 % after appearance of condensation which acts as a heat barrier.

Savage (1980) observed rapid cooling in a plastic tunnel after sunset as a result of a PE film being highly transparent to long wave radiation. This rapid cooling caused condensation of water on the inside of the cover. The plastic cover with its water film transmitted only wavelengths of less than 2500 nm, resulting in a considerably reduced cooling rate.

Quite commonly, the cover temperature drops at night below dew point. The water vapor of the humid interior air condenses on the cold surface and in the process, gives up heat to the cover (exothermic process; Nijskens et al., 1985; Tanner, 1974). However, whether water condenses as droplets or as a continuous film on the inner surface also acts on temperature. Avissar, Mahrer, Kargulies and Katan (1986 a, b) investigated the reason why temperatures of soils mulched with old PE sheets were always higher than those mulched with new ones. Since new PE sheets are hydrophobic, water condensed on them in very small droplets. These droplets increased solar radiation reflectance of the cover and, therefore, reduced radiative solar energy flux that reached soil surface. As the plastic aged in the field, the hydrophobic properties of the PE vanished due both to weathering and the adhesion of fine soil particles. Then, as a water film formed on the sheet, more radiative solar energy reached the soil surface and relatively less IR radiation was transmitted. The authors have also shown the reduction in transmittance to solar radiation of new PE sheets to have a more profound effect than the reduction in IR transmittance.

Narrow row covers do not produce the same rise in temperature as wider ones. Working with PE mulches, Mahrer and Kathan (1981) found that soil heating at the edges of a PE film was lower than at the center and thus a narrow mulch provides less efficient heating than a wider one. Working with low PE tunnels, Shadbold, McCoy and Whiting (1962) found that both air and soil temperatures under the narrow cover were generally several degrees cooler than those of the wider covers. They concluded therefore that the wider cover would afford more frost protection. Plant growth was also reported to be reduced under the narrow cover.

Row cover effect on temperature was found to be influenced by cloud cover. Guttormsen (1972 b), working with plastic tunnels, showed cloud cover to be strongly correlated to tunnel air temperature, and particularly to the day-time maximum temperature (the coefficients of curvilinear correlation were April, -0.945, July, -0.897, September -0.802, all significant at the 0.01 level). The relationship between the effect of the tunnels on air night time minima and mean cloud cover was less and dependent on the month (April, -0.741, July -0.477, September, 0.567, all significant at the 0.01 level). In April, cloud cover reduced nocturnal thermal radiation and increased the effect of the tunnels on night time minima. In July, cloud cover reduced global radiation and also reduced the effect of the tunnels at night, probably as a result of the greater effect of the soil as a source of heat at night as compared to April. Guttormsen also found a greater tunnel effect on minimum night time temperature in the soil than in the air, especially on sunny days. Although these effects were on average consistently positive, he observed a negative effect (generally not greater than 1 ^{o}C in April) on air temperature on clear nights just before sunrise, when the movement of air in an open field was at its lowest.

The earth surface provides a source of heat which influences night-time heat balance beneath the covers. The minimum night-time temperature is dependent upon the accumulation of heat in the ground during the preceeding day (Guttormsen, 1972 b). The soil heat flux (S), or heat flow into and out of the soil, is given by:

$$S = K \; dT/dz$$

where dT/dz is the temperature gradient within the soil and K is the thermal conductivity (Rosenberg, Blad and Verma, 1983). Thermal conductivity depends on porosity, moisture content and organic matter content of the soil. At similar moisture contents, conductivity decreases from fine sand to silt loam to clay soil because of increasing porosity. Since soil temperature change with time as a result of heat transfer will vary with its heat capacity, it is useful to introduce thermal diffusivity (D)(in $m^2 s^{-1}$) as a function of volume specific heat (C_v; Rosenberg et al., 1983; Payne and Gregory, 1988):

$$D = K / C_v$$

Thermal diffusivity (D) of a soil is a parabolic function of moisture content (Moench and Evans, 1970). A small amount of water reduces the insulating effect of the pore space filled with air, (i.e. K increases more rapidly than C_v), but further increases in water content markedly increase the heat capacity. This is because the heat capacity of water, which is high, is substituted for that of air, which is almost negligeable (Rosenberg et al., 1983; Payne and Gregory, 1988). Soil organic matter lowers thermal diffusivity because of its influence in increasing porosity. Compaction increases the thermal diffusivity by decreasing the volume of the insulating pore space (Rosenberg et al., 1983).

2.1.3.2 Effects on air movement

In a cold climate, wind, or forced convection (Rosenberg et al., 1983), may be the major factor affecting the temperature level of crop plants and thus yield (World Meteorological Organization, 1964). Row covers act as a barrier to air circulation. In calm weather, the cover is immobile and the air circulates by free convection, in which the warm air rises due to density differences (Rosenberg et al., 1983; CTIFL, 1987). Under windy conditions, the cover follows air turbulence. It is alternatively flattened to the ground and sucked by the air producing a flapping movement of the cover which may be detrimental to the plants (Rickard, 1979; Hassel,1986; CTIFL,1987). The greater the degree of porosity of the cover, the less likely it will be caught up by the wind. The level of porosity varies from 2 to 8 percent for perforated films and 10 to 20 percent for agrotextile. According to CTIFL (1987), air renewal under Agryl P17 is three times more rapid than under perforated PE with 500 holes per square meter.

Agrotextiles floating row covers appear to be less effective in enhancing plant growth in windy climates (Wells and Loy, 1985). Pollard, Loy and Wells (1987) working in controlled environments, found that increased air velocities appreciably reduced heat retention of three tested agrotextile materials. Compared with low air movement (0.2-1.0 m/s), air velocities ranging between 2.0 to 3.0 m/s resulted in a more than 50 % decrease in air temperature gradients between interior and exterior of chambers covered with spunbonded polypropylene (SPP),spunbonded polyester (SPE) and extruded polypropylene (EPP). They concluded that wind speeds of over 8 km/h (2.2 m/s) would largely nullify any air temperature differences between the inside and the outside of agrotextile floating row covers. On the other hand, one might expect under windy conditions materials with greater porosity to allow for improved air circulation and hence to reduce the danger of night frost on clear night. However, as pointed out by Guttormsen (1972 a), if the air is motionless as it is often just before dawn, the danger of frost is not reduced.

2.1.3.3 Effects on moisture

Many studies have shown that PE mulches reduce water evaporated from the soil to the atmosphere, resulting in an increased soil moisture content compared with a bare soil (van Wijk, Larson and Wilding, 1959; Waggoner, Miller and de Roo, 1960; Couter and Oebker, 1964; Lippert, Takatori and Wilding, 1964; Takatori, Lippert and Wilding, 1964; Hopen, 1965; Shales and Sheldrake, 1966; Mayrya and Lal, 1981; Mahrer, Naot and Katan, 1984). However, the effect of a row cover on soil moisture is more complex and has been poorly investigated. Information on the subject has been limited to observations compiled in grower guides from France (CTIFL, 1987) and England (Rickard, 1979).

Row covers are permeable to rainwater. Agrotextiles readily allow percolation of water. However, the rate of passage may not be instantaneous due to the presence of small amounts of fatty acids on the material that makes initial wetting difficult. For perforated PE films, the water passage increases in uniformity as the number of holes increase (CTIFL,1987).

Evapotranspiration produces water vapor which rapidly saturates the ambiant air under the cover. At night, the cooling down of the cover favours condensation. During the day, in clear weather with dry air, the water vaporises into the atmosphere through the semi-permeable material and the row cover tends to become dry. Under cloudy conditions, relative humidity is at a maximum and the condensate drips on to both plants and soil (CTIFL,1987).

The increased rates of growth from the use of row covers may result in increased rates of evaporation from the soil/plant complex which may lead to an earlier soil moisture deficit. Rickard (1979) estimated the rate of water loss in the spring under a plastic row cover with 4 percent perforation to be about 1.7 times as much as that from a bare soil. If the soil moisture deficit is not compensated by irrigation or rainfall, the advantages of using row covers may be lost.

2.1.3.4 Effects on soil structure

The nature and size distribution of soil aggregates and that of pore space is referred to as soil structure and plays an important part in determining soil physical properties and hence soil fertility (Payne and Gregory, 1988). Bulk density (weight per unit volume) of soil was found to be lower under PE mulches (Emmert, 1957; Liptay and Tiessen, 1970). Water from rain or irrigation falling directly on the soil tends to compact the surface of the soil thus reducing soil aeration. Raindrop impact shatters soil clods and causes splashing, with some of the splashed droplets carrying fine soil particles, most of which are smaller than 0.2 mm (Ekern, 1950; Payne and Gregory, 1988). The finer dispersed particles will tend to clog coarser pores in the soil surface and this, coupled with soil levelling and compaction by raindrop impact, can cause a surface cap to be formed.

Row covers spread the impact of the water droplets over a larger surface area and hence reduce soil compaction (Liptay and Tiessen,1970; CTIFL, 1987). This is particularly important for seeded crops like onion, carrot, leek, red beet and others (Sale and Harrison, 1964; Hegarty, 1971; Hegarty, 1976; Hegarty, 1978; Hegarty and Royle, 1978; Finch-Savage, 1986; Mansour and Hemphill, 1987) where soil capping, caused by rainfall occuring shortly after sowing, was identified as a major factor causing emergence problems.

2..1.3.5 Effects on light

Radiation is one of the factors that determines the rate of photosynthesis and hence plant growth. Photosynthetically Active Radiation (PAR) is a measure of the radiation available for photosynthesis, that is radiation in the 400 to 700 nm waveband (McCree, 1981; Cathey and Campbell, 1980). PAR may be reported in either quantum as Photosynthetic Photon Flux Density (PPFD) in uE(einsteins).$s^{-1}m^{-2}$) or energy units as Photosynthetic Irradiance (PI) in ($W.m^{-2}$), although McCree (1981) suggested that PPFD was a more adequate measure of PAR as it leads to less systematic errors.

Wells and Loy (1985) reported that about 90 % of PPFD was transmitted through new clear PE covers and 80 % through spunbonded materials. CTIFL (1987) reported that agrotextiles transmit PAR with a loss of 10 to 20 %, that is 10 to 15 % for polypropylene and 15 to 20 % for polyester. The reduction in light transmission through agrotextiles should not limit growth of young plants in full or partial sun since

PPFD of full sun is well above the light saturation point for crop plants (Wells and Loy, 1985).

However, Loy and Wells (1982) and Wolfe, Wyland, Albright and Novak (1986) found transmission of PPFD to be lower on cloudy days. This was explained by a greater proportion of diffuse radiation (Wolfe et al., 1986) and the presence of water droplets condensed on the under surface of the cover which decreased light transmittance (Loy and Wells, 1982).

Ageing of the cover and dirt deposition also tended to decrease light transmittance (Dubois,1978). It was estimated that when a row cover was reused, the light loss could be as much as 25 to 30 % (CTIFL,1987). Hassel (1986) observed that small particle size muck soil became trapped in the weave of a polypropylene material and this caused a reduction in PFFD.

With floating row covers, one may reach a time during the growing season where temperatures are no longer limiting but when the radiation penetrating the lower layers of leaves is insufficient for optimum photosynthesis. Furthermore, Wolfe et al. (1986) pointed out that PAR levels under these covers may be well above the light saturation point of individual leaves, but that a saturation point for entire canopies of crop plants had not been well established.

2.1.3.6 Effects on pests

Another benefit provided by floating row covers might include insect protection. Row covers have shown to be effective in controlling cabbage maggot and flea beetle on radish (Wells and Loy, 1985), insect damage in cabbage (Nelson and Young, 1987), white flies, aphids, stripped cucumber beetle, Colorado potato beetle (Wells and Loy, 1986), and some virus-vectoring insects like aphid (Hemphill, Reed and Gutbrod, 1987) and sweet potato white-fly (Natwick, Durazo and Laemmlen, 1987)

Row cover effect on disease has been poorly documented, although heavy condensation that forms on the underside of the cover may lead to warm moist conditions that might favor disease propagation (Rickard,1979).

Successful spraying of pesticide solutions through agrotextiles have been performed (Crabtree, Mansour and Hemphill, 1987; Stall and Kostewicz, 1987).

2.2 Row covers and carrot

As a seeded crop, carrot seed germination present a difficult problem for commercial growers. Since carrots have small seeds, they cannot be planted deep and may suffer from surface drying, and crusting of the soil (Hegarty, 1978; Hegarty and Royle, 1978). Finch-Savage (1986) found that covering carrot seeds with PE sheets advanced seedling emergence and increased the percentage that emerged. Gerber (1984) reported an improved emergence of carrot seeds under spunbonded polypropylene and polyester covers which resulted in more marketable roots. However, in both experiments, no meteorological data were taken to explain the improved germination.

Use of floating row covers is now a well established technique for early crops of carrots in Europe. Different criteria for cover removal are used depending on the country (Table 2.2).

In England, 450 hectares of carrots were cultivated under cover and the earliest roots were produced by sowing in early-mid october and overwintering seedlings under film cover (MAFF, 1984a). These reached the 2-leaf stage prior to the onset of winter, grew very little during the winter months and were ready to harvest from the end of May to early June. Second early carrots, sown in the January and harvested mid-June, were less speculative. In both cases, English farmers were advised to remove the film cover at the 7-8 true leaf stage. After this point, it was found that the foliage developed at the expense of the roots, so yields would suffer if cover removal was delayed (MAFF,1984a).

In Belgium, Benoit, Ceustermans and Calus (1982), working with PE covers with 400 holes of 1 cm diameter per square meter, tried different covering periods for early carrots sown March 5 and harvested June 10. Under these conditions, optimum development was obtained when the plants were covered until the minimum soil temperature at a depth of 10 cm exceeded 8.5 ^{o}C. In an other study (1983), the same authors showed that with higher degrees of perforation (e.g. 800 holes per square meter) the cover could be left on the plants until harvest without decreasing the weight of the roots.

Table 2.2: Optimum covering time for row covers used in different countries on early carrots. (see text for details).

COUNTRY	ROW COVER TYPE	SOWING	ROW COVER DURATION	HARVEST	REFERENCE
ENGLAND	PE 200 holes/m^2	beg to mid Oct	7-8 leaves	end May-beg. June	ADAS, 1984
BELGIUM	PE 250 to 1000 holes/m^2	Dec. to March	-10cm $>$ 8.5 °C +5 cm $<$ 26 °C	May-June	Benoit et al., 1981,-82,-83,-86
FRANCE	PE 500 Agryl 17 Agronest	maritime:Nov-Jan continent:Feb-March	15-20 cm leaf height	15 days earlier	CTIFL, 1985

In France, the growing of early carrots depends on the region. Sowings are made in the fall (November to January) in coastal zones and at the end of winter (February-March) in region with a more continental climate. Row cover removal is advised when the leaf height is 15 to 20 cm (CTIFL,1987).

Optimum covering time for different types of row covers are summarized in table 2.2. However, one must take into account that all these experiments were performed on standard, not mini carrot cultivars.

Consumer's interest in mini carrots, also called baby carrots, finger, baby finger, cocktail carrots (Valk, 1975), has increased in the last few years (Pauls, 1975, Millette, Bernier and Hegert, 1980). Mini carrots are esteemed as a gourmet food because of their flavor, small size and delicate texture (Liptay, Hegert and Loughton, 1981). This fresh delicacy is available in fresh packet cello bags of 340 g from Canadian sources or imported as in canned or frozen form (Millette, Bernier and Hegert, 1980). Although not ruled by the Canada Agricultural Products Standarts Act, mini carrot roots are usually graded to obtain a maximum diameter of 19 mm and length of 115 mm (Millette et al.,1980; Liptay and Muehmer, 1981), but some growers have no limit on length.

The roots produced by the true mini carrot cultivars are smaller than those produced by the normal carrot cultivars. Specific strains are selected for their ability to attain and maintain optimal size for a maximum period of time (Liptay and Muehmer, 1980). This criterion is necessary since harvesting conditions and/or harvesting capacity may be limiting and carrots that outgrow the maximum size of the mini carrot category do not return maximum economic benefits.

Moreover, the size of mini carrots is also a result of plant overcrowding and harvesting at a somewhat immature stage (Liptay et al., 1981). It takes 85 to 150 days for normal carrot cultivars to mature at densities of 80 to 250 seeds per m^2 compared with about 60 days for mini carrot cultivars at densities of between 500 and 1000 seeds per m^2 (Nuttal, 1975; Bernier, 1975).

Bussel (1973) in New Zealand studied the effect of plant densities, ranging from 533 to 2500 seeds per m^2, on yield and harvest time of mini carrots grown in mineral soils. He found the highest yields were obtained at the highest densities although maximum yield was reached earlier at the lower rather than high densities.

However, Millette, Bernier and Hergert (1980) working at densities between 555 and 1388 seeds per m^2 in organic soils found that yield increased with increasing densities to rates of 1100 seeds per m^2 above which no further increases were reported.

2.3 Row cover and lettuce

Optimum covering time for lettuce differs depending on microclimatic conditions. Benoit and Hartmann (1974) observed the effect of a PE floating row cover (11 holes per m^2) for a period of 8, 15, 21 and 23 days on spring transplanted lettuce under two different ecological conditions. Geisenheim (German Federal Republic) had a continental climate with more sunshine, a drier and less windy weather compared with the maritime climate of St-Katelijne-Waver. The plastic row cover increased fresh weight of lettuce in both places but the best weights were obtained after 21 days of covering in St-Katelijne-Waver and after only 8 days at Geisenheim. The average dry and fresh weights were lower, the size of the leaves smaller and the number of leaves larger at Geisenheim compared to St-Katelijne-Waver. With increasing period of covering, lettuce fresh weight increased, the percentage of dry matter decreased resulting in greater succulence. The number of leaves also increased. This was later confirmed by Benoit (1975) who further related optimum covering time of a row cover with 44 holes per m^2 to soil temperature. He suggested that the row cover should not be removed until the minimum soil temperature at a depth of 10 cm reached 4 ^oC, a figure corresponding to the minimum temperature required for lettuce root growth. If the period of covering was too long, Benoit and Ceustermans (1980) suggested that an excessive number of leaves will develop on stalk which are limited in length. Owing to the lack of space in the head, the leaves will tend to increase in length , with a higher length to width ratio. The heads will be looser and their leaves will have an increased capacity to transpire which can , in turn, result in a reduced head weight.

In France, lettuce is transplanted in January-February in maritime climates or in March-April in more continental areas (CTIFL, 1987).

Table 2.3 : Optimum covering time for row covers used in different countries on lettuce.

COUNTRY	ROW COVER TYPE	PLANTING DATE	ROW COVER DURATION	HARVEST	REFERENCE
ENGLAND	PE or FM 200-500 holes/m^2	Feb-mid March	hearting plus 1 week	3 weeks earlier	MAFF, 1985
WEST GERMANY	PE tunnels 11 holes/m^2	March 29 March 9	8 days	May 17 May 8	Benoit and Hartman, 1974
BELGIUM	PE 11 to 800 holes/m^2	March 19	20 to 40 days min -10cm $> 4\ ^{o}C$ max +5cm $< 20\ ^{o}C$	May 21	Benoit and Ceustermans, 1985
DENMARK	PE 250 to 500 holes/m^2 Agryl 17	April 15	4-6 weeks	8-10 days earlier	Henriksen, 1981
FRANCE	200-500 ho/m^2 500 ho/m^2	maritime:jan-feb continent:march-apr	3-6 weeks till harvest	8-12 days earlier	CTIFL, 1987
UNITED STATES	PE (Vispore 5042) Reemay	Sept. 16	7 weeks	7 days earlier	Abbes at al., 1987

Growers are advised to consider row cover removal when the minimum soil temperature is 6 ^{o}C and should remove these covers when the maximum soil temperature is 22 ^{o}C. Also, the duration of row covering depends on the degree of perforation. Films with 500 to 1000 holes per m^2 can be left 6 to 9 weeks and perhaps until harvest, whereas those with 200 to 500 holes per m^2 must be removed earlier, after 3 to 6 weeks of covering (Benoit and Ceustermans, 1980).

In England, growers guides indicate that row covers on lettuce transplanted late February or early March may advance the maturity of the crop by up to 3 weeks (MAFF,1985). Although the critical stage for a PE cover removal correspond to hearting plus one week, agrotextiles may be left longer since they are more porous. However, risks of sun scorch and tipburn are high if covers are left on in hot conditions after the second week of May.

In Denmark, Henriksen (1981), found that PE covers with 250 holes per m^2 (as compared to 500 to 700 holes per m^2) produced the earliest and heaviest iceberg lettuce after 5 weeks of covering. A prolonged period of covering resulted in fewer marketable heads because of physiological disorders like tipburn.

In an attempt to extend the growing season of Romaine lettuce into late autumn in Northern United States, Abbes, Hemphill and Mansour (1987) covered the crop with SPE and PE floating row covers for two planting dates and several covering periods. They found that delaying cover removal increased yield for both planting dates. A 7 weeks covering period appeared adequate for the Romaine lettuce production from mid-September planting but marketable plants were not produced before the onset of hard freeze in the October planting.

All the techniques mentioned above are summarized in table 2.3.

3. THE MINI CARROT EXPERIMENT

In 1987 and 1988, the following experiments were conducted to determine the optimum stage of growth and/or critical temperatures for the removal of a floating row cover in early crops of mini carrots (Daucus carota L. hybrid 'Baby Sweet').

A first experiment was undertaken to compare different covering periods using a 12.8 m wide floating row cover.

A second experiment was performed using narrow covers (2.3 m wide) in order to resolve statistical limitations imposed by the first experiment.

The sites of testing were in 1987 at the Leclair Brothers Farm from Sherrington (45° 10′ Lat., 73° 31′ Long.), Quebec, and in 1988 at the Ste-Clothide experimental sub-station of Agriculture Canada (45° 10′ Lat., 73° 41′ Long.), Quebec. Both areas have an organic muck soil profile, 1.5-2.5 meters deep with a pH of 5.9-6.1.

3.1 Meteorological data

For both years, minimum/maximum mercury thermometers were installed in covered and non covered plots and were checked daily during the covering period.

In 1987, the sensor probe was placed in a reversed styrofoam cup at 2 cm above the soil level for air temperature. In 1988, they were placed in a white painted polyvinylchloride (PVC) tube at a height of

2-4 cm to allow for better air circulation.

Figure 3.1 shows the minimum, mean and maximum air temperatures obtained under the floating row cover during the period from 19 May to 22 June 1987. Mean temperatures were estimated as (min+max)/2. Very high temperatures were found periodically under the Agronet, with frequent maxima of 40^{o}C or more. Problems with sensors in 1987 meant that air temperatures of covered and uncovered plots could not be compared. This was corrected in 1988. Figure 3.2 shows the minimum and maximum air temperatures at a height of 2-4 cm for the covered and uncovered plots between April 6 and July 4 in 1988. Air temperatures were generally higher under the row cover with an average temperature lift of 1.4 ^{o}C. During germination, the lowest external minima of -3, -4 ^{o}C corresponded to minimum temperatures of 0, -1 ^{o}C under the row cover (Fig. 3.2). Later in the season, inversions occurred in a few cases where minimum temperatures were lower under the row cover (e.g. on May 29, 1.8 vs -1.1 ^{o}C under the row cover).

Soil temperatures for both years were recorded at a depth of 7 cm. Figures 3.3 and 3.4 show the minimum and maximum soil temperatures recorded in covered and uncovered plots from 24 April to 22 June 1987 and from May 6 to July 4 in 1988. Soil temperatures were generally higher under the Agronet. The differences in minimum soil temperatures between covered and uncovered plots were greater during the colder, windier period of the end of April beginning of May. The floating row cover raised the minimum soil temperature by 1.4 and 1.2 ^{o}C, the maximum soil temperatures by 3.0 and 1.9 ^{o}C and the mean temperature by

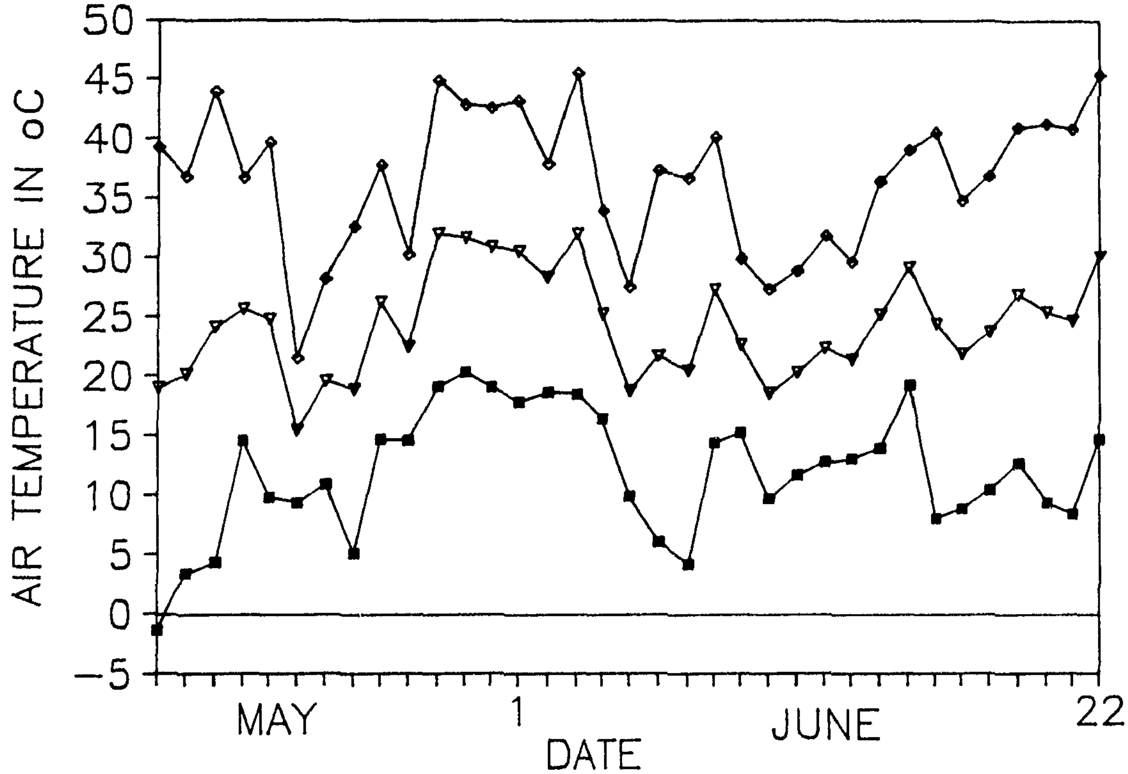


Fig. 3.1: Minimum (■), maximum (◇) and mean (▽) air temperatures at a height of 2–4 cm recorded daily under a floating row cover during the 1987 spring at Sherrington.

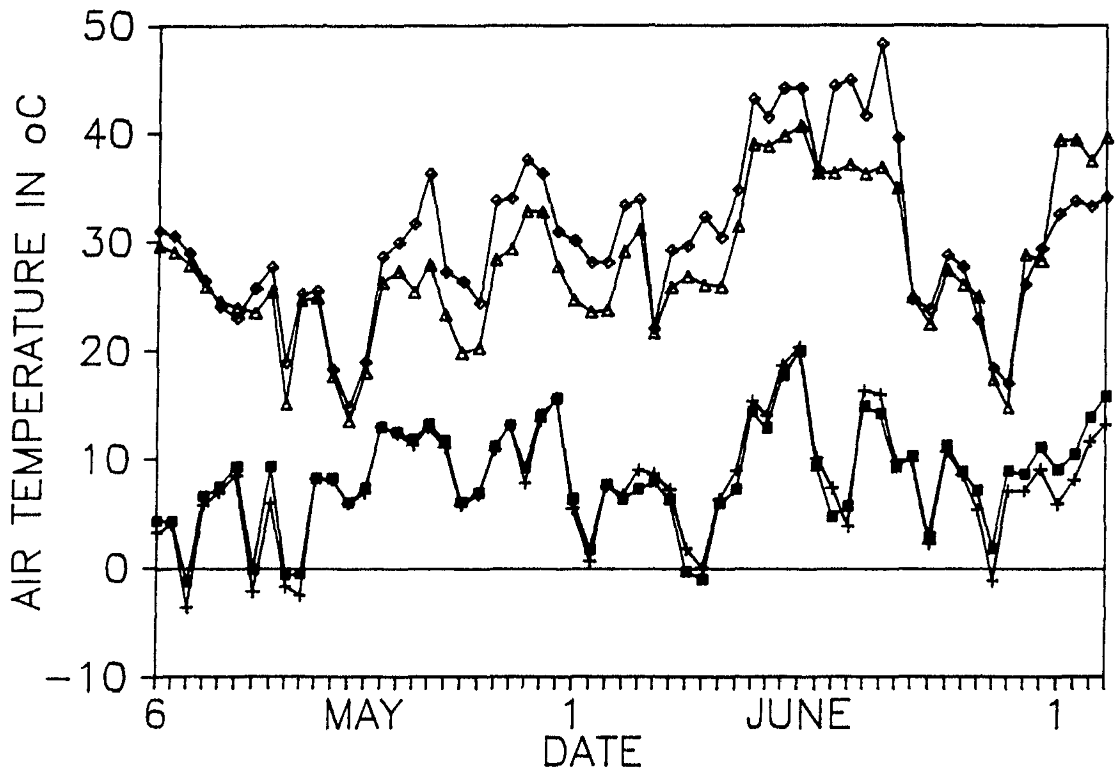


Fig. 3.2: Effect of a row cover on air temperatures at a height of 2–4 cm during the 1988 spring at Ste–Clothilde. Maximum covered (◇) maximum uncovered (Δ), minimum covered (■), minimum uncovered (+).

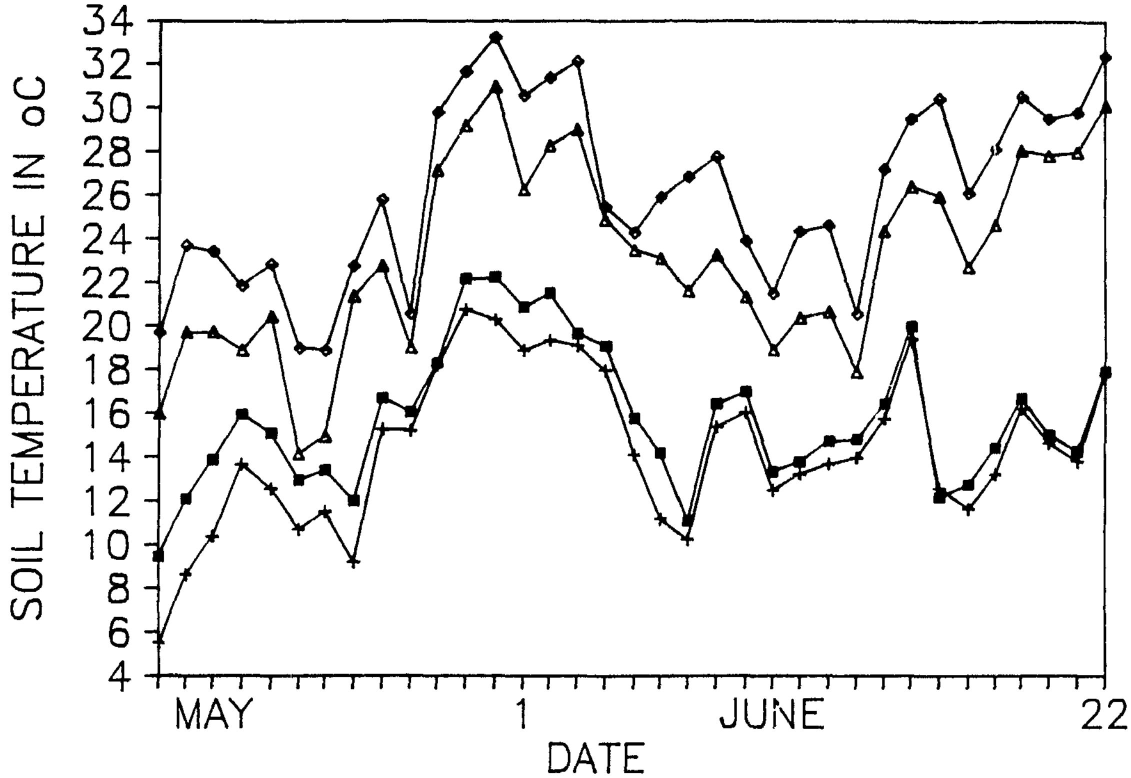


Fig. 3.3: Effect of a row cover on soil temperatures at a depth of 7 cm during the 1987 spring at Sherrington. Maximum covered (◇), maximum uncovered (Δ), minimum covered (■), minimum uncovered (+).

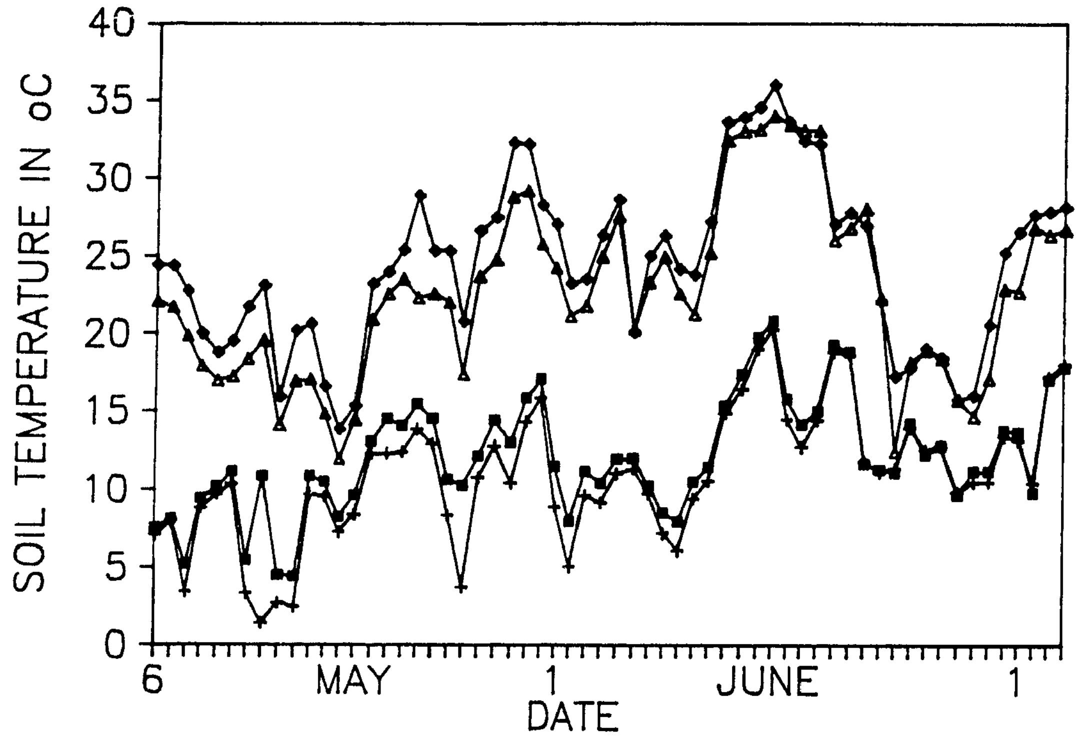


Fig. 3.4: Effect of a row cover on soil temperatures at a depth of 7 cm during the 1988 spring at Ste-Clothide. Maximum covered (◇), maximum uncovered (△), minimum covered (■), minimum uncovered (+).

2.2 and 1.5 ^{O}C in 1987 and 1988, respectively. Mean daily air and soil temperature fluctuation was consistently higher under the row cover over the 2 years (10.4^{O}C in 1987 and 12.4 in 1988) compared with bare soil (8.8 ^{O}C in 1987 and 11.7^{O}C in 1988). This was primarily due to the higher maxima under the row cover.

The basic concepts of microclimate modification were clearly described in a review article by Tanner (1974). He explained that temperature regimes of plants are a consequence of the energy balance rather than being a primary parameter. The total energy balances states that the net radiant energy absorbed by a surface (Rn) must be converted to other forms of heat (Tanner, 1974; Montheith, 1976; Rosenberg, 1983):

$$Rn = H + LE + S + uA$$

where (H) is the convected heat exchanged by an object with the air. It is also called 'sensible neat flux' because it is that transport that warms the air and determine its temperature (Rosenberg,1983). (LE), the latent heat flux, is the heat used to vaporize liquid water without any change in temperature to yield evapotranspiration. (S) is the stored heat, i.e. the heat exchanging with the surface of the object which changes its temperature. This surface can be a field or any plant surface. (uA) is the biochemical storage flux or energy used for photosynthesis; although very important to production, it is a negligible part as an energy exchange factor.

Net radiation, as the main driving force of the total energy balance is made up of two components: solar and thermal radiations. About 80 % of the beam and diffuse sunlight incident to a typical field is absorbed and converted to heat (R↓), the rest is reflected (R↑) (Tanner, 1974; Jackson, 1985). Thermal or heat radiation consists of wavelengths longer than 4 microns whereas solar radiation is less than 2.5 microns. The sky radiates to the earth (Rt↓) but the earth radiates to the sky even more (Rt↑) resulting in a net loss in thermal radiation. It is this thermal loss, that causes night time cooling and radiation frost (Tanner, 1974).

The net radiation (Rn) is the difference between radiation received, indicated by an arrow (↓) and radiation lost (↑) (Tanner, 1974; Jackson, 1985; Liakatas et al., 1986). Then,

$$Rn = (Rs\downarrow - Rs\uparrow) + (Rt\downarrow + Rt\uparrow) = H + LE + S$$

During the day, the solar radiation gained by the surface exceeds the thermal radiation lost and there is a net radiation heat input. Part of the radiation heats the plants and the soil, part goes to evapotranspiration and part goes to heating the air. A row cover modifies radiation by reflecting some solar radiation and reducing thermal radiation. The classical term 'greenhouse effect' refers to the greater reduction of thermal radiation loss by the glass than the decrease the glass effects on the solar radiation (Tanner, 1972; Rosenberg et al., 1983). While this is true that glass does cause a net warming by radiation, Lee (1973) pointed out that the biggest effect is the suppression of convection by shielding the greenhouse space from the wind and thus prevent the heat from mixing away.

Tanner then explained that during the night, there is no solar input and net radiation loss exists. The surface cools and heat flows back out of the soil. The evaporated water from the soil condenses to the cooler leaves. If the sky is clear and cold, the radiant heat losses are greater than on cloudy and warm night, and so, the leaf surface cools more before the heat flows to it from warmer air. If there is dew, it can provide heat and help to prevent freezing. If enough radiation is lost, frost will occur. Typically, radiation frosts occur with clear skies, light winds and low relative humidities (Goldsworthy and Shulman, 1984).

Furthermore, row covers, by creating a layer of calmer air compared to a bare soil, may increase the strength of the inversion, resulting in greater risks of frosts. There are many examples of inversion causing lower temteratures under the plastic cover in the literature (Savage, 1980; Wells and Loy, 1985; Wenwei and Chaim, 1985; Silva and Rosa, 1987).

Soil moisture was recorded weekly at depths of 0-4 cm using the gravimetric method (Hansen, Israelsen and Stringham, 1980). Soil moisture content was consistently higher under the row cover over the entire growing season (Fig 3.5). The depression in the 2 curves represented a 21 day period without rain. The increase in soil moisture content ranged from 2 to 67 % under the row cover, the highest differences occuring during the dryest period.

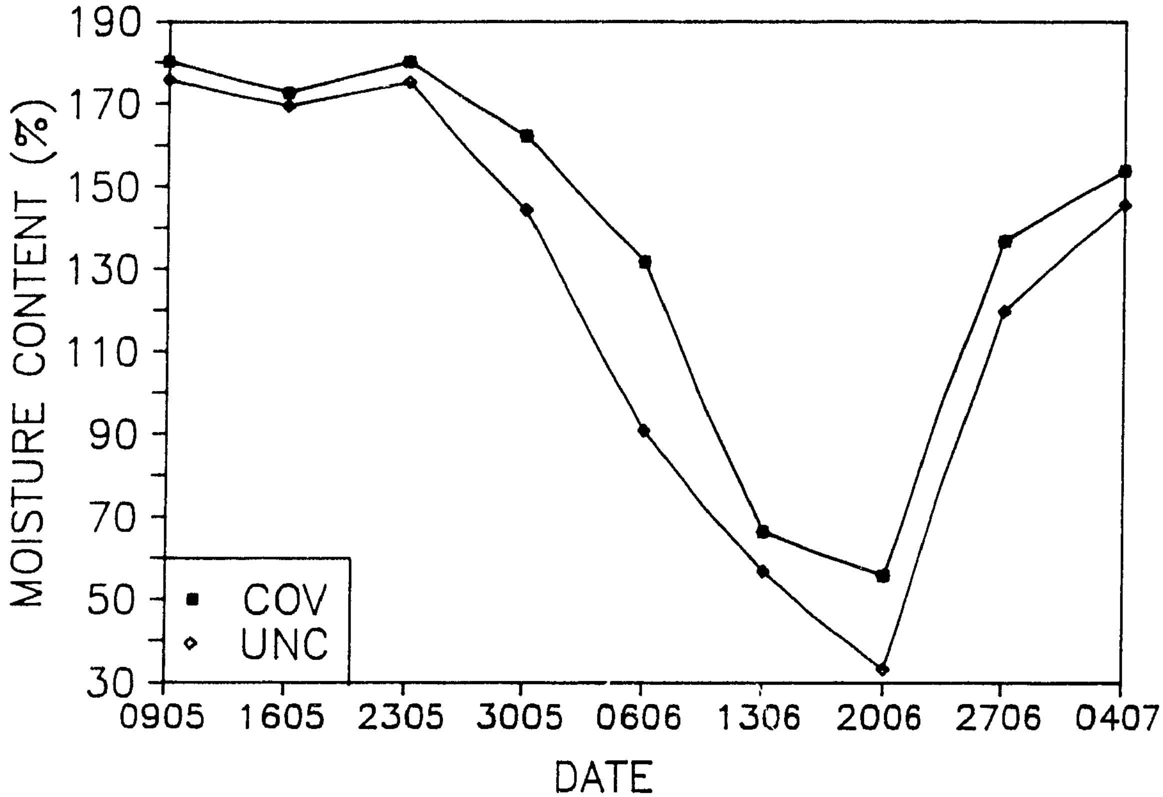


fIG. 3.5: Effect of a floating row cover on moisture content expressed on a percent dry weight basis in a mini carrot field from May 9 to July 4, 1988.

3.2 The wide cover experiment (1987)

3.2.1 MATERIALS AND METHODS

3.2.1.1 Sowing procedure

Mini carrot seeds (hybrid 'Baby Sweet') were purchased from Stokes Seeds Ltd, Ste-Catherines, Ontario.

In April 14 1987, seeds were sown using a 5-row Planet Jr. seeder into a 1.83 m wide bed. Seeds were spaced at a rate of 82 seeds/m.

3.2.1.2 Field preparation

In the spring the field was prepared with an harrow. This was followed by discing and ground levelling.

Fertilization consisted of one spring application of 5-5-20 containing 1% Boron at a rate of 900 kg/ha.

Weeds were controlled with linuron applied at the recommended rate (CPVQ, 1982). The herbicide was sprayed over the row cover and resulted in good weed control.

3.2.1.3 Covering material

The floating row cover used in the experiments was a 95 % polypropylene, 5 % polyamid extruded material (Trademark Agronet; Plate 1) obtained from Plasti-tech Culture Inc, St-Remi, Quebec.

Plate 1: Agronet floating row cover

Sheets were 12.8 m wide by 100 meters long and covered 30 rows of mini carrots. The floating row covers were layed 3 days after seeding (Plate 2 A).

After anchoring the wide cover at one end of the field, a pipe was run through the core of the cover roll and a person at each end of the pipe walked the roll down the middle of the field. Two others followed, unfolding the material and temporarily securing the edges into a previously formed furrow. After the roll was laid, the edges were buried with 5 cm soil. Ample slack was left to allow for growth of the mini carrot underneath the cover.

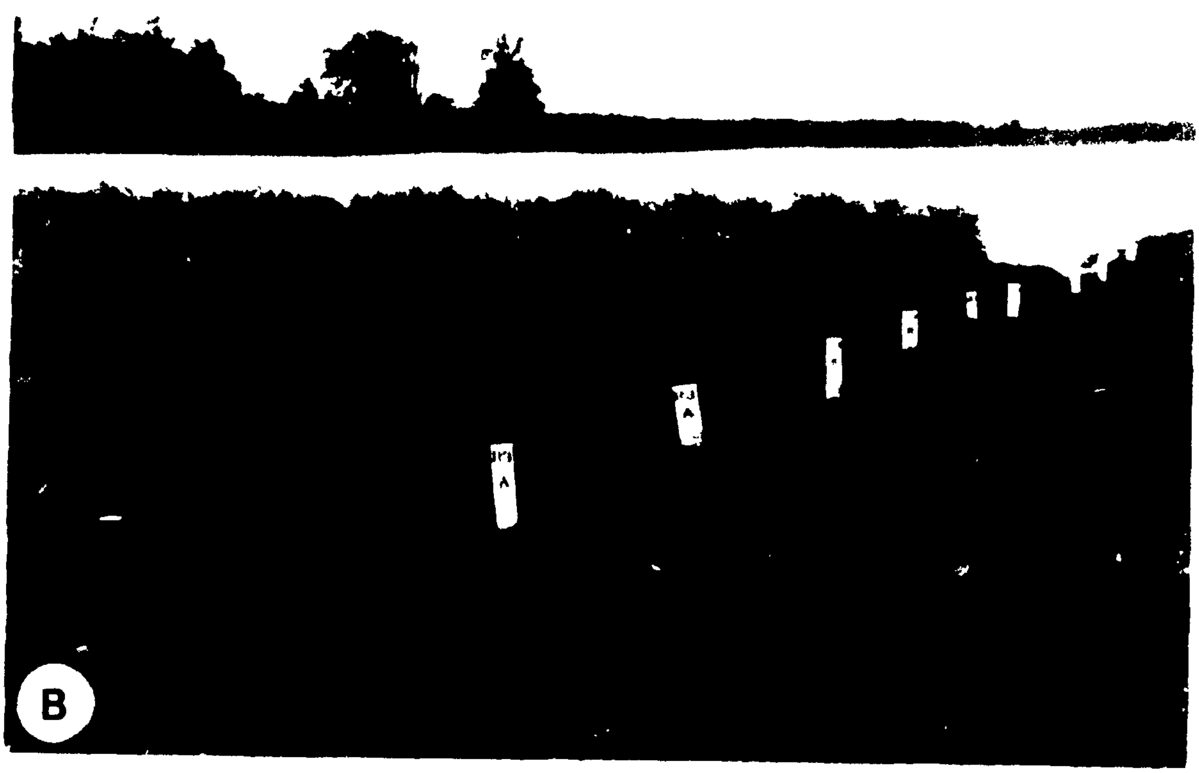
3.2.1.4 Experimental layout and data analysis

The intention was to establish a series of covering treatments based on growth stages and temperature levels. Leaf number initially was selected as an easily identifiable growth criterion. In a controlled environment, Benjamin and Wren (1978) identified the 6, 10 and 14-leaf stage for 35, 58 and 67 days old carrot, respectively.. However, in this experiment, field grown mini carrots, which were harvested about 60 days after seeding, did not produce more than 8 leaves. Therefore, for mini carrot, the data are simply presented on a basis of 'days of covering' rather than stages and temperature levels.

Instead of cutting through the wide cover and randomizing the treatments, which could result in a disturbed microclimate and edge effects (Shadbolt, McCoy and Whiting, 1962), the covering periods were applied systematically by successive rollings of the cover.

Plate 2: (A) A 12.8 meter wide floating row cover on a mini carrot field at Sherrington, Quebec. (B) The wide cover experiment: each marker represents one uncovering of the floating row cover.

A



B

Pictures of the field layout of the wide cover experiment are shown in plates 2 A and B. For each treatment, the row cover was successively rolled back over 1 meter. At the end of the experiment, the wide cover was rolled back 10 meters. A control non covered plot, having the same surface area, was located in a adjacent field. There were 3 replicates.

The systematic design, originally suggested by Nelder (1962), was definitely not optimal. However, it maximized the efficiency of the row cover by reducing the number of guard plants. Doing a wide cover experiment with a conventional randomized design would have involved carrying out experiments of enormous size with a large amount of guards. Taking into consideration that I was dealing with a large area and expensive covering material and grower's land, it was felt that a systematic design was most appropriate in order to obtain informations under commercial conditions. Similar justifications for use of a systematic design had been put forward by Freeman (1964), Bleasdale (1966), Mead (1966) and Sale (1966) for spacing trials, Cleaver, Greenwood and Wood (1970) for fertilizer trials and Huxley and Maingu (1978), Willey and Rao (1981) for intercropping trials.

3.2.1.5 Harvesting procedure

Mini carrots were harvested by hand on June 22, 1987. This date corresponded to the optimum size (ie. roots with diameter between 13 and 19 mm) for most of the covered mini carrots. The uncovered plots were harvested at the same time regardless of plant maturity.

3.2.1.6 Recorded characteristics

Two sets of data were collected. One set at each cover removal time to determine the effect of the floating row cover on the growth pattern of mini carrots. Fresh weights of leaves and roots from a sample of 20 plants were recorded.

A second set of data was collected at harvest time to determine the effect of the different covering periods on yield. Fresh weights of roots and leaves of 20 plants were again recorded.

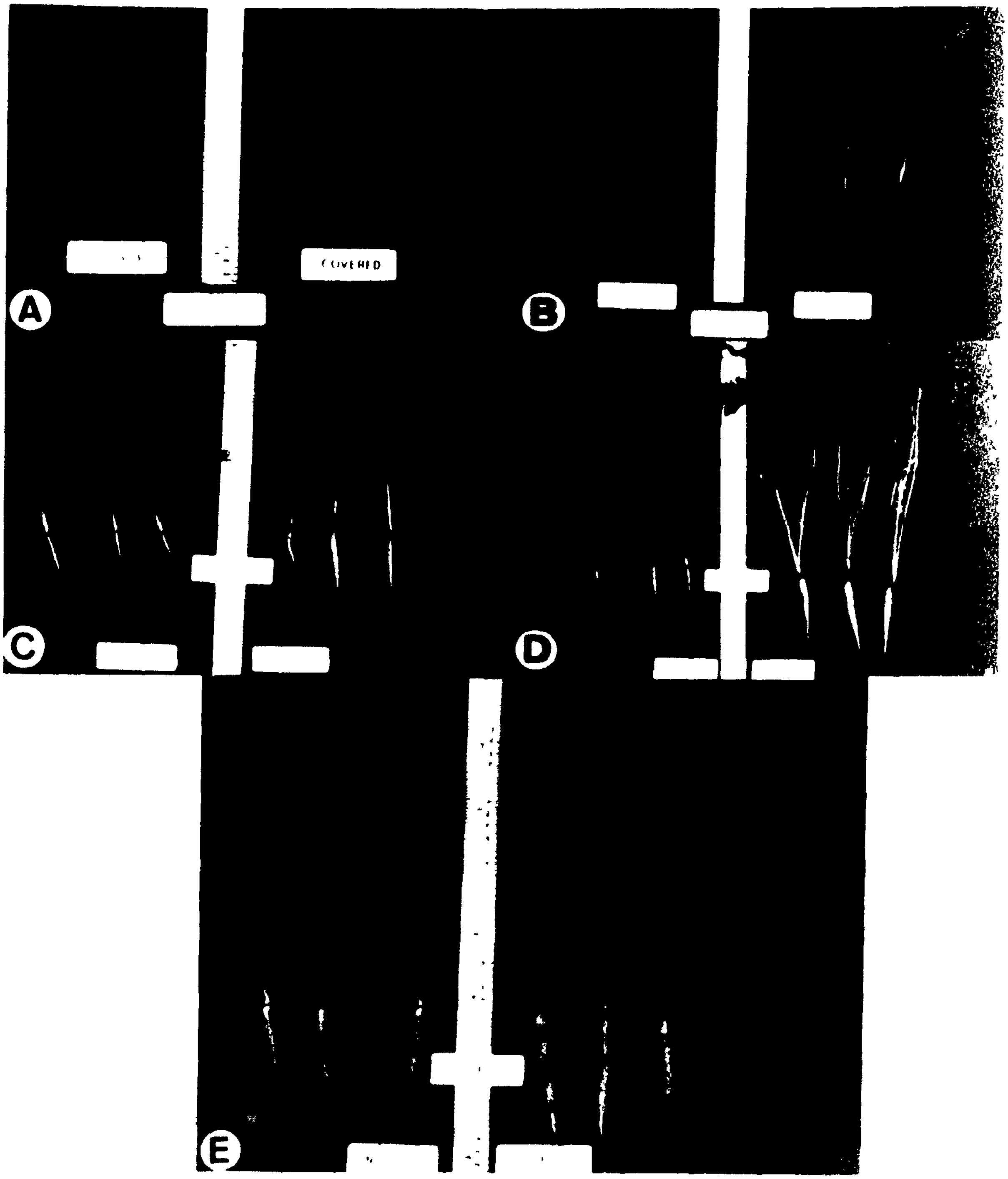
3.2.2 RESULTS

Plate 3 shows the difference between covered and uncovered mini carrots as they were sampled 5 times during the growing season. Growth was generally increased under the floating row cover. The taller leaves reflected etiolation of the row-covered mini carrots.

Figure 3.6 represent the actual fresh weights of roots (A) and leaves (B) for covered and uncovered mini carrot plants as they were sampled at each cover removal time. Row covering mini carrots increased the fresh weight of roots and leaves. Further, the leaf to total fresh weight ratio was lower for the covered mini carrots after 44 days of covering (Fig. 3.6 C).

Data collected at harvest time indicated that the mini carrot root fresh weights under the row cover were heavier compared to that of the uncovered plants, with an average over all covered plants of 14.4 g

Plate 3: A comparison of covered and uncovered mini carrot at 39 days (A), 47 days (B), 52 days (C), 62 days (D) and 69 days (E) after seeding.


A
COVERED
B
C
D
E

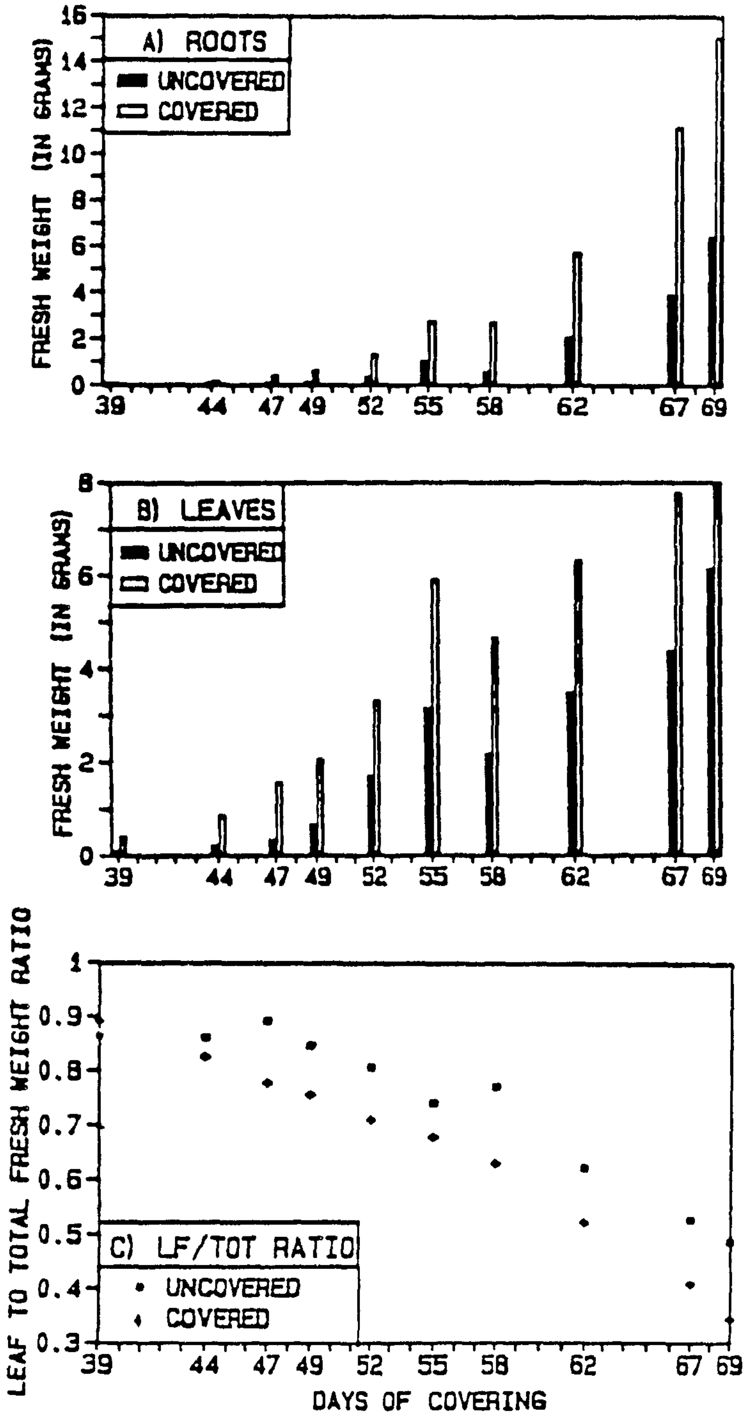


Fig. 3.6: Mean fresh weights of covered and uncovered mini carrots sampled at each cover removal time during the 1987 spring. (A) roots (B) leaves (C) leaf to total (lf/tot) ratio.

Table 3.1: Mean fresh weight of mini carrots (in grams) at harvest time under different covering regimes (average of 60 plants)*.

days of covering	Root	Leaves	Total
0 (control)	6.49	6.17	12.66
39	14.54	8.82	23.24
44	13.39	7.15	20.54
47	13.01	7.10	20.12
49	14.19	7.94	22.13
52	14.56	7.94	22.50
55	13.87	7.44	21.31
58	16.01	8.20	24.21
62	13.96	7.87	21.82
67	15.40	9.39	24.79
69	15.15	7.95	23.14

* this experiment had a systematic design and the results were not statistically analysed.

versus 6.5 g for the control (Table 3.1). The Cox-Stuart test for trend, a non parametric test requiring independent observations and at least an ordinal scale as the only basic assumptions (Daniel, 1978), detected an upward trend at the 0.05 level of significance in the root fresh weight of mini carrots under the different covering regimes. The leaf to total fresh weight ratio of the uncovered mini carrots were always higher than mini carrots under any of the covering regimes (Table 3.1).

3.2.3 DISCUSSION

The higher soil temperatures recorded under the floating row cover (Fig.3.3) was reflected in the increased root and leaf fresh weight observed during the growing season (Fig. 3.6 A, B). The greater leaf fresh weight obtained under the Agronet (Fig. 3.6 B) appeared, solely from a visual point of view, to be based on increased height rather than greater leaf number (Plate 3). The enhanced leaf growth of mini carrot did not occur at the expense of the roots when the row cover was kept on until harvest since the leaf to total fresh weight ratio was always lower than that of the control after 44 days of covering (Fig. 3.6 C). This was in contrast with work done on standard [illegible]ot cultivars (MAFF, 1984a) where it was suggested that delaying cover removal could result in competition between leaf and root.

At harvest time, all covering periods resulted in yields superior to those of the uncovered mini carrots (Table 3.1), and the Cox-Stuart test for trends detected an upward trend in root fresh weights with increasing covering periods. The row cover could then be left until harvest without lowering the mini carrot root fresh weight in spite of the high temperatures (more than 40°C maximum air temperatures) observed during this spring (Fig. 3.1). Benoit Ceustermans and Calus (1983) found similar results with standard carrot cultivars and polyethylene films with high degree of perforation, ie. 800 holes of 1 cm diameter per m^2

Although much information was obtained from the wide cover experiment, it had its limitations. It was felt that much of the effect of the row cover occurred during germination. An English Grower's Guide (MAFF,1984a) mentioned that row covers, by giving increased soil temperatures and a moist soil, encourage quick, even emergence.

Further, the first uncovering occurred only 39 days after seeding and it may have been possible that the even higher yields could be obtained with shorter covering periods. In the muck soils of the Chateauguay County, MacMillan and Hamilton (1971) obtained significantly longer roots with 16°C soil temperature compared to 12 or 20°C Then, with longer covering periods, the higher soil temperatures which prevail under the cover (Fig. 3.3) may have been detrimental causing higher respiration and transpiration, and earlier senescence. Indeed, Banga and de Bruyn (1968) proposed the theory that the primary vegetative growth of the roots and protein synthesis occur at rather low temperatures (8°C) whereas ripening or ageing, determined by carotene synthesis occur with higher temperatures (18°C). Synthesis of both carotene and proteins was realized at the expense of the synthetized hydrocarbons. Further, Benoit, Ceustermans, Rouchard and Vlossak (1984) found a higher carotene content in covered carrots. The above mentioned aspects will be dealt with the next experiment.

3.3 The narrow cover experiment (1988)

A germination experiment was planned in 1988 to determine the effect of the row cover on the percentage and the uniformity of germination. If the emergence is greater and more uniform, is it reflected at harvest time in terms of increased yield on a per area basis and decreased root variability?

Also, it was proposed to try shorter covering periods since it may be possible that the optimal removal date occured earlier than 39 days of covering (first uncovering of the 1987 experiment).

To answer these questions, it was necessary to perform experiments which could be statistically analysed and in 1988, narrow row covers were used.

3.3.1 MATERIALS AND METHODS

3.3.1.1 Sowing procedure and field preparation

In May 5, 1988, the seeds were sown into 1.83 by 5 m beds containing 4 rows with 115 seeds/m. Sowing was delayed due to poor weather conditions.

Field preparation was similar to the 1987 trial. However, in this case, a preemergence herbicide was applied before the cover was laid.

3.3.1.2 Covering material

The Agronet sheets measured 2.3 by 6.4 m to fit plot sizes 1.83 by 5.0 m. The Agronet was applied the day after seeding.

These narrow covers were installed manually, by making a furrow around each plot, anchoring the edges with 5 cm of soil and leaving enough slack for the growth of the mini carrots.

3.3.1.3 Experimental layout and data analysis

A randomized complete block design was set in 1988 using narrow covers to overcome the statistical limitations of the systematic design (Plate 4). There were 4 replicates. Each replicate was composed of 2 guard plots at the edges, 8 covered plots and 4 uncovered (control) plots. Row cover material measuring 2.3m by 6.4 m covered plots of 1.83 m by 6.4 m. Each treatment involved uncovering a plot at weekly intervals starting May 23 and ending at harvest of the covered plants (July 4). For regression purposes, an additional covered plot was maintained until the harvest of the uncovered plot. A plot contained four 5 meter rows of plants: two guard rows surrounding two rows of experimental plants. Within the 2 center rows, sampling units each 40 cm long were randomly chosen and separated from one another by 30 cm strips.

For this experiment, data were analysed statistically using the

Plate 4: The narrow cover experiment: a randomized complete block design with plots of 1.83 meters by 5 meters and four replicates.

Statistical Analysis System (SAS). A sample analysis output is presented in the appendix.

3.3.1.4 Recorded characteristics

At each cover removal time, 30 plants were sampled. A subsample of 10 plants were used to determine leaf number and length of the longest leaf. Then, all plants were separated into root and leaf portions and the fresh weights taken. Plants were then oven dried at 70 ^{o}C for a 24-hour period and the dry weight taken.

Mini carrots were hand harvested on July 4, 1988, when the plants in the covered plots had reached maturity. One week later, both the uncovered and a single covered plot maintained for regression purposes were harvested. Leaf and root dry weights of 30 plants, number of leaves and length of the longest leaf of 10 plants were recorded for each covering regime. In order to determine the effect of a floating row cover on root-weight variation, the individual root fresh weight of 30 mini carrots were measured for 5 covering periods. From these data, it was possible to calculate the coefficient of variability (CV) of the mini carrot roots at harvest time as:

$$CV = \frac{s}{Y} \; 100 \; \%$$

with (s) being the sample standard deviat on and (Y) the sample mean (Steele and Torrie, 1980).

3.3.1.5 The germination experiment

In 1988, an additional experiment was set to compare the effect of a narrow floating row cover with an uncovered control on mini carrot emergence. This experiment was a complete randomized design with 4 replicates. Plots and date of sowing were similar to those previously described for the narrow cover experiment except that 100 seeds were hand seeded into a pre-marked section of row (0.87 m long), randomly selected from the two middle rows. Emergence counts were made daily until maximum emergence was attained. Mean emergence time and spread of emergence times were calculated (Orchard, 1977). The percentage emergence data were angularly transformed to improve homogeneity of variance before being subjected to SAS.

3.3.2 RESULTS

Figure 3.7 represents the effect of the row cover on the specific daily germination of mini carrot seeds. Between 8 and 11 days after seeding, 74.3 % of the seeds germinated under the row cover compared to only 48.8 % in the uncovered plots. Total emergence was 5.0 % higher under the Agronet although this difference was not significant at the 0.05 level (Table 3.2). Mean emergence time and standard deviation of emergence times were significantly reduced ($P<0.05$) by the row cover (Table 3.2). This improved uniformity of germination was also reflected at harvest time. The coefficient of variability of root fresh weight at harvest time was smaller for all covered treatments and tended to decrease with longer covering time (Fig. 3.8).

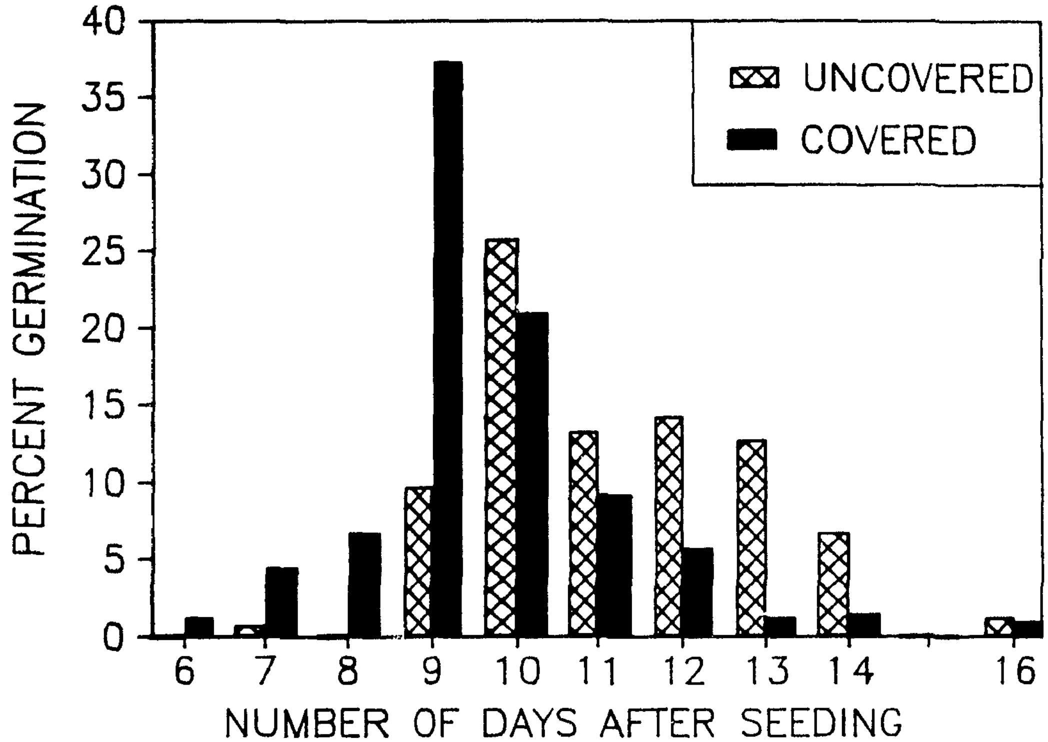


Fig. 3.7: Effect of a floating row cover on daily germination percentage of mini carrot seeds in 1988.

Table 3.2: Seedling emergence characteristics for the mini carrot experiment in 1988.

Seedtreatment	UNCOVERED	COVERED	DIFFERENCE[b]
% emergence	84.5 (67.1)[a]	89.5 (71.3)	5.0 (4.2) ns
Mean emergence time (days)	11.2	9.6	1.6 *
Standard deviation of emergence times	2.29	1.55	0.73 *

(a) angular transformation of the percentages are bracketed.
(b) * = significant at the 0.05 level, ns = non significant

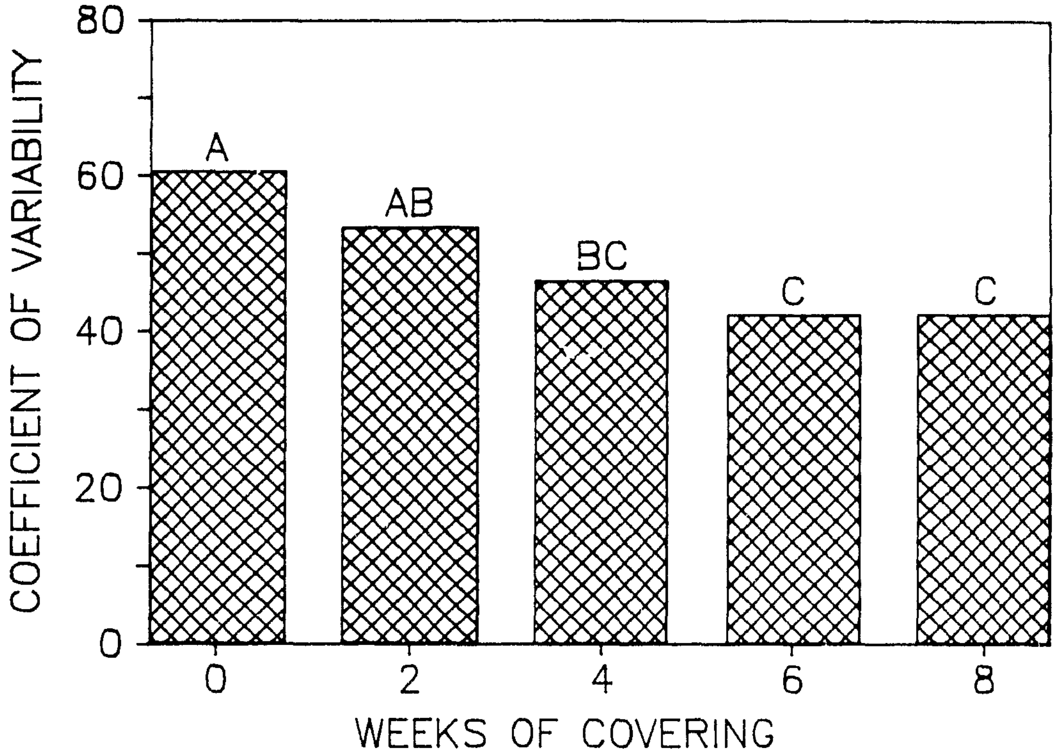


Fig. 3.8: Effect of different covering durations on the coefficient of variability (CV) of mini carrot root fresh weight at harvest. Means with a common letter are not significantly different at the 0.05 level based on a protected LSD test.

The change in root and leaf fresh and dry weight over time is presented in figure 3.9 A and 3.9 B. The roots and leaves of covered plants were consistently heavier than those of the uncovered plants throughout the growing season. A stepwise regression was carried out by SAS using a polynomial equation up to the cubic term to describe the change in $\log_e$ fresh weight and $\log_e$ dry weight with time. Third degree polynomials were fitted to these growth curves (Fig 3.9 A, B) and gave higher coefficient of determination (R^2) compared with quadratic equations. Relative growth rates (RGR) were obtained directly from these curves and absolute growth rates (AGR) were calculated as the product of dry weight and relative growth rate (Hunt, 1982).

The effect of the row cover on absolute growth rate (AGR) of roots and leaves of mini carrots is shown in Table 3.3. The plant AGR was 14-44 % higher under the row cover compared to the control. During early growth, root AGR was lower under the row cover although total plant AGR was greater. Leaf AGR was at that time 18 % higher and until 39 days after seeding, leaf growth was greater for covered plants compared to uncovered ones. After this, root filling was greater under the row cover. For example, at 60 days after seeding, root AGR represented 71 % of plant AGR for covered mini carrot compared to 61 % for the control.

At harvest time, covered plants had significantly larger roots and a better developed foliage, especially in terms of height compared to the uncovered plants. Mini carrot roots at harvest time in 1988 looked very similar to those of 1987 (Plate 3 E). There was no significant difference (P>0.05) between the number of leaves at harvest time (Fig.

Fig. 3.9: Effect of a floating row cover on growth of leaves (W) and roots (Y) in the developing mini carrot on fresh weight (A) and dry weight basis (B). Each point represents the mean of four replicates. Equations for plotted lines are:

for fresh weights:

Root—covered:

$$\ln Y = 1.9265 - 0.3876\ N + 0.01530\ N^2 - 0.000127\ N^3 ;\ R^2 = 0.992$$

Root—uncovered:

$$\ln Y = 1.0975 - 0.3290\ N + 0.01358\ N^2 - 0.0001131\ N^3 ;\ R^2 = 0.991$$

Leaf—covered:

$$\ln W = -7.1595 + 0.4466\ N - 0.005039\ N^2 + 0.00001917\ N^3 ;\ R^2 = 0.997$$

Leaf—uncovered:

$$\ln W = -6.8977 + 0.4126\ N - 0.004375\ N^2 + 0.00001473\ N^3 ;\ R^2 = 0.996$$

for dry weights:

Root—covered:

$$\ln Y = -2.2346 - 0.2263\ N + 0.01137\ N^2 - 0.00009823\ N^3 ;\ R^2 = 0.993$$

Root—uncovered:

$$\ln Y = -3.9635 - 0.0907\ N + 0.007878\ N^2 - 0.00007170\ N^3 ;\ R^2 = 0.992$$

Leaf—covered:

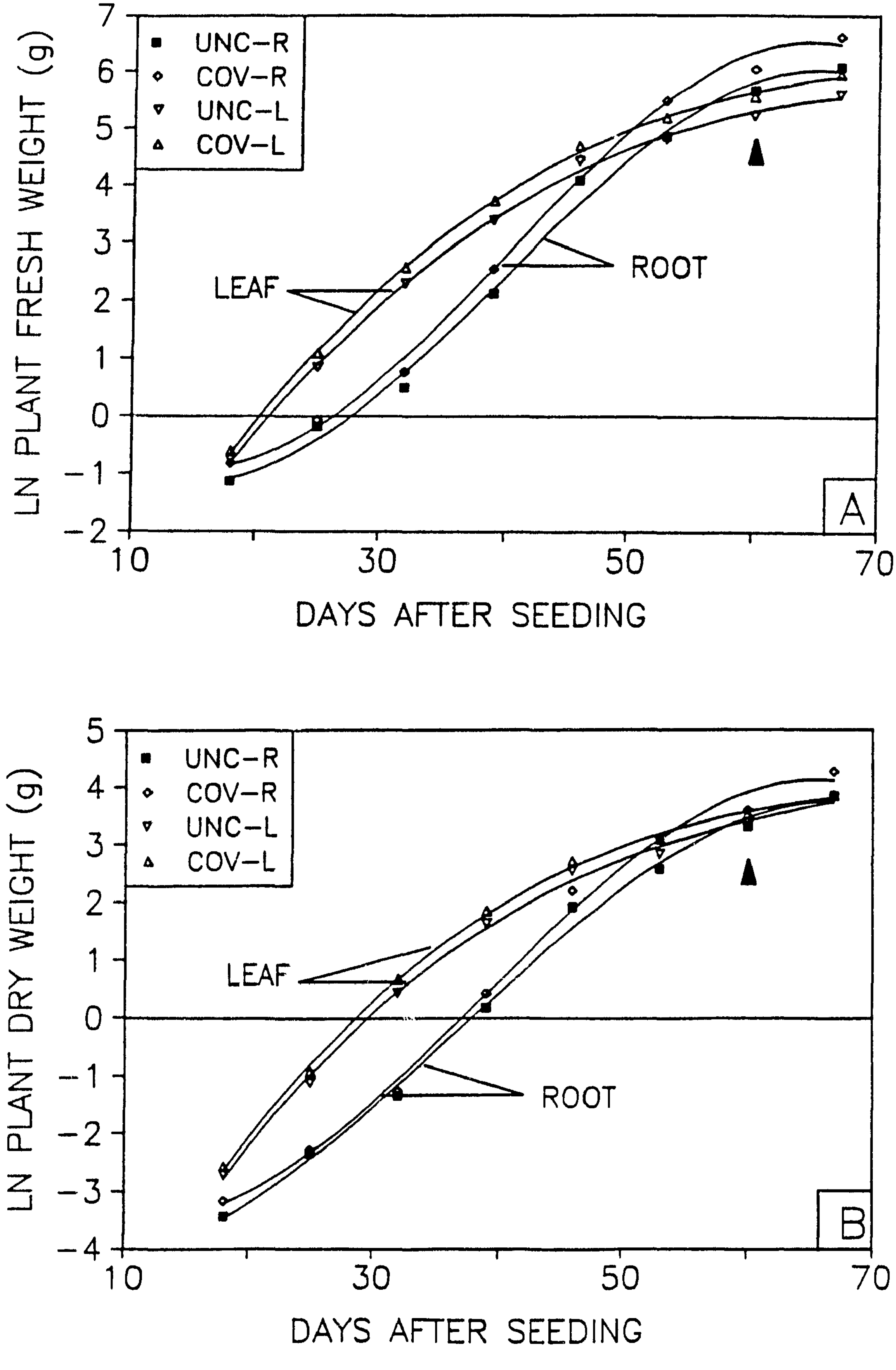
$$\ln W = -9.5228 + 0.4797\ N - 0.005807\ N^2 + 0.00002416\ N^3 ;\ R^2 = 0.997$$

Leaf—uncovered:

$$\ln W = -9.6224 + 0.4799\ N - 0.006032\ N^2 + 0.00002757\ N^3 ;\ R^2 = 0.996$$

with (N) being the number of days after seeding.

The arrow shows harvest time of the covered plots.



LN PLANT FRESH WEIGHT (g)
UNC-R
COV-R
UNC-L
COV-L
LEAF
ROOT
A
DAYS AFTER SEEDING
LN PLANT DRY WEIGHT (g)
UNC-R
COV-R
UNC-L
COV-L
LEAF
ROOT
B
DAYS AFTER SEEDING

Table 3.3 : Effect of a row cover on absolute growth rate of root and shoot of mini carrot expressed as $g.d^{-1}$ and as percentage of plant absolute growth rate on a dry weight basis.

Age of plant (a)	COVERED				UNCOVERED			
	ROOT $g.d^{-1}$	%	LEAF $g.d^{-1}$	%	ROOT $g.d^{-1}$	%	LEAF $g.d^{-1}$	%
18	0.0036	14	0.0212	86	0.0038	18	0.0180	82
25	0.0156	13	0.1074	87	0.0149	15	0.0876	85
32	0.0770	16	0.3576	84	0.0612	18	0.2827	82
39	0.3210	28	0.8186	72	0.2465	28	0.6388	72
46	1.2628	48	1.3433	52	0.8449	44	1.0702	56
53	3.3469	67	1.6447	33	2.0459	59	1.4202	41
60	3.8884	71	1.5665	29	2.5654	61	1.6257	39

(a) in days after seeding.

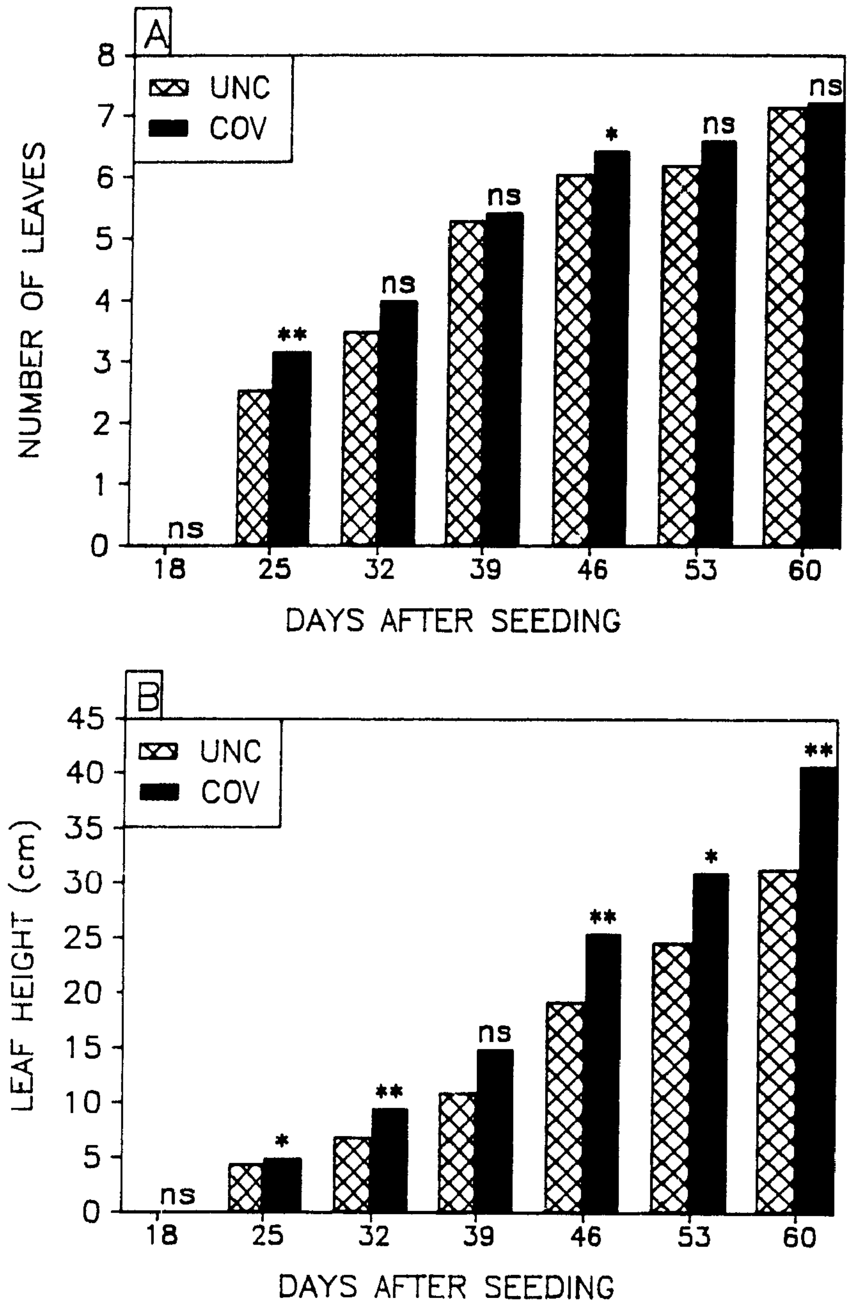


Fig. 3.10: Effect of a floating row cover on (A) number of leaves and (B) length of the longest leaf of mini carrot during the 1988 growing season. Covered (COV) and uncovered (UNC) treatments are not significant (ns) or significant at the 0.05 (*), 0.01 (**) level.

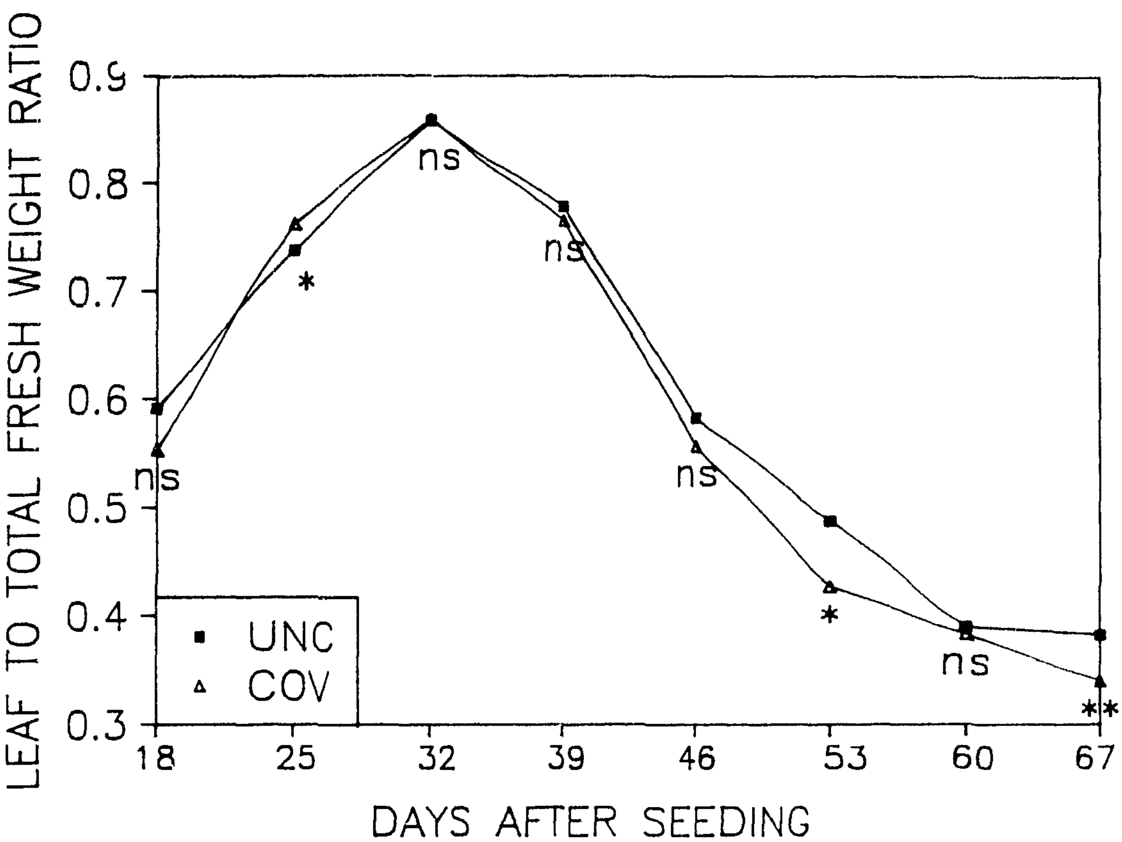


Fig. 3.11: Effect of a floating row cover on leaf to total fresh weight ratio during the 1988 growing season. Covered and uncovered treatments are not significant (ns) or significant at the 0.05 (*), 0.01 (**) level.

3.10 A) but significantly taller leaves ($P<0.01$) for the covered plants versus the non covered plants (Fig.3.10 B). Figure 3.11 shows the leaf to total fresh weight ratio of covered and uncovered mini carrots during the growing season. The lower this ratio, the more efficient is each unit of foliage in producing root. The pattern of the ratios was similar for both the covered and uncovered plants. Values reached a maximum approximatively 32 days after seeding and then declined. At harvest, the covered mini carrots had a significantly lower ratio ($P<0.01$) than did the uncovered ones. When based on dry weight, the curves followed a similar pattern and as such, the data are not presented.

In order to understand the effect of the row cover on root/leaf partitioning during the growing season, an attempt was made to relate root and leaf weights. Logarithms of shoot and storage root weights, termed allometric, were often found to be linearly related (Richard, 1969; Stanhill, 1977; Currah and Barnes, 1979). The simple form of this relationship is $Y = a W^k$, where Y represent the size of one of the growing variables at a given time, W the size of another and a and k parameters, the latter representing the ratio of the relative growth rates of the two variables.

Richards (1969) stressed that, because of the empirical nature of the allometric relationships, its goodness of fit should be tested against the alternative relationship between absolute growth rates which would lead to a linear relationship. Linear and allometric relationships were compared by fitting equations relating root to leaf fresh/dry weight to the covered and uncovered mini carrot data. The first relationship was a linear regression Y = b W + a and the second, allometric in the form $y = a W^k$, equivalent to a linear regression of ln Y on ln W in which the slope k was the ratio of relative growth rates of roots and leaves. The results are presented in Table 3.4 using coefficients of determination (R^2) to compare the degree of variation accounted for by the different relationships. Linear regression based on fresh weight gave a slightly better fit to the data, but both regressions gave similar fits when dry weights were used This is in contrast with Stanhill (1977) who found that the allometric equation gave the best fit for data compared with linear regressions, from a field experiment in which carrots were harvested at 14 weekly intervals from a succession of 14 weekly sowings.

When plotted on the same graph, it was found that the relationship between the logarithms of root and shoot was not linear especially during early growth (Fig. 3.12) . A second degree polynomial was fitted to a common regression line for both covered and uncovered mini carrot data and resulted in a better coefficient of determination (R^2=0.991 for fresh weight and R^2=0.992 for dry weight) than did either a linear regression or simple allometric relationship.

Figure 3.13 shows the effect of the row cover on water content of mini carrots during the entire growing season. The water content of roots and leaves of covered plants were higher than those of the uncovered plants. The depression in the curve corresponded to a period of drought during the 1988 spring.

Table 3.4. Parameters and coefficients of determination (R^2) for linear and simple allometric equations of mini carrot growth, 1988.

EQUATION	LINEAR REGRESSION* $Y = a + bW$			ALLOMETRIC* $Y = aW^k$		
Treatment	a	b	R^2	a	k	R^2
FRESH WEIGHT						
Covered	-27.0480	1 6217	0.956	0.3273	1.1962	0.936
Uncovered	-44.8279	1.8806	0.955	0.3205	1.2093	0.932
DRY WEIGHT						
Covered	-2.5049	1.0531	0.966	0.3714	1.1672	0.957
Uncovered	-4.8650	1.4078	0.936	0.3739	1.2011	0.939

* Y = root weight (g)
W = shoot weight (g)

Fig. 3.12: The relationship between the logaritms of root (Y) and shoot (W) weight of covered (COV) and uncovered (UNC) mini carrot on a fresh weight (A) and dry weight (B) basis. Each point represents the mean of four replicates. Equations for plotted lines are:

for fresh weights:

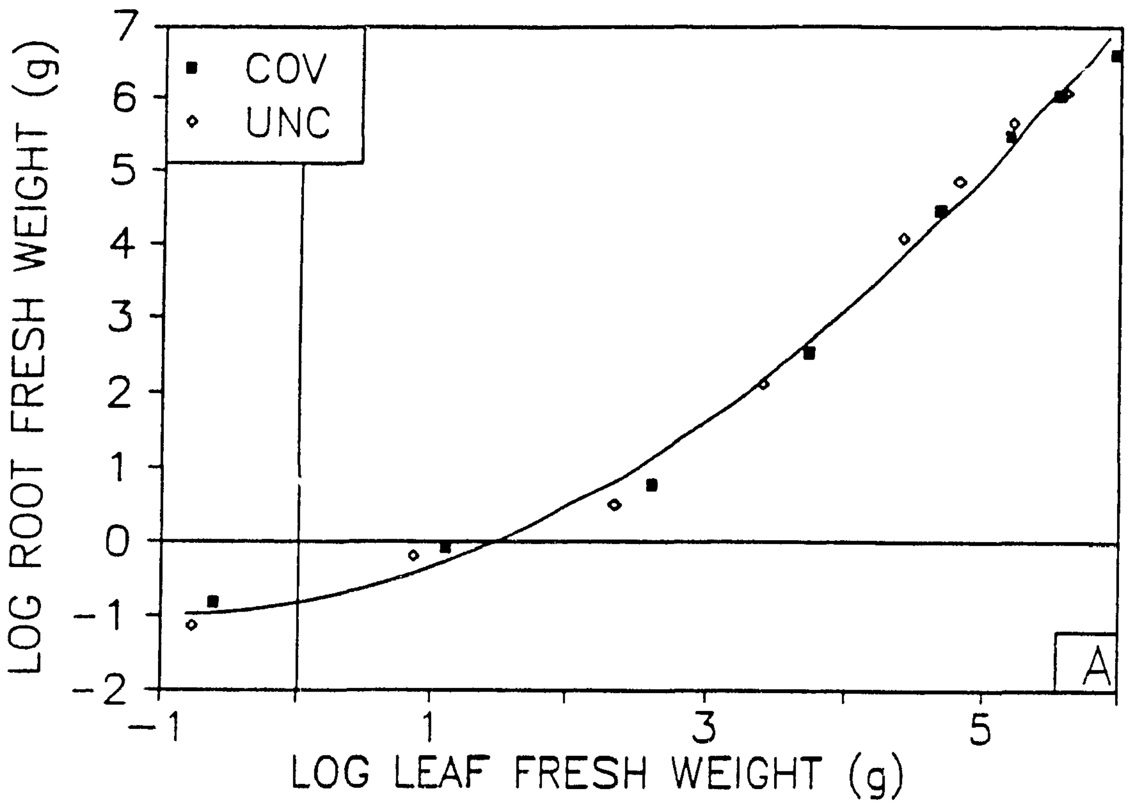
$$\ln Y = -0.8187 + 0.3279 \ln W + 0.1649 \ln^2 W$$

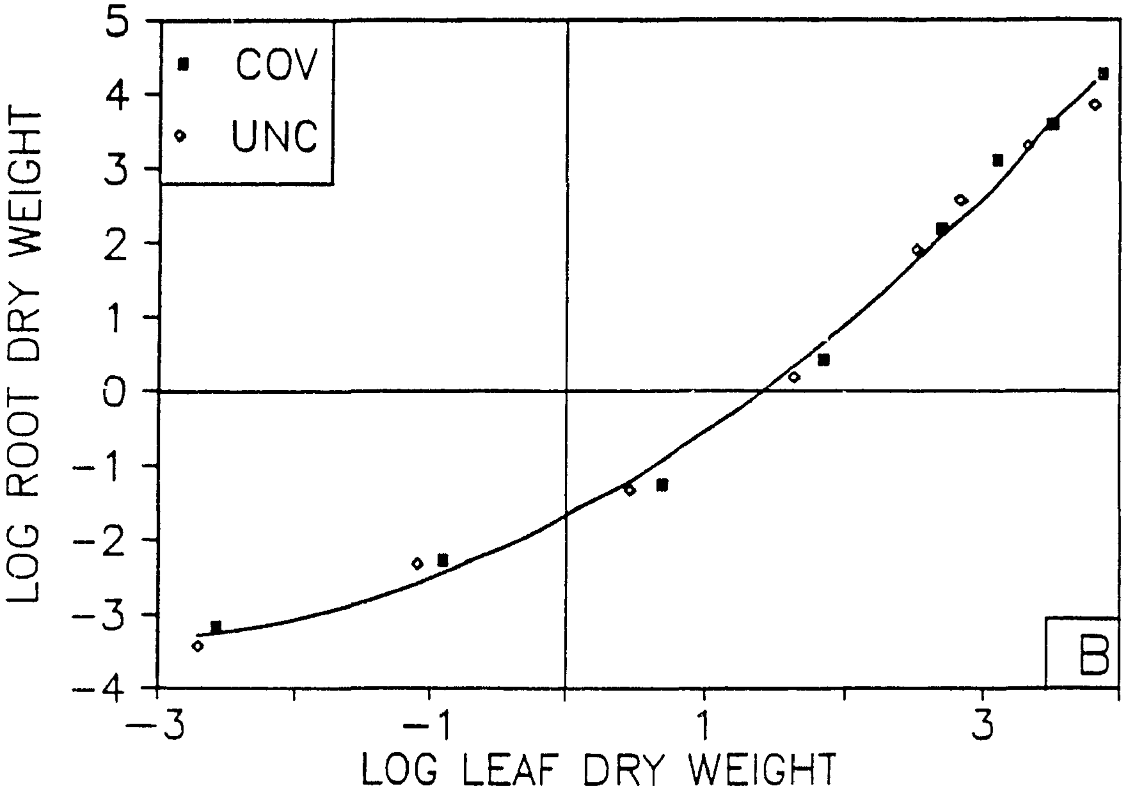
$R^2 = 0.991$

for dry weights:

$$\ln Y = -1.6727 + 0.9876 \ln W + 0.1449 \ln^2 W$$

$R^2 = 0.992$


COV
UNC
A
LOG ROOT FRESH WEIGHT (g)
LOG LEAF FRESH WEIGHT (g)
7
6
5
4
3
2
1
0
-1
-2
-1
1
3
5


COV
UNC
B
LOG ROOT DRY WEIGHT
LOG LEAF DRY WEIGHT
5
4
3
2
1
0
-1
-2
-3
-4
-3
-1
1
3

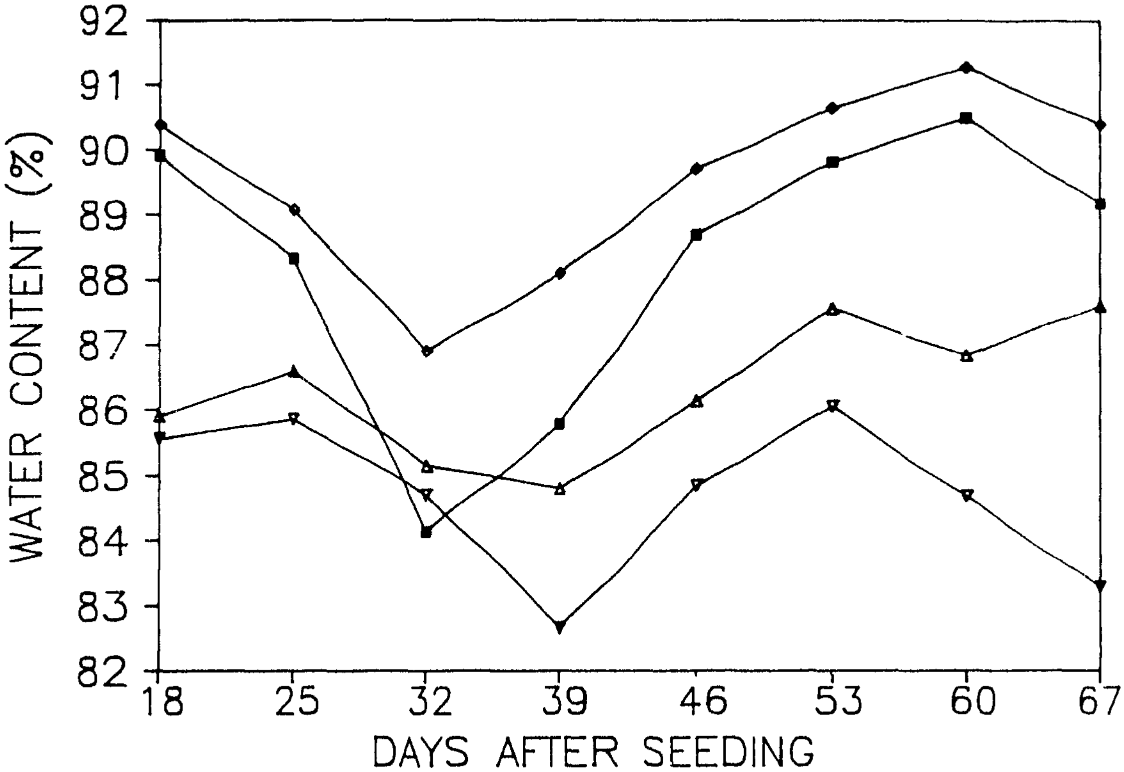


Fig. 3.13: Effect of a floating row cover on water content of mini carrot root and leaves during the 1988 growing season. Root-covered (◇), root-uncovered (■), leaf-covered (Δ), leaf-uncovered (∇).

Figure 3.14 represents the mean fresh weight of mini carrot roots and leaves at harvest time for the different covering regimes. Mean fresh weight of roots tended to increase with longer covering periods and became significantly greater than the uncovered treatment (P<0.05) after 32 days of covering. Although leaf fresh weight followed the same trend, it became significantly greater than the control only after 53 days of covering.

The effect of the different covering regimes on yield (in t/ha) of mini carrots at harvest time is presented in figure 3.15. Total yield was divided in marketable yield and culls. The latter was further subdivided into large roots, those more than 19 mm in diameter, roots infested with carrot weevils and others (roots with a diameter of less than 13 mm as well as forked and twisted roots). Total yield and marketable yield increased with the longer covering times and became significantly greater than the uncovered control after 32 days of covering. After this period, total and marketable yields did not increase significantly.

Also, after 32 days of covering, the yield of large roots were significantly greater than that of the control. The percentage of roots infested with carrot weevils decreased from 10-13 % to 1-2 % after 32 days of covering

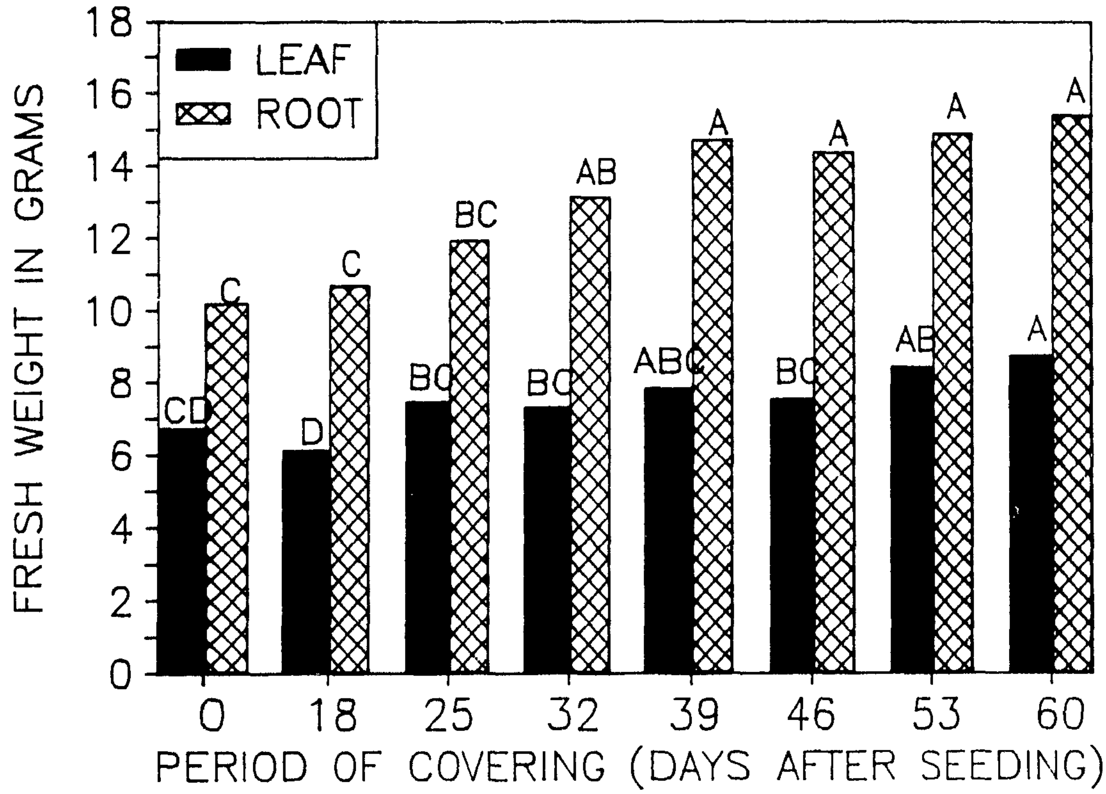


Fig 3.14: Mean fresh weight of root and leaves of mini carrot plants at harvest subjected to different covering durations. Means with a common letter are not significantly different at the 0.05 level based on a protected LSD test.

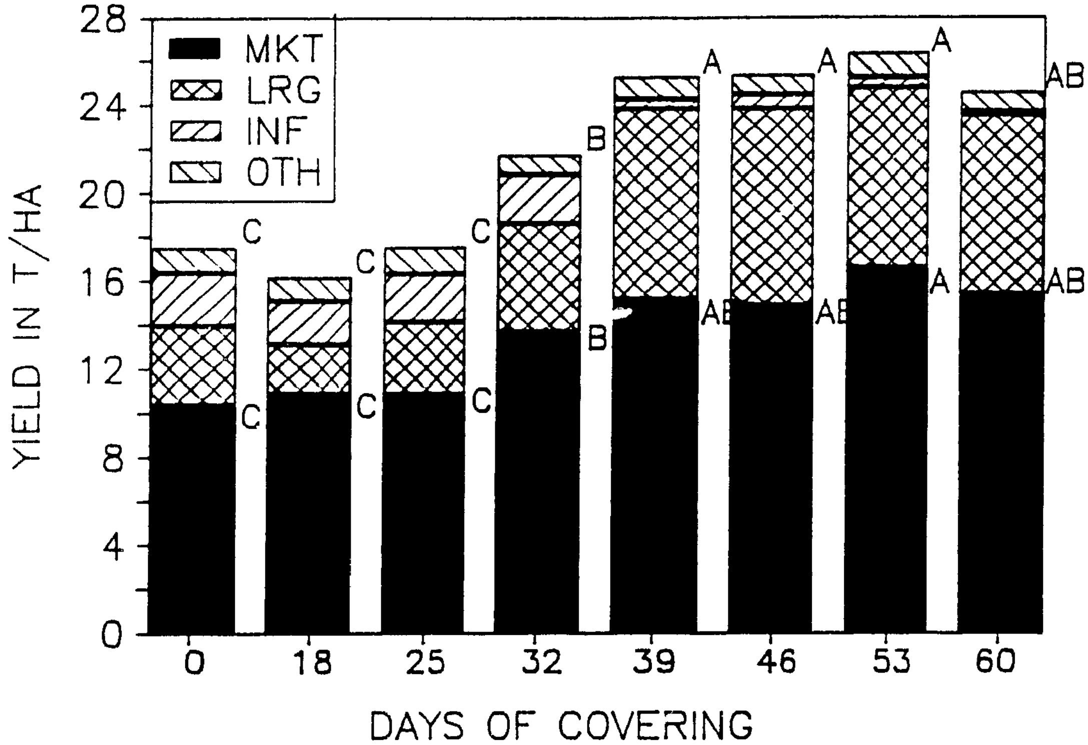


Fig. 3.15: Effect of different covering durations on yield (t/ha) of mini carrot at harvest. Stacks are divided in marketable yield (MKT), large roots with a diameter greater than 19 mm (LRG), roots infested by carrot weevils (INF) and other culls (OTH) including small roots with a diameter less than 13 mm, forked and twisted roots. Means of total (top letters) and marketable yield (bottom letters) with a common letter are not significantly different at the 0.05 level based on a protected LSD test.

3.3.3 DISCUSSION

Plant to plant root weight variation in mature carrots is of considerable importance because it determines the proportion of a crop which can meet the specific market requirements. Marketable mini carrots have a diameter between 13 and 19 mm. Lack of uniformity in the roots results in crop losses during the 'once-over' mechanized harvesting procedure. In field grown crops, the coefficient of variability (CV) of root weights is usually at least 50-60 % (Salter, Currah and Fellows, 1981) and can be as high as 100 % (Austin and Longten, 1967). In this study, the CV for uncovered mini carrot roots was 61 % in uncovered plots but this value ranged from 42 to 54 % for the covered treatment (Fig. 3.8).

Benjamin (1984) studying the relative importance of some sources of root weight variation in carrot crop concluded that factors which affected time of seedling emergence such as sowing depth and physical conditions around the seeds were more important than umbel order, seed size and distance to nearest neighbouring plant.

Indeed, the time at which seedlings emerge and their size at emergence can influence the size of carrot plants several months after sowing (Mann and McGillivray, 1949; Salter et al., 1981, Benjamin, 1982). This was confirmed in this experiment as the more uniform seed emergence of the covered mini carrots, indicated by a significantly reduced mean emergence time (11.2 versus days) and spread of emergence (Table 3.2), resulted in a lower CV of root fresh weight at harvest time compared to the control (Fig. 3.8).

Similarly, Finch-Savage (1986) reported that covering carrot seeds sown in February with polyethylene film decreased mean emergence time from 52.2 to 44.5 days and increased total emergence from 60.9 to 68.4 % although there were no effect on spread of emergence. The less than optimal environment conditions for germination in February might account for this difference in results. Further, Gray (1984) reported that high percentage germination (> 90 %) was associated with low mean germination times and low spreads of germination times whilst the reverse was true for low percentage germination. Finch-Savage (1986) also reported an increased mean seedling weight under a plastic film and this effect was maintained through to the final harvest. Benjamin (1982, 1984 a) has shown that variation in seedling weight soon after emergence occured largely as a result of differences in the size of the seedlings at emergence and differences in the times of emergence of different seedlings This author found that, after a period of 4 months, plants which emerged relatively late had lighter roots than those plants which had emerged earlier. He also found that asynchronous emergence (i.e. over 8-21 days) increased the CV of root fresh weight from 27-33 to 32-37 % (Benjamin, 1982). This effect was magnified by the high population densities because when any competition for growth factors becomes intense, a seedling favoured in competitive ability will dominate its neighbours (Salter et al., 1981; Benjamin, 1984 b). However, as pointed out by Currah (1978), competition was not a prime source of variation: approximatively two thirds of the variation in carrot weights at harvest were present at seedling emergence and one third was caused by the subsequent effects of competition.

Beside viability, inherent to the seed, seedling emergence is affected by a complex interaction of seed and soil factors. The latters include temperature (e.g. Hegarty, 1973), moisture (Doneen and MacGillivray, 1943), fertilizer level (Greenwood and Cleaver, 1971), pathogen content and activity (Perry and Hegarty, 1971) and structural properties such as resistance to seedling penetration and liability to crusting (capping; Sale and Harrison, 1964). In this experiment, factors likely to have influenced seedling emergence were temperature, moisture and some aspects of soil structure deterioration.

The literature on the effects of temperature on both final level and the rate of germination on emergence dates back to the last century and in particular to Sachs (1860) and Haberlandt (1874) (as quoted by Hegarty, 1972). Briefly, these authors showed that the maximum level of germination and the rate of germination tended to occur over a range of temperatures above or below which the level of germination was reduced. resulting in the characteristic 'inverted-U' curves. Harington (1923) using a number of constant and alternating air temperatures within the range of 15 to 35 ^{o}C showed that the final level of germination in 2 carrot seed lots was reduced only in temperature regimes which included a period at 35 ^{o}C. Apart from its effect on the final level of emergence, temperature has an effect on the rate of emergence in the field. Hegarty (1971, 1972) showed that the rate of germination was linearly related to temperature in the laboratory, as was the rate of emergence with mean temperature in the field. For carrot, this linear relationship hold over a relatively wide temperature range, i.e. from 2 to 26 ^{o}C.

Bierhuizen and Wagenvoort (1974) established the minimum soil temperatures for germination (T_{min}, in ^{o}C) and the heat sum to achieve 50 % germination (S, in degree days) for 31 vegetables, assuming the following relationship:

$$S = (T-T_{min}) * t$$

where T is the soil temperature (in ^{o}C) and t, the germination period to achieve 50 % germination (in days). They found carrot seeds could be sown early because of a low minimum temperature of 1.3 ^{o}C requirement but they germinate slowly with a heat sum of 170 degree days (for example for radish, T_{min} = 1.2 ^{o}C and S = 75 degree days). Further, based on a minimum germination percentage (65%) for an acceptable quality of commercial seed, the authors established an optimal temperature range for germination between 9 and 28 ^{o}C (Wagenvoort and Bierhuizen, 1974). There were no significant differences between the results at constant and fluctuating temperatures.

In this experiment, the row cover increased mean air temperature from 14.9 to 16.2 ^{o}C and mean soil temperature from 13.2 to 15.4 ^{o}C during the germination period (from May 6 to May 23). Germination rate can be expressed as the rate of half germination which is the reciprocal of time to half emergence ($1/T_{50}$). Half emergence (T_{50}) is the time when one half of the seedling ultimately emerging had done so

(Hegarty, 1973). Germination rate was 0.113 ($days^{-1}$) for covered plots and 0.0957 (day^{-1}) for uncovered plots and reflected the higher temperature recorded under the row cover (Fig. 3.4).

Furthermore, the lower soil moisture content of the uncovered versus covered plots (Fig. 3.5) may have resulted in a lower rate of seedling emergence of the uncovered carrots seeds. Finch-Savage (1986) showed that the rate of seedling emergence of onion seeds under non-limiting soil moisture conditions was correlated with mean temperatures, but there was an overriding effect of soil moisture stress in delaying seedling emergence. Doneen and MacGillivray (1943) showed that most vegetable seeds gave good germination if the soil moisture content was maintained between field capacity and permanent wilting point, but that the rate of emergence was faster at high moisture contents. Roberts (1984) emphasized the importance of soil moisture in delaying or restricting crop emergence. He stated that if the seed bed after sowing dries out, rapidly germinating crops such as radish and cabbage will become established, but seedling emergence from slower germinating crops like carrot and onion will be delayed until rain falls.

Finally, soil capping and soil impedance are major factors affecting growth and emergence of the cotyledons (Sale and Harrison, 1964; Royle and Hegarty, 1977). Impedance to the seedling can result from soil compaction, from the formation of a soil crust, caused by rain and subsequent drying or from the slumping of poorly structured soils after rainfall, even though no crust is formed (Mc Intyre, 1958; Hegarty and Royle, 1976). Hegarty (1976) reported that reduced emergence levels of carrot, red beet, calabrese and onion seeds when a heavy rain fell shortly after sowing and was followed by a dry period. Hegarty and Royle (1978) showed a negative relationship between seedling emergence and soil integral impedance (work done by penetrating the soil to 15 mm depth), which accounted for over 80 % of the variation in percentage emergence of carrot when soil moisture was not limiting. Indeed, soil crusting appeared to be a function of soil moisture at sowing, as well as the intensity, duration and timing of any rainfall (Hegarty, 1976). Sale and Harrison (1964) showed that while emergence was reduced by soil capping caused by post sowing irrigation and subsequent soil drying, a wet cap did not affect emergence of lettuce, spinach and beet seeds.

Although no data are presented here, observations from the field tended to agree with that of Finch-Savage (1986) who suggested that covering carrot seeds with plastic may have reduced soil impedance under the row cover where moisture was not limiting and soil was protected from the splashing effect of rain.

The carrot plant produces a swollen tap root which acts as a sink for assimilates produced in the shoot. Growth analysis and $^{14}CO_2$ feeding experiments performed by Benjamin and Wren (1978) have shown that during the development of the carrot plant, the thickening tap root became an increasingly important sink for assimilate. The storage organ was found to be dependent on current photosynthates and accumulated 40 % of dry matter produced by the carrot plant within 63 days after sowing. In this experiment, the root accumulated 60 % and 51

% of the dry matter for the covered and uncovered plants 60 days post sowing. The covered mini carrot appeared to be particularly effective in partitioning material to the root.

Furthermore, the leaf to total fresh weight ratio was found to be lower under the row cover after 39 days after seeding (Fig. 3.11). These results contrast with those of Barnes (1936) who found that increasing moisture or the temperature from 4.4 to 26.7 ^{o}C increased leaf to total ratio of a Chantenay type carrot. Increases in leaf weight resulted more from soil moisture rather than an augmentation in temperature. Similarly, Norje and Henrico (1986) irrigated a carrot field to field capacity after depletion of 20, 40, 60 and 80 % of available moisture and found that leaf growth and leaf to total ratio were enhanced by frequent irrigation. However, Barnes (1936) also reported that root shape was modified more by temperature than by moisture. The temperature range that produced normally shaped root for Chantenay carrots growing in greenhouse was 15.5 to 21.1 ^{o}C. Lower temperature produced a longer, more conical and pointed root while higher temperature produced shorter, thicker and more blunt-ended root. Similar results were obtained with other carrot cultivars (Banga, de Bruyn and Smeets, 1955).

The storage root dry weight of a plant depends largely on the shoot's photosynthetic activity, which is in turn closely related to the size of the shoot (Currah and Barnes, 1979). The simple allometric equation $Y = a\ W^k$ was used to predict the root weight of carrot plants (Y) from leaf weight (W). The exponent k, representing the ratio of relative growth rates (RGR) of roots to leaves, was found to be associated with root shape (Stanhill, 1977). Pearsall (1927) suggested that a ratio of RGR of approximatively 3/2 is to be expected for those species in which the apical meristem in the root develops equally in all three dimensions as storage tissue and the apical meristem in the stem develops in two dimensions as superficial leaf tissue. The experimental value of k reported by Pearsall was 1.82 for carrot. However, lower k values were reported by Robinson (1969) with k=1.257 and Stanhill(1977) with k=1.268. Stanhill (1977) suggested that k values were less than 1.5 because a carrot root does not develop equally in all three dimensions, but develops as a cylinder or cone, growth being greatest in the vertical axis. He also found k value of 0.81 when leaf fresh weight per plant was less than 0.1 g. During this very early stage of plant development, leaves rather than roots were predominantely growing.

In this experiment, k values of 1.196 and 1.209 were lower than those found for normal carrot cultivars and higher than those found for very early growth. Indeed, mini carrot has a shorter growing season than normal carrot cultivars and is harvested at a relatively immature stage (Liptay et al., 1981). The higher ratio of relative growth rate for covered mini carrot (1.209 for fresh weight, 1.201 for dry weight) compared to uncovered mini carrot (1.196 for fresh weight, 1.167 for dry weight) reflected the faster root growth induced by the higher soil and air temperatures found under the row cover (Fig. 3.9 A, B).

By analogy, Stanhill (1977) found higher k values for Amsterdam Forcing, a carrot cultivar with a higher relative rate of root growth, an earlier maturity, a smaller final root weight and a larger root to foliage ratio compared to late maturing Chantenay group.

However, fitting a second degree polynomial between the logarithms of root and shoot gave a higher coefficient of determination (R^2) than linear or simple allometric relationships (Fig. 3.12). This is in agreement with Currah and Barnes (1979) and later with Hole, Barnes, Thomas, Scott and Rankin (1983) who also found a curved relationship between the logarithms of root and shoot for plants sampled on successive occasions although this relationship was found to be linear for plants of the same age but of different whole-plant weights. Further, the authors reported a difference between the relationship at early and later harvests. This was attributed to the difficulties in distinguishing between fibrous and tap root in early stages, and to the major physiological changes occuring during the transition from an emerging seedling to a plant producing a storage tap root.

Both covered and uncovered data followed the same allometric relationship . This result suggests that, by increasing the ambiant temperature of the crop, the row cover may have altered the physiological age of the plant. Similarly, Terry (1968) found that a five fold change in light intensity had no effect on partitioning in sugar beet but that temperature change had an effect equivalent to an 'age shift'.

This would further explain the lower leaf to total ratio found under the row cover. Indeed, Barnes (1936) reported a decreasing leaf to total ratio as the plants were aging. If the covered mini carrots were physiologically older than the non covered mini carrots, they would then be expected to have a lower leaf to total ratio relative to uncovered mini carrots.

This experiment showed consistently higher water content (or lower dry matter content) under the row cover (Fig. 3.13). Barnes (1936) found that temperature had little effect on the percentage of dry matter, while soil moisture altered the percentage very greatly. The percentage of dry matter was highest for plants grown with low soil moisture. Similarly, plants with higher water content were found under the row cover where higher soil moisture content was recorded (Fig. 3.5).

The marketable yield of a carrot crop depends on the total plant yield, the proportion of which is storage root, and the parameters, particularly the mean and the variance of the storage weight distribution, which determine the proportion of roots which are of marketable size (Currah and Barnes, 1979).

The increase in marketable yield with longer covering time reflects the decrease in the coefficient of variability of fresh root weights. This improved uniformity in the covered crop at harvest time was in part explained by the beneficial effect of the row cover on germination and growth, but also by the ability of the row cover to exclude carrot weevils from the crop. Indeed, the row cover appeared to have served as a physical barrier to this important carrot pest. Other authors reported similar findings with other crops (Wells and Loy, 1985 and 1986; Hemphill et al., 1987; Natwick et al., 1987).

3.4 CONCLUSION

Row covers generally increased mean air temperature by 1.4 ^{O}C and mean soil temperatures by about 2 ^{O}C. Although at several occasions during early spring, frosts were mediated by the row cover, they did not afford frost protection. Indeed, a few cases of inversion occurred, when temperatures were lower under the row cover than for the unprotected field. In muck soils, it was found that the row cover increased soil moisture content by 2-67 %, with the greatest differences occurring at the lowest moisture content.

The row cover was well adapted for use with mini carrot and reduced time to harvest by one week in both 1987 and 1988. It was felt that some of the success of row cover on mini carrot was due to the effective use of herbicides which may be applied before laying the row cover or sprayed above it.

Mini carrot, as a seeded crop, profited from the improved microclimate provided by the row cover since germination. The improved uniformity of seed germination under the row cover, as reflected by a higher rate of seed germination and a lower spread of emergence times, resulted from higher temperatures, higher soil moisture and probably reduced soil impedance. The row cover also affected root/shoot partitioning of mini carrots. Indeed, 60 % of dry matter accumulated in the covered mini carrot roots compared to 51 % for those uncovered within the 60 days of the crop growing season. The greater dry matter accumulation of the covered mini carrots could be attributed to improved growth as well as improved sink capacity of the root system. However, this conclusion can only be related to the mini carrot crop and may not apply to the standard carrot cultivars having a longer growing season.

Surprisingly, the relationship between the logarithms of root and shoot for both covered and uncovered mini carrots followed the same second order polynomial curve, suggesting that the row cover could have simply affected the physiological age of the mini carrots. However, leaves of the covered plants were taller than those of the uncovered ones, although the number of leaves was about the same. Etiolation of the covered mini carrot leaves may have been an indication of morphological differences.

When the row cover was left in place for at least 39 days, plants produced the greatest marketable and total yields as well as mean root fresh weights. However, in the case of adverse weather conditions, the row cover could be left in place until harvest without detrimental effects.

4. LETTUCE EXPERIMENT

4.1 MATERIALS AND METHODS

In 1987 and 1988, experiments were conducted to determine. the optimum stage and/or critical temperatures for the removal of a floating row cover in early crops of crisphead lettuce (Lactuca sativa L. cultivar 'Ithaca M.I.')

In 1987, an experiment was undertaken to compare different covering periods using a 12.8 m wide floating row cover employed by Quebec growers.

In 1988, in addition to the wide row cover trial, a second experiment was performed using narrow covers (2.3 m) in order to solve statistical limitations imposed by the preceeding experiment.

The experiment was carried out in Napierville Quebec, on the Hotte and Van Winden Farm (45^{o} 11' Lat., 73^{o} 25' Long.). The site had a well decomposed organic muck profile, 1.5 m deep and a pH of 6.3.

4.1.1 The wide cover experiment (1987,1988)

4.1.1.1 Transplant production

Coated lettuce seeds (cv. 'Ithaca') were sown March 21 and March 16 in 1987 and 1988, respectively into styrofoam flats (28 by 54.5 cm) containing 128 3.5 by 3.5 cm cells (Todd Planter Flat, model #150).A peat based growing medium was used. Greenhouse night air temperature was maintained at 18.3 ^{o}C and 12.8 ^{o}C after germination. Plants were grown with natural light. After the cotyledonary stage, plants were fertilized weekly at a rate of 1.8 kg of 20-10-20 for a greenhouse of

232 m^2.

4.1.1.2 Field preparation and transplantation

The experimental site was spring disked, levelled and fertilized at a rate of 80 kg nitrogen, 110 kg phosphate and 220 kg potash per hectare.

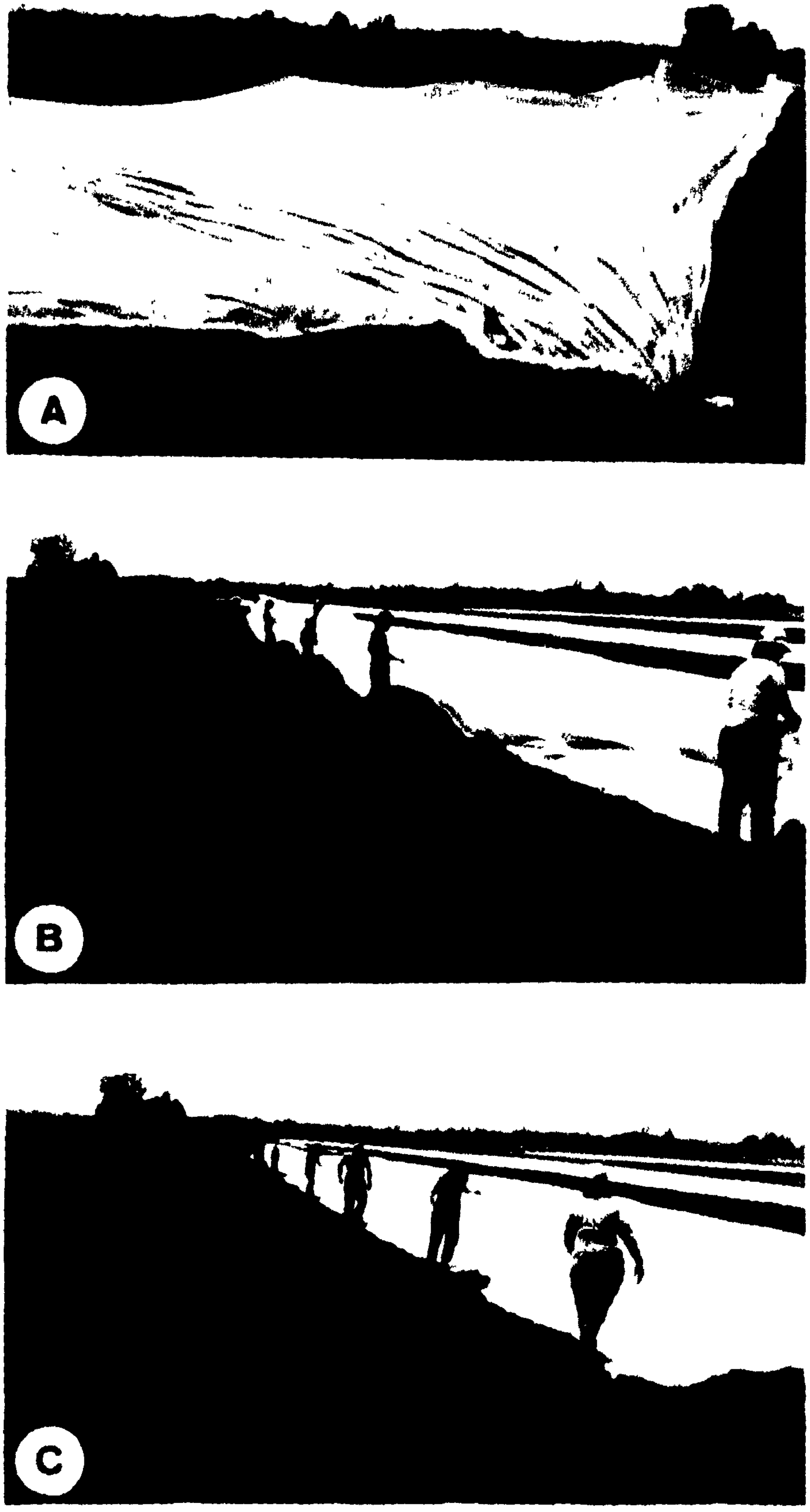
Lettuce were mechanically transplanted on April 23, 1987 in 1.68 m wide beds. Within each bed, there were three rows of lettuce spaced at 51 cm between and 30 cm within the row.

In 1988, lettuce were transplanted on April 26. In this case, four rows of lettuce were planted in the 1.83 m wide beds. Lettuce were spaced 43 cm between and 30 cm within the row. Spacing was reduced in 1988 in order to increase plant density and reduce the per plant input cost of the row cover.

When the lettuce covered the soil surface, the row cover was temporarly removed and weeds were controlled (Plate 5). A rototiller was used on weeds between the rows, whereas hand weeding was done in the row.

Disease and pest control measures were performed with the cover intact. Dithane M45 (Mancozeb) was applied at a rate of 2 kg/ha to control mildew and Monitor 48E (Methamidophos) at a rate of 1 l/ha to control aphids.

Plate 5: Replacing the 12.8 meter wide floating row cover after mechanical weeding of the lettuce field.


A
B
C

4.1.1.3 Covering material

Both the floating row cover and the installation procedures used in the lettuce experiments were similar to those described in section 3.2.1.3 for mini carrots. The floating row cover was applied 2 and 0-1 days after transplantation in 1987, 1988, respectively. The wide cover emcompassed 18 rows of lettuce in 1987 (Plate 6 A) and 22 rows in 1988.

4.1.1.4 Experimental layout and analysis of data

In order to study the behaviour of a wide cover commercially used by vegetable growers, a systematic design was used. Each treatment consisted of a specific covering duration based on plant growth stage and air temperature. Five growth stages have been clearly defined for lettuce (CTIFL, 1982): rosette or 10-leaf stage, soil cover i.e. when the leaves are touching within the row, start of hearting, hearting plus one week, and harvest (Plate 7).

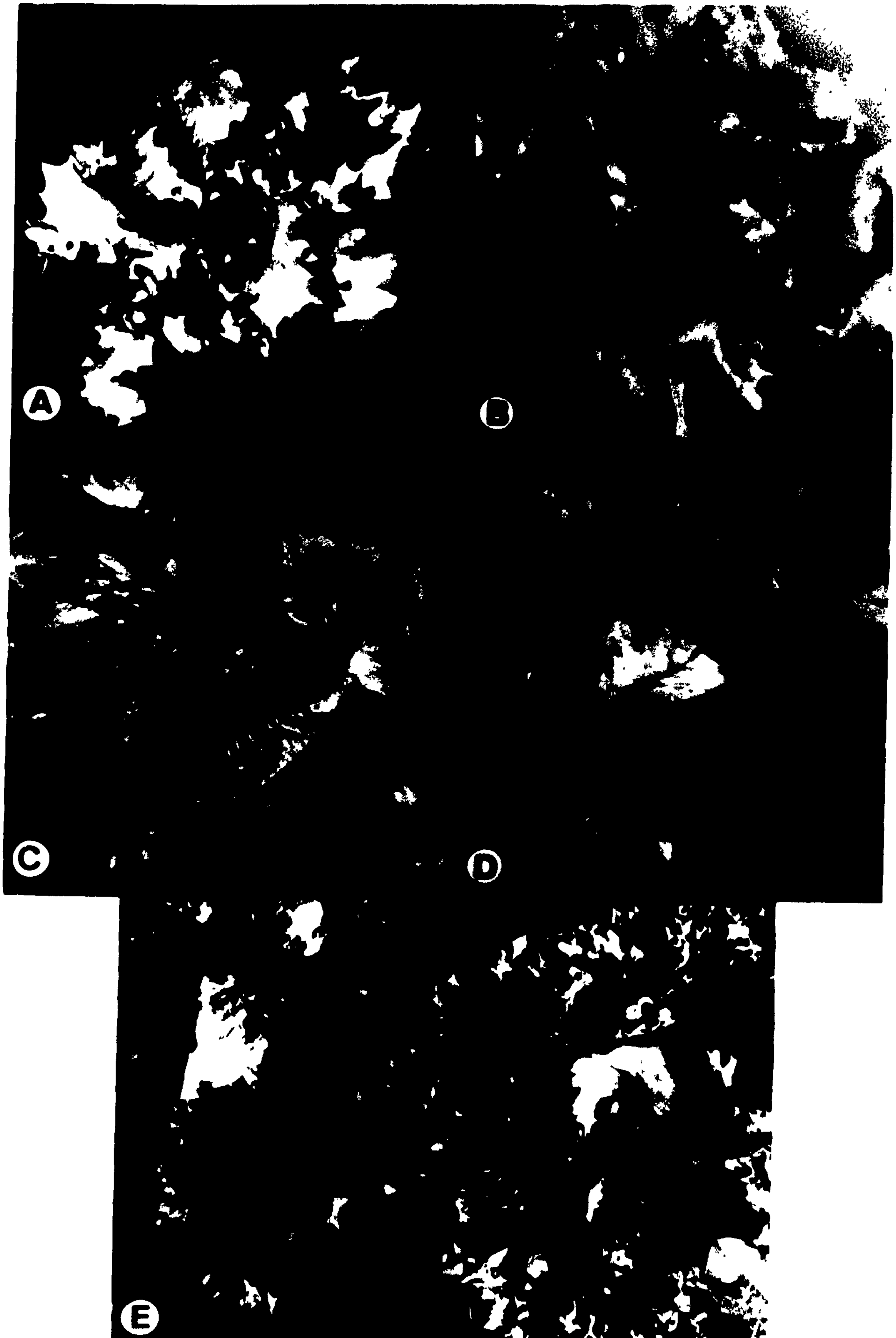
For the wide cover experiment in 1987, each time a specific growth stage was reached, the row cover was rolled back 3 meters (Plate 6 B). The control which covered the same surface area was located in an adjacent uncovered field. There were 3 replicates. As for the 1987 mini carrot experiment, analysis of data was limited to simple comparision of response curves (MEAD, 1979).

In 1988, a similar experiment was conducted with the 1987 recycled wide row cover.

Plate 6: (A) A 12.8 meter wide floating row cover used on a lettuce field at Napierville, Quebec. (B) The wide cover experiment: the floating row cover was rolled back three meters at each treatment stage.


A
B

Plate 7: The five stages of lettuce growth at which the floating row cover was removed: (A) rosette or 10-leaf stage, (B) soil cover, (C) start of hearting, (D) hearting plus one week, (E) harvest.


A
B
C
D
E

4.1.1.5 Harvesting procedure

Harvesting took place on June 22 in 1987 and on June 20 in 1988. Lettuce plots were harvested when 90 % of the heads under the floating row cover were judged to be mature. The main criteria used to assess maturity were head size and firmness. Firmness was evaluated using the Canada Agricultural Products Standards Act (1981) which states that a mature head is one that "is compact and yield only shightly to pressure". The minimum marketable head size was 15 cm in diameter.

The control plots were harvested at the same date as the covered plots regardless of lettuce maturity. All lettuce heads were cut at soil level and weighed.

4.1.1.6 Recorded characteristics

Lettuce being a leafy crop is very susceptible to edge effects. Therefore, plants were sampled only from the inner section of the wide cover experiment. Ten lettuce per replicate were randomly chosen for fresh weight and qualitatives test included percent firm lettuce, lettuce less than 15 cm diameter, lettuce with tipburn, sunscald and lettuce affected by bottom rot caused by fungal diseases.

4.1.2 The narrow cover experiment (1988)

4.1.2.1 Field set up

Thirty eight days old lettuce were transplanted on April 20 1988. In this experiment, plot size were 1.83 by 5 meters and consisted of four rows of lettuce spaced 43 cm within and 30 cm between the rows. The size of the row cover needed to cover the plots was 2.3 by 6.4 m. These covers were layed on April 23 1988 and covered 4 rows of lettuce plants.

Weeds and pest control was performed as described in section 4.1.1.1.

Lettuce were harvested on June 20 1988 following the same procedure described in section 4.1.1.5.

4.1.2.2 Experimental layout and analysis of data

A randomized complete block design experiment was layed out and replicated 4 times. Each block consisted of seventeen 1.83 by 5 m plots. The two outermost plots served as guards and the remaining 15 plots were divided into 10 treatments and 5 controls. In the narrow cover experiment, the 5 original growth stages of the wide cover experiment were used as the main treatments. Each individual plots consisted of 4 rows of lettuce. The outer two rows were guards and two sets of experimental plants were chosen from the inner two rows analysis: 5 plants during growth at each cover removal and 10 plants at harvest. For this experiment, data were analysed statistically using Statistical Analysis System (SAS) and sample analysis outputs are presented in Appendix B.

4.1.2.3 Recorded characteristics

As each of the identified growth stages was reached and the cover rolled back, 5 lettuce plants were removed for sampling from both the covered and uncovered plots. The lettuce heads were weighed and oven-dried at 70^{o}C until a constant dry weight was reached (24-48 hours). In addition, the number of leaf initials (<1 cm in length), leaves longer than 1 cm, and the length and breadth of the 13th leaf were recorded in order to study the hearting process. Leaf initials were counted by dissection beneath a binocular microscope.

At harvest, the number of leaves prior to hearting (frame leaves), leaves longer than 1 cm forming the heart and the number of leaf initials (<1 cm) were also recorded.

4.1.3 Meteorological data

In both 1987 and 1988, minimum and maximum temperatures of the air (at a height of 2-4 cm) and soil (at a depth of 7cm) were recorded daily as described in section 3.1.

4.2 RESULTS

4.2.1 Meteorological data

The minimum, maximum and mean air temperatures recorded under the floating row cover are shown in figure 4.1 for the period May 19 to June 22 in 1987. A similar problem in term of obtaining temperatures to that encoutered in the carrot experiment (section 3.1) also occured for the lettuce experiment. Extremely high temperatures were found periodically under the covers, with maxima of 50^{o}C or more.

In 1988, temperatures were taken in both the covered and uncovered plots and these data are presented in figure 4.2 between April 23 to June 22 in 1988. The air temperatures under the row cover were routinely greater than the uncovered counterpart, with an average

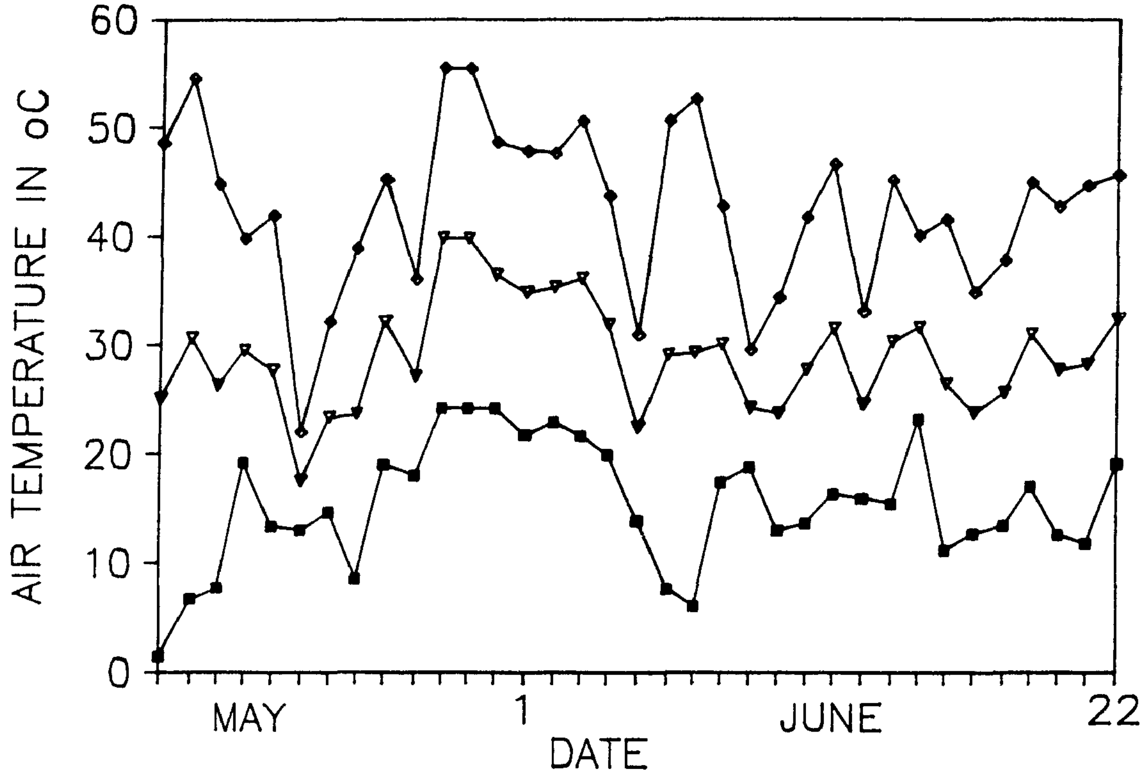


Fig. 4.1: Minimum (■), maximum (◇) and mean ▽) air temperatures at a height of 2—4 cm recorded daily under a floating row cover during the 1987 spring at Napierville.

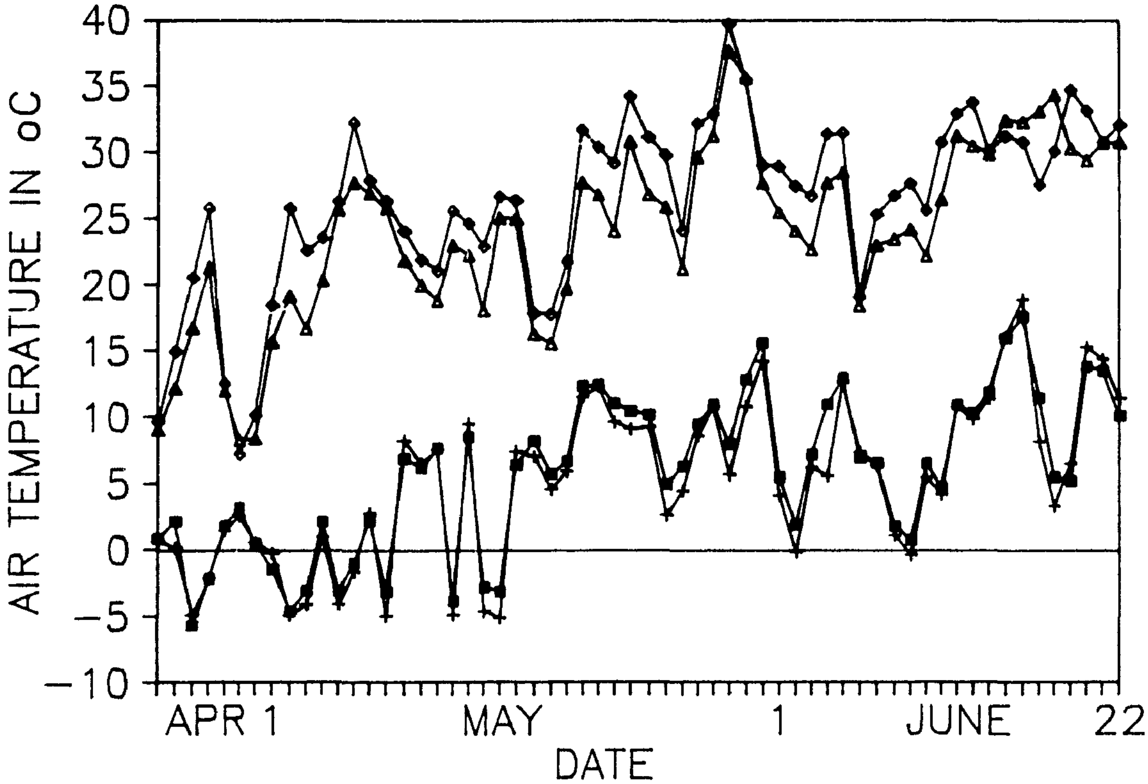


Fig. 4.2: Effect of a row cover on air temperatures at a height of 2–4 cm during the 1988 spring at Napierville. Maximum covered (◇), maximum uncovered (Δ), minimum covered (■), minimum uncovered (+).

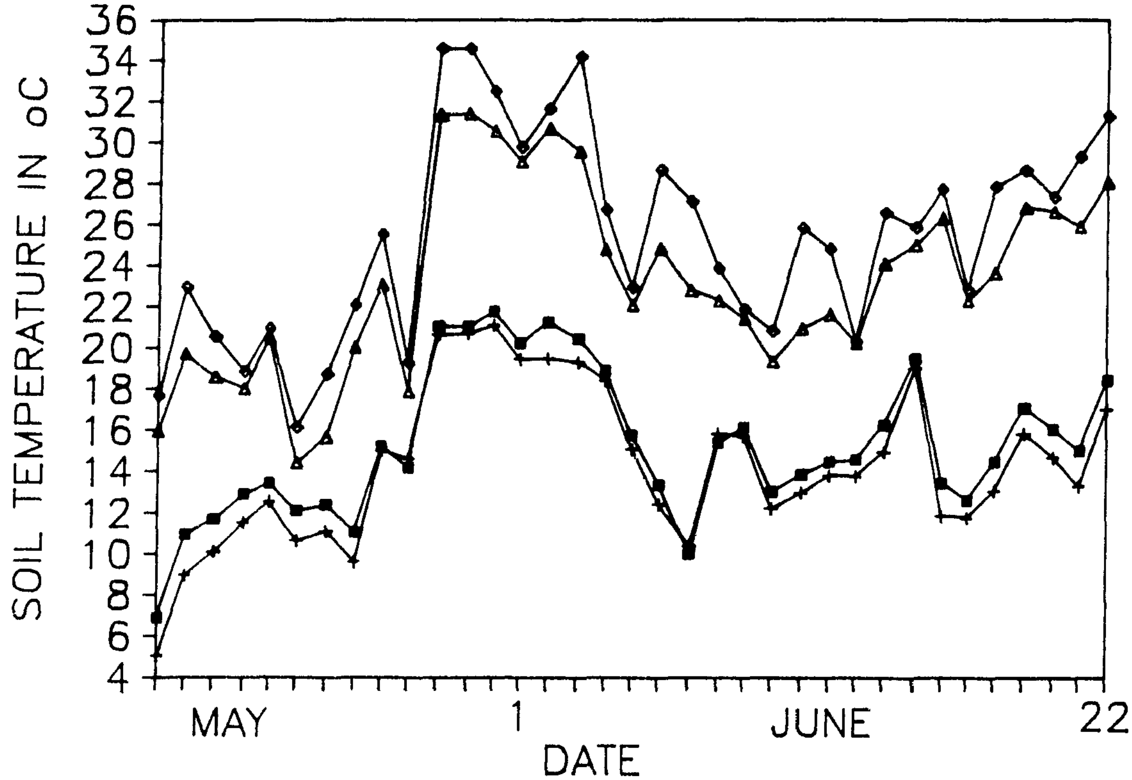


Fig. 4.3: Effect of a row cover on soil temperatures at a depth of 7 cm during the 1987 spring at Napierville. Maximum covered (◇) maximum uncovered (Δ), minimum covered (■), minimum uncovered (+).

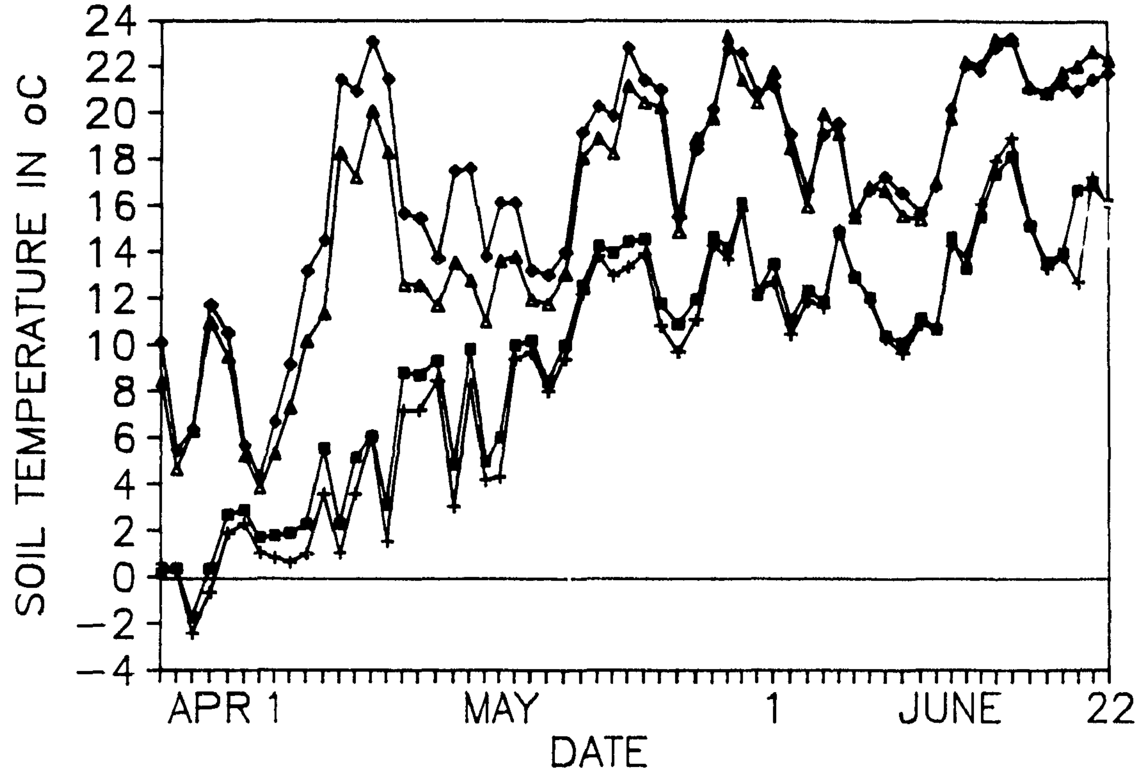


Fig. 4.4: Effect of a row cover on soil temperatures at a depth of 7 cm during the 1988 spring at Napierville. Maximum covered (◊), maximum uncovered (Δ), minimum covered (■), minimum uncovered (+).

temperature rise of 1.4 °C. At the beginning of the growing season, frosts of -5°C occurred and these were mediated by the row cover. The higher maxima was 40 °C under the row cover but these were lower than the maxima greater than 50 °C found under the row cover in 1987 (Fig. 4.1).

Soil temperatures were taken from both covered and uncovered plots in 1987 and 1988 and are presented in figures 4.3 and 4.4, respectively. In 1987, temperatures were consistently higher under the row cover than for the uncovered plots, with increases of 1 °C in the minimum and 1.5 °C in the maximum. Maximum soil temperatures varied over the season from approximatively 17 °C at the start of the measurement period until 30 °C at the end of the growing season. For a period of 6 days at the end of May-beginning of June, soil temperatures were extremely high, reaching values of 34 °C under the row cover. The minimum soil temperatures showed similar trends.

In 1988, soil temperatures were generally lower than during the 1987 season. Minimum temperatures increased by 0.6 °C and maximum temperatures by 1 °C. At the start of planting, a frost occurred. However, by the end of the growing season, minimum soil temperatures have risen to 16 °C.

4.2.2 The wide cover experiment

The lettuce suffered severe frost damage early in the 1987 growing season. This was most apparent for lettuce close to the edge of the cover where the material actually touched the plant (Plate 8).

For both years, lettuce fresh weight at harvest increased with all

Plate 8: Frost damage in a lettuce field with a floating row cover in 1987. Damage area in the center of picture (A) corresponds to the end of the row cover.

A

B

Table 4.1: Influence of row cover period on lettuce fresh weight at harvest in 1987 and in 1988 (mean of 30 plants)*.

Stage of cover removal	1987		1988	
	Days of covering	Fresh weight (g)	Days of covering	Fresh weight (g)
No cover	0	739.1	0	999.8
10-leaf (TA)	27	846.5	28	1100.0
soil cover (TB)	37	969.0	32	1195.0
hearting (TC)	44	956.7	39	1179.2
hearting + 1 week (TD)	50	914.5	46	1204.3
harvest (TE)	61	932.8	56	1198.7

* these experiments had a systematic design and the results were not statistically analysed.

covering treatments compared to the control (Table 4.1). However, the Cox-Stuart test for trend (Daniel, 1978) detected no upward or dowmward trends. Covering up until the lettuce leaves touch within the row gave the highest yield in 1987. Thereafter, yields were variable. In 1988, leaving the cover until at least the stage 'soil cover' produced plants that were 18-20 % heavier than the control. The 1988 yields were consistently higher than those obtained in 1987.

The percentage of firm lettuce heads are presented in figure 4.5. In 1987 (Fig. 4.5 A), there were no firm lettuce heads in the uncovered plots. This was more a result of a poor head formation or a small immature head rather than of loose heads. The percentage of firm lettuce rose as the length of covering period increased, reaching a maximum when the cover was left until the stage hearting plus one week. The 1988 trial produced similar results (Figure 4.5 B). However, in 1987, the best treatment, hearting plus one week, gave a maximum of 60 % firm lettuce whereas in 1988, this rose to above 80 % for the same treatment.

The evaluation of the percentage of small lettuce was performed only in 1988 (Fig. 4.6). This percentage tended to decrease with longer covering time, going from 70 % for uncovered to 23 % when the row cover was left until harvest.

Two physiological problems, tipburn and sunscald, were observed in the lettuce trials. Tipburn damage was characterized by necrosis on the extremities of external leaves. Sunscalded plants had a white upper surface on the top of the lettuce head. For both years, the percentage of lettuce with tipburn increased with longer covering time (Fig. 4.7

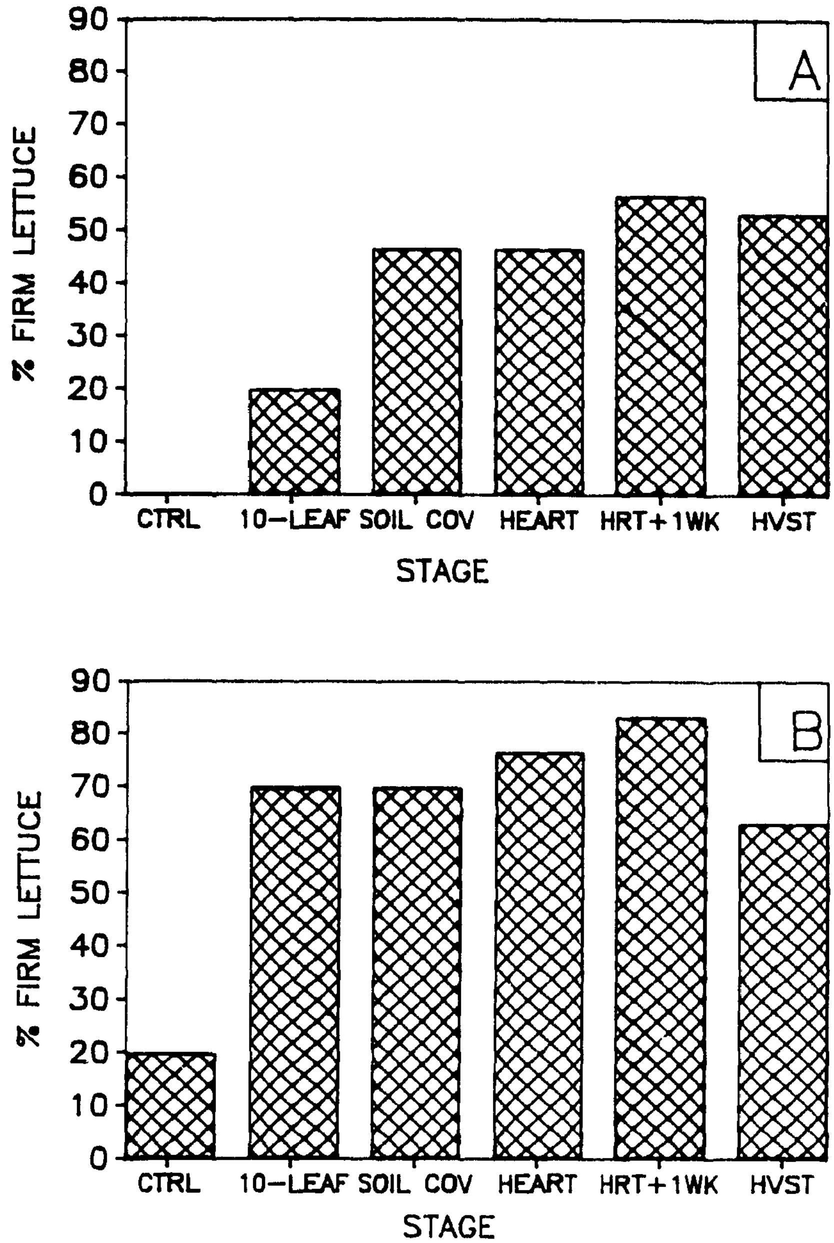


Fig. 4.5: Effect of row cover duration on percentage of firm lettuce at harvest (A) in 1987 and (B) in 1988.

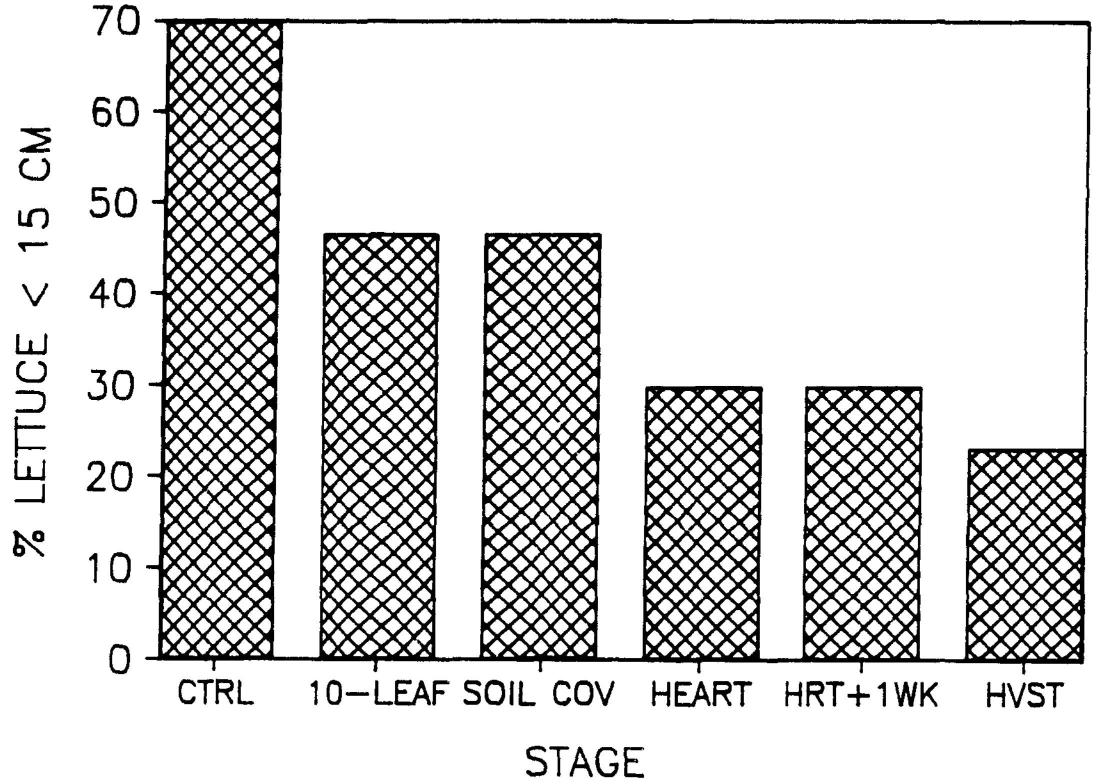


Fig. 4.6: Effect of row cover duration on percentage of small lettuce, i.e. with a diameter less than 15 cm, in 1988.

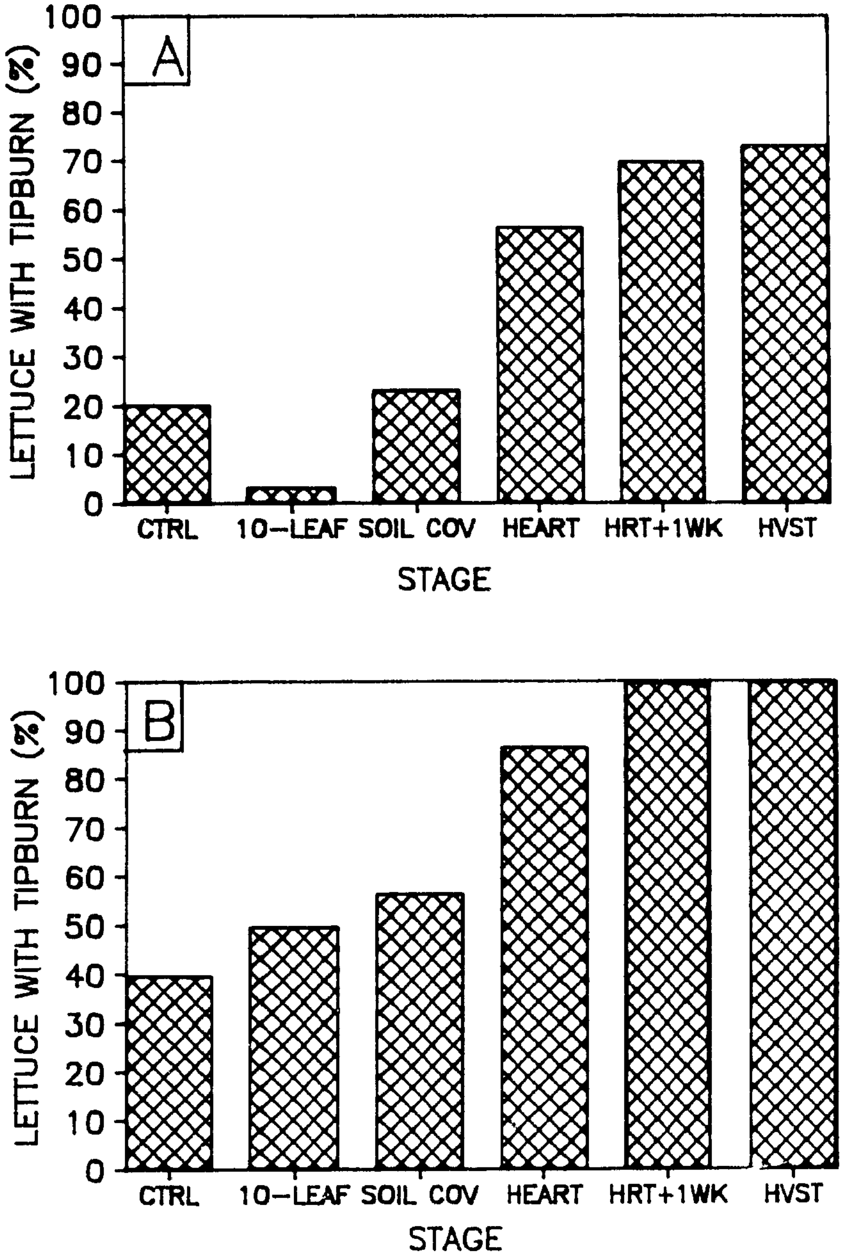


Fig. 4.7: Effect of row cover duration on percentage of lettuce with tipburn at harvest (A) in 1987 and (B) in 1988.

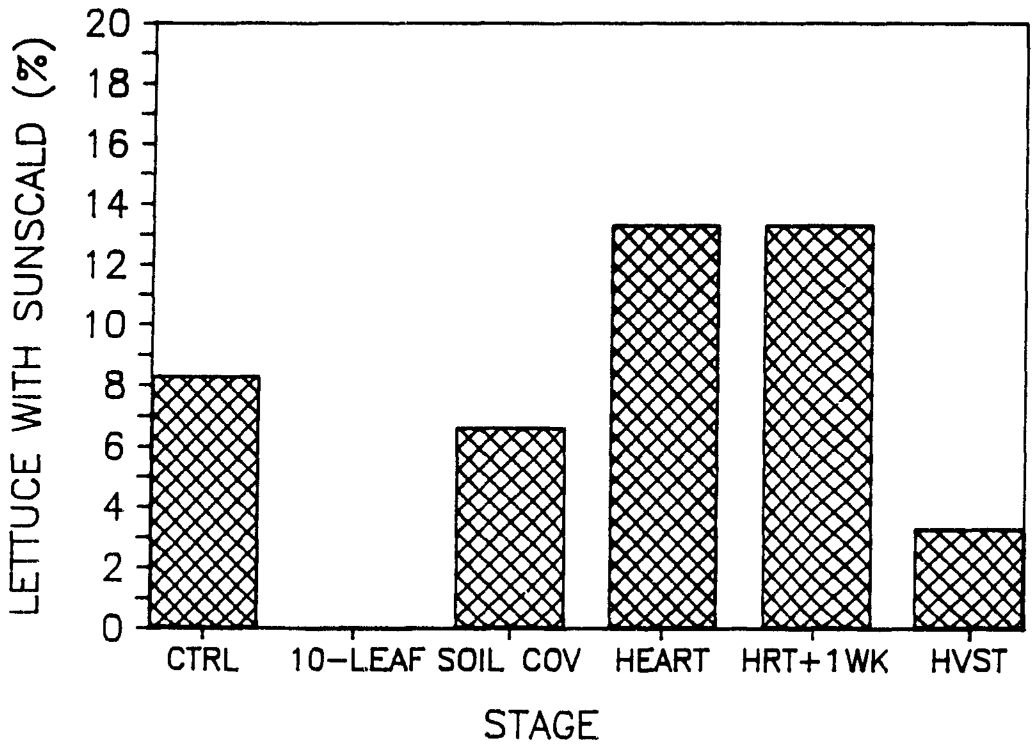


Fig. 4.8: Effect of row cover duration on percentage lettuce with sunscald at harvest in 1987.

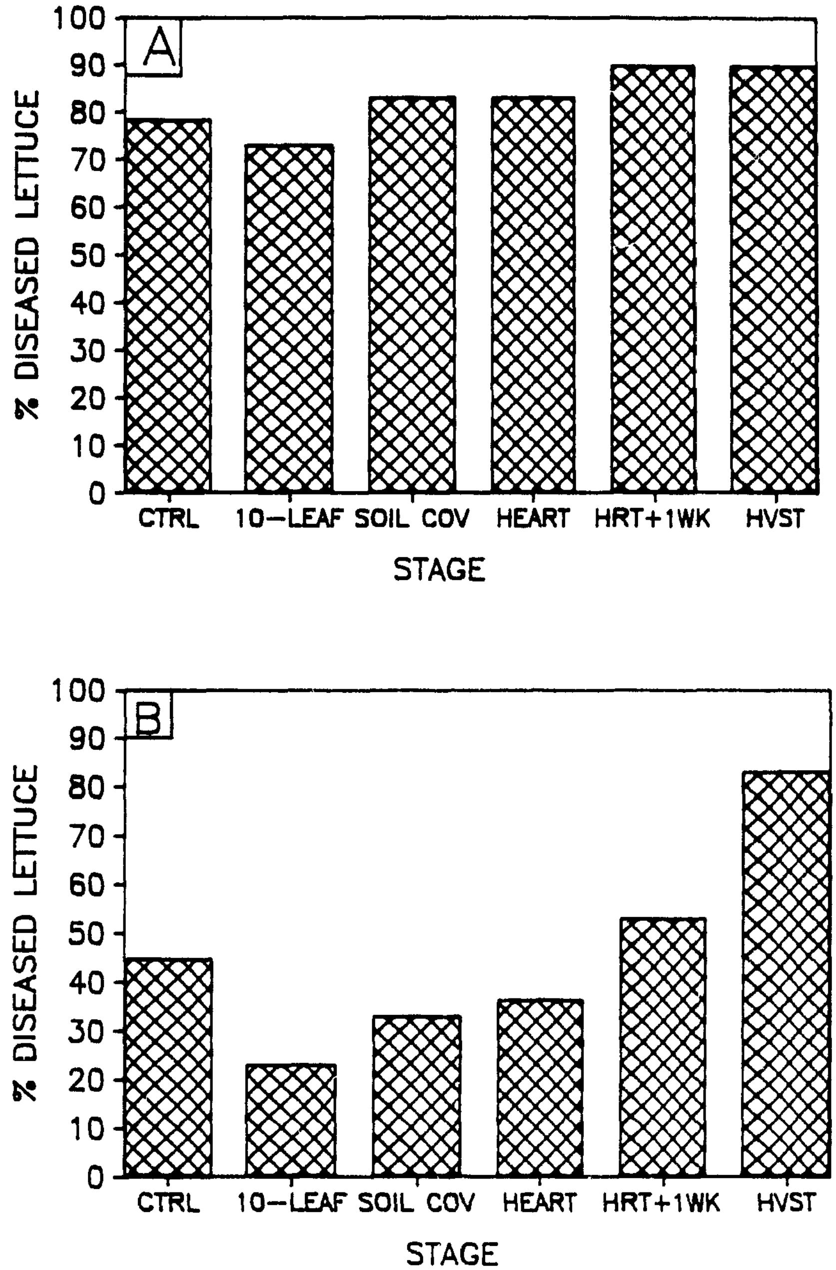


Fig. 4.9: Effect of row cover duration on percentage of lettuce with bottom rot at harvest (A) in 1987 and (B) in 1988.

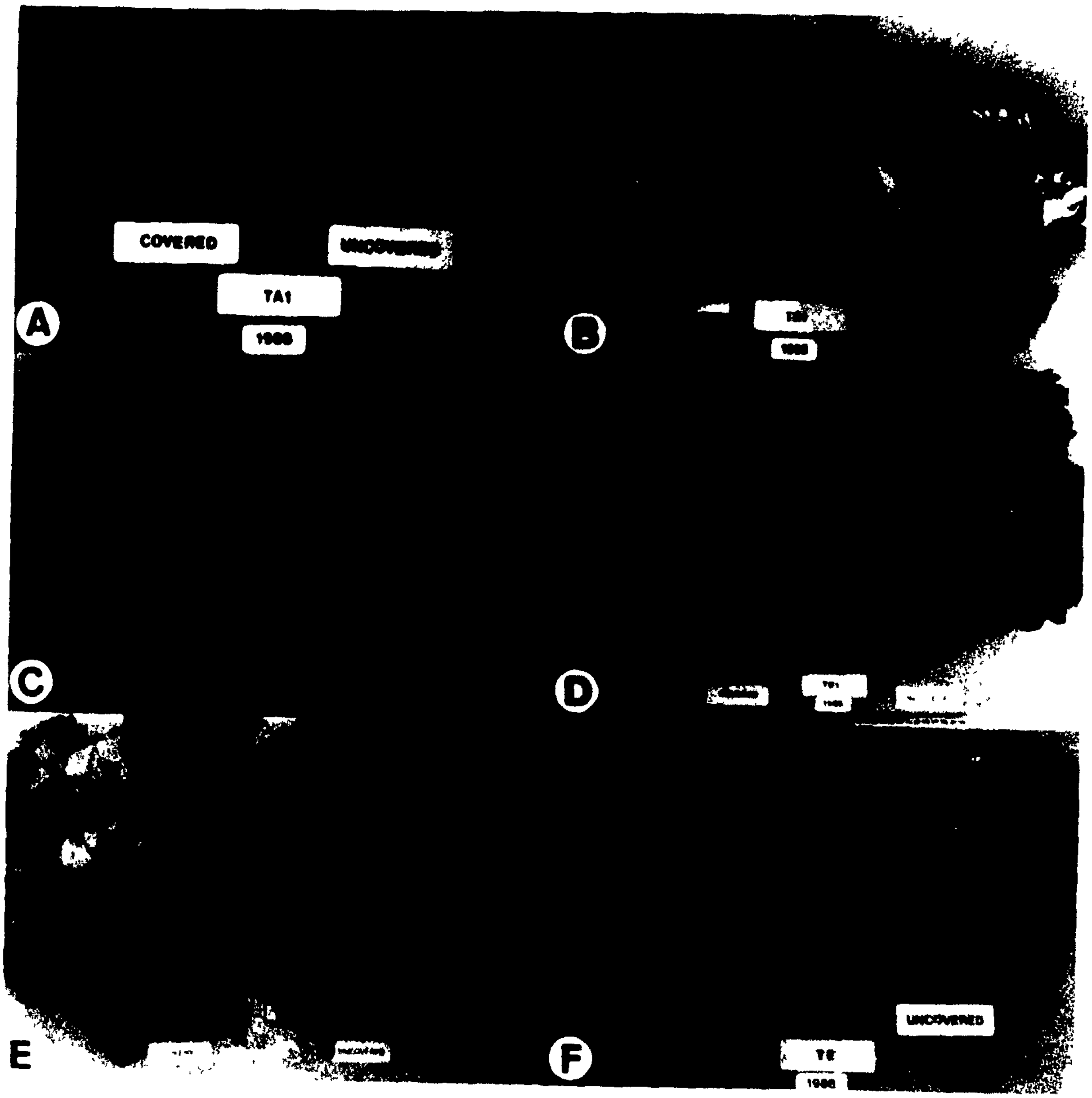
A, B). In fact, in the 1988 trial, fully 100 % of lettuce covered until the stage hearting plus one week showed signs of tipburn. In 1987 when plants were covered for a relatively short period of time until soil cover the percentage of sunscalded heads were comparable to the control (Fig. 4.8). Longer covering periods appeared to increase the problem. However, plants at harvest stage were less affected probably due to reduced cover contact. No sunscald was observed in the 1988 trial.

A final test, evaluating the percentage of lettuce affected by a complex of fungal diseases including *Botrytis cinerea*, *Sclerotinia scerotiorum*, *Rhizoctonia solani* and *Bremia lactucae* which produced symptoms of bottom rot are presented in figure 4.9 for both years. In 1987, use of a row cover increased the percentage of diseased lettuce. As the covering period increased, so did the percentage of diseased plants (Fig. 4.9 A). In 1988 however, keeping the row cover on until the stage hearting reduced the number of diseased heads relative to the control (Fig. 4.9 B).

4.2.3 The narrow cover experiment

Plate 9 shows the difference between covered and uncovered lettuce heads at each cover removal time in the 1988 experiment. At harvest time, heads of the covered lettuce were larger than the uncovered ones (Plate 9 E), although uncovered lettuce had generally a greater number of frame leaves, i.e. outer non hearting leaves . A comparison of the number of leaf types was done between control plants and those covered until harvest. The results are presented in figure 4.10. No differences were observed in the number of leaf initials, frame leaves and dead leaves between control and covered plants at harvest. The main

Plate 9: A comparison of covered and uncovered lettuce at several growth stages. (A) rosette, (B) soil cover, (C) start of hearting, (D) hearting plus one week, (E) harvest, (F) at harvest once frame leaves has been removed.


COVERED
UNCOVERED
TA1
A
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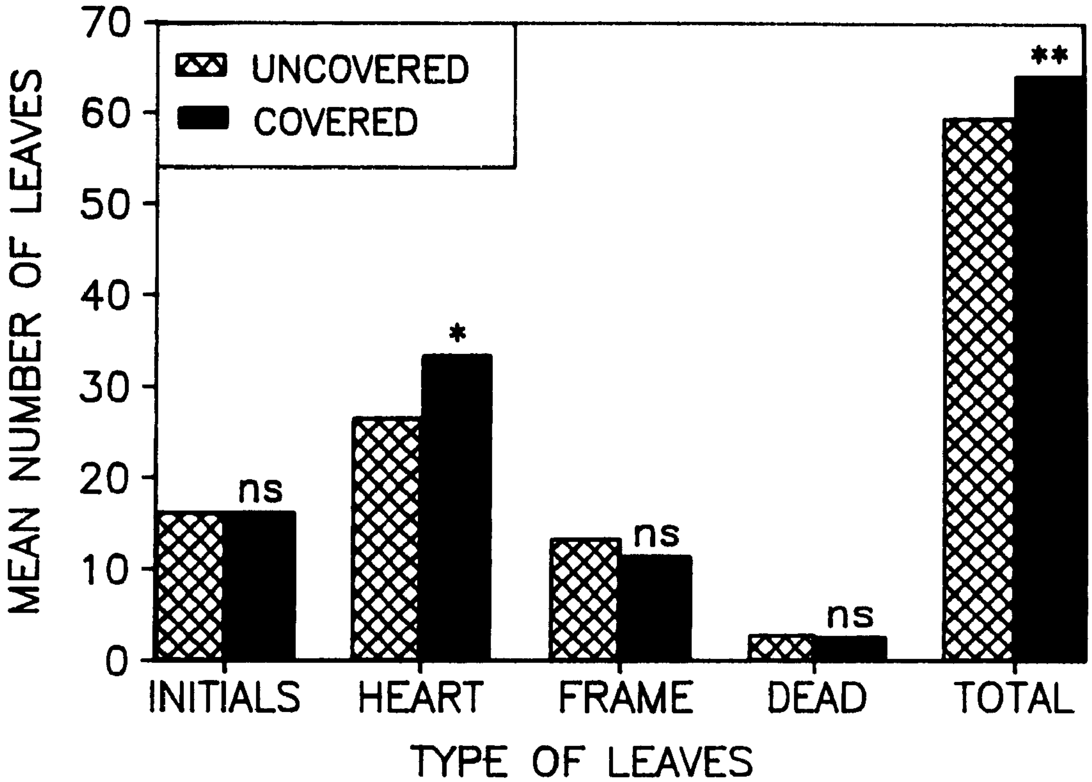

Fig. 4.10: Effect of a row cover on numbers of leaf initials (< 1 cm), leaves forming the heart, frame leaves, dead leaves and total number of leaves at harvest. For each leaf type, (ns) means not significantly different from the control or (*), (**) significantly different at the 0.05, 0.01 level, respectively.

difference between the uncovered and covered plants was in the number of heart leaves with the covered plants having significantly more leaves in this category ($P<0.05$) than the uncovered plants. The total number of leaves for covered and uncovered lettuce was significantly different at the 0.01 level.

The width to length ratio of leaves and the rate of leaf production are two important parameters used to study the hearting process of lettuce during the growing season. The 13^{th} leaf of covered lettuce grew faster than its uncovered counterpart both in length (Fig. 4.11 A) and in width (Fig. 4.11 B). The width to length ratio of the 13^{th} leaf of covered lettuce was also greater in early stages (Fig. 4.11 C). Up until the penultimate growth stage, the 13^{th}leaf of the covered plants were significantly longer and wider, resulting in a higher width to length ratio than their uncovered counterparts.

In order to observe leaf development throughout the growing season, the number of leaf initials, growing and dead leaves were measured at each of the plant growth stages of the covered plots (Fig. 4.12). Leaf initial production was significantly higher ($P<0.01$) for the first two growth stages. From hearting until harvest, no significant differences ($P>0.05$) were observed between the covered and uncovered treatments. The number of growing leaves was significantly higher at least at the 0.05 level for the covered plants for all stages of growth. At harvest, total number of leaves for covered lettuce was 66 versus 60 for the control.

In order to determine if a relationship existed between leaf number

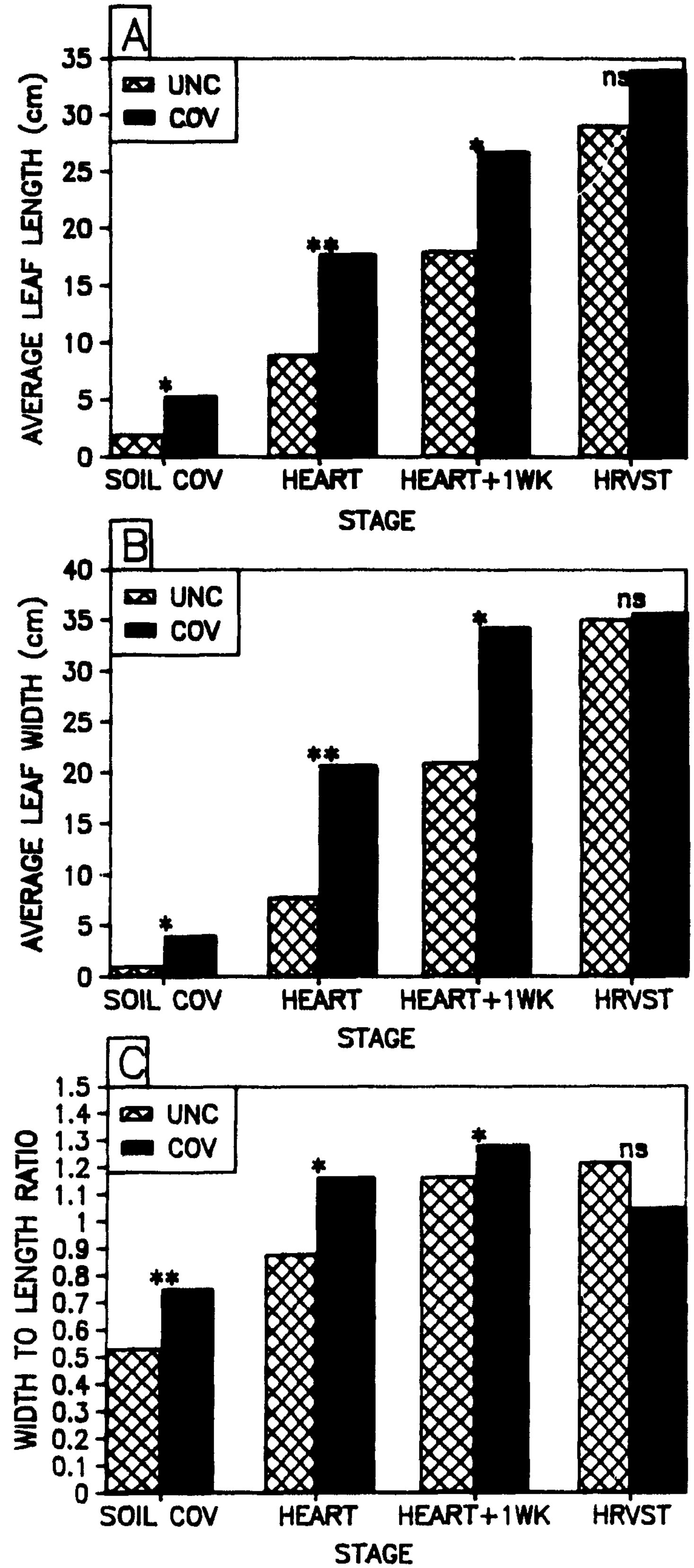

Fig. 4.11: Effect of a row cover on length (A), width (B) and width to length ratio (C) of the thirteen leaf of lettuce during the growing season. Covered and uncovered treatments are not significant (ns) or significant at the 0.05 (*), 0.01 (**) level.

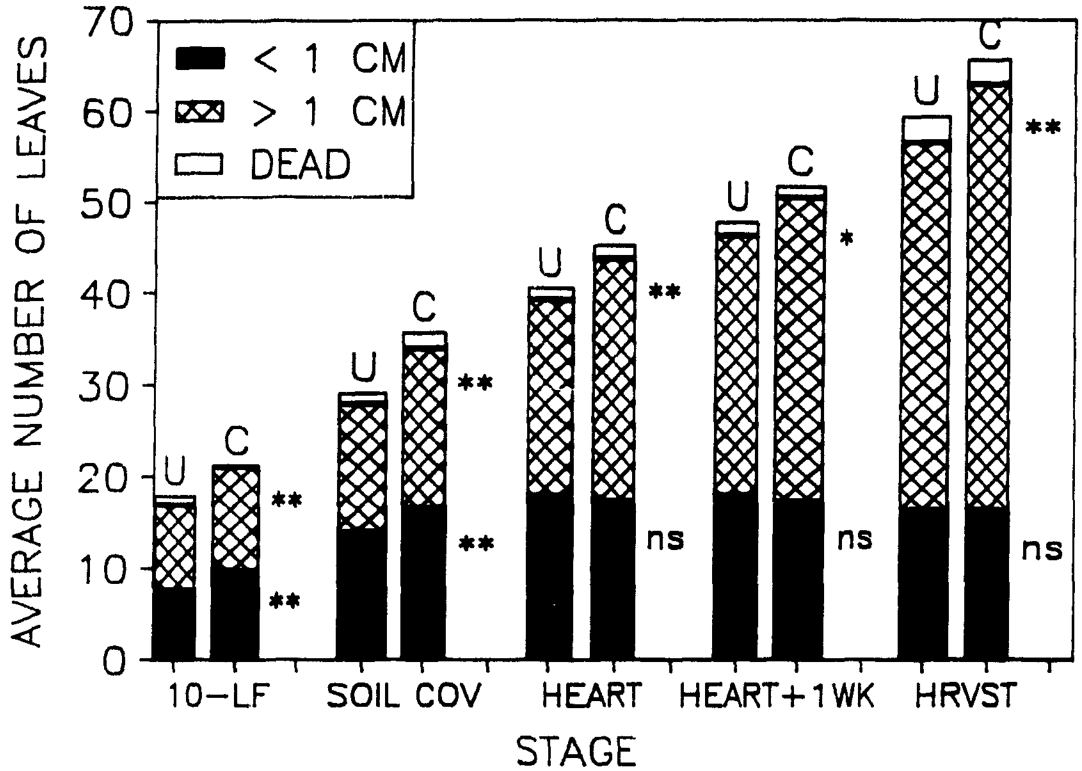

Fig. 4.12: The influence of a row cover on numbers of leaf initials (< 1 cm), leaves greater than 1 cm and dead leaves throughout the growing season. For each growth stage, the covered treatment (C) in not significantly (ns) or significantly different at the 0.05 (*), 0.01 (**) level from the uncovered treatment (U).

and environmental data, total leaf number was regressed on both air and soil temperatures. A linear relationship was found between leaf number and accumulated growing degree-days (GDD) based on air temperature above 0 ^{o}C (Fig. 4.13). This gave a better fit than using soil based temperatures. Three base temperatures were used, with 4 and 6 ^{o}C giving a slightly poorer fit compared to a base temperature of 0 ^{o}C. These accounted for 99.0, 98.7 versus 99.2 %, respectively of the variation in leaf number. The rate of leaf production was 10.5 leaves per 100 GDD above 0 ^{o}C.

The changes in plant fresh and dry weight with time for covered and uncovered lettuce are presented in figures 4.14 A and B. The dependent variables of plant fresh weight (FW) and dry weight (W) could be estimated by a logistic relationship (Nelder, 1961) using days after transplanting (t) as the independent variable:

$$FW \text{ (or } W) = \frac{c}{1 + \exp\left[-b(t-m)\right]}$$

where c is the final fresh (dry) weight, b the initial relative growth rate (RGR) and m the time to 50 % of final fresh (dry) weight. The initial RGR was higher for covered lettuce but the difference was small because measurements only started 24 days after transplanting and initial fresh weight of covered lettuce was at that time larger than that of uncovered plants. The time to 50 % final fresh weight was more than 4 days earlier for the covered plants.

Plant fresh and dry weights were consistently higher under the row cover. This improved growth reflected a greater accumulation of growing

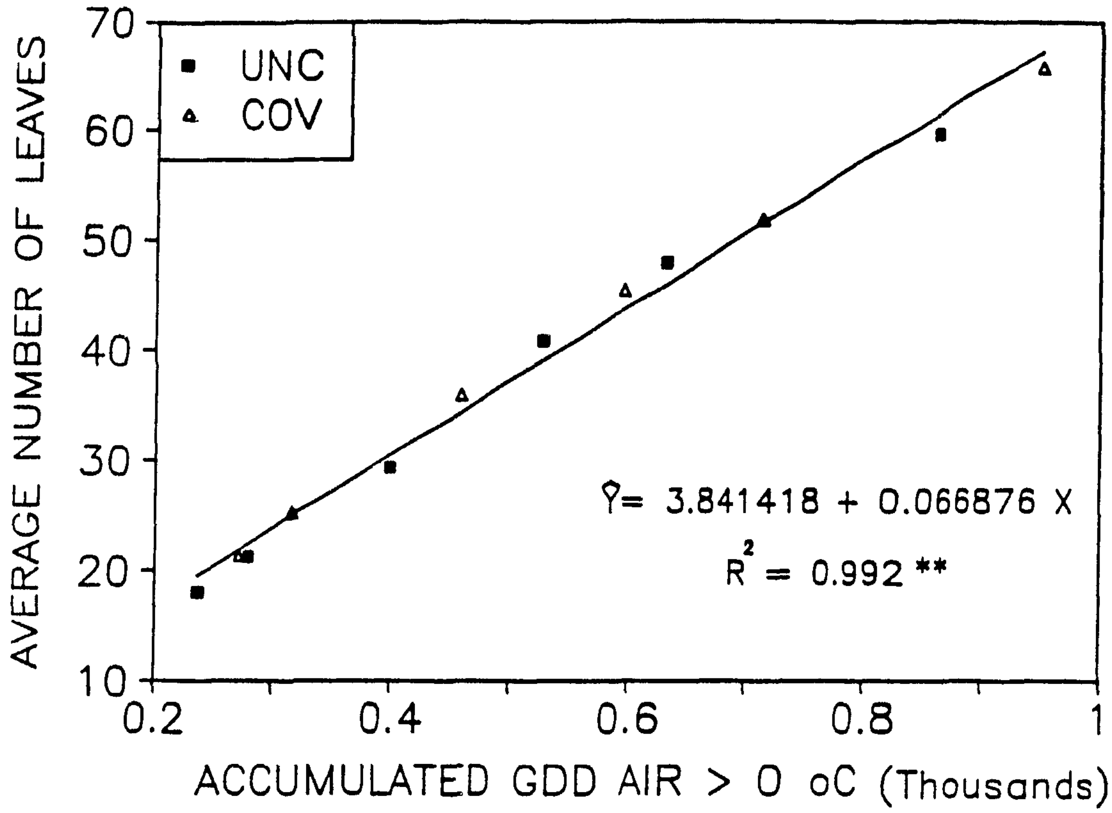

Fig. 4.13: The relationship between accumulated growing degree-days and total number of leaves for covered and uncovered lettuce.

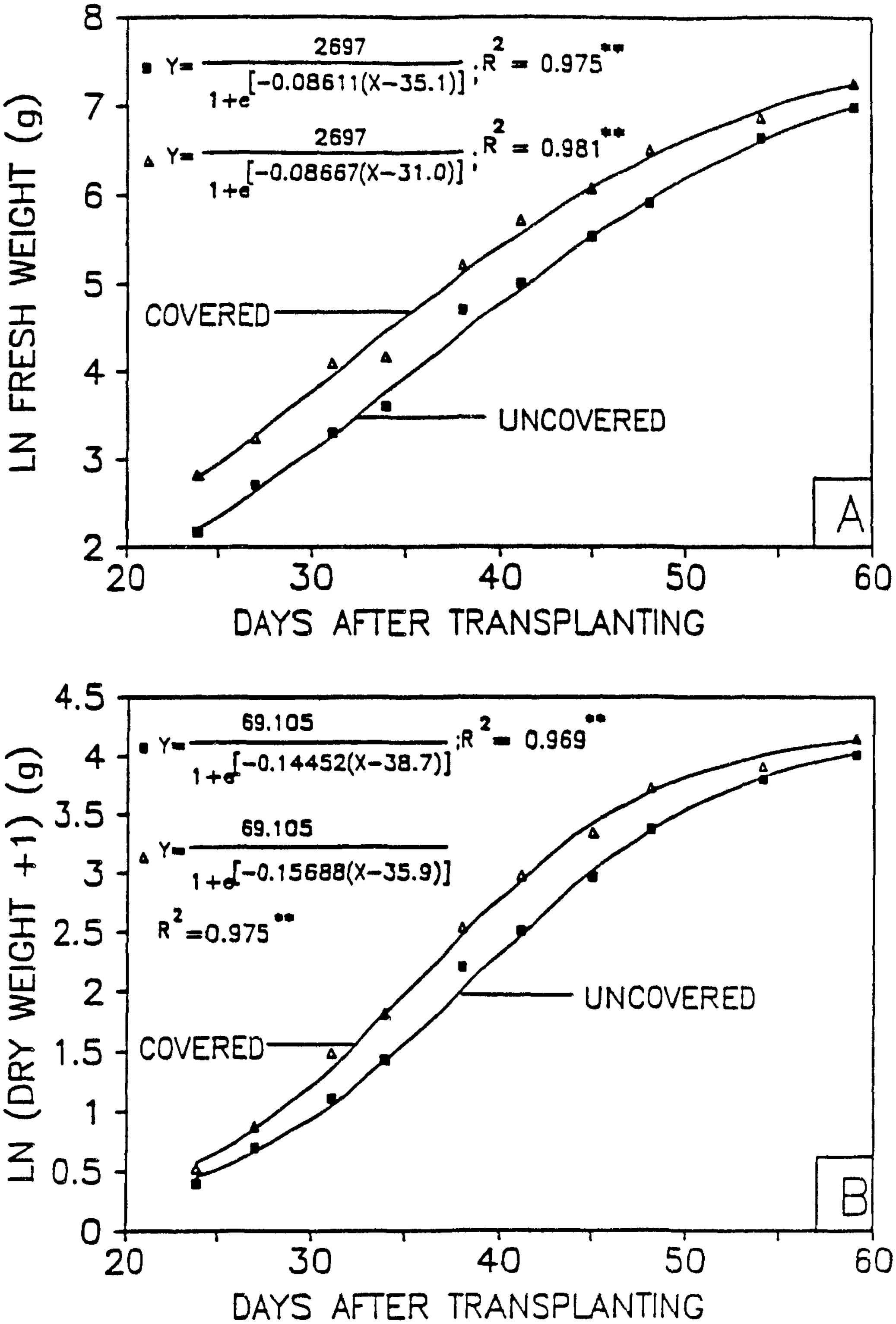

Fig. 4.14: Change in plant weight with time for covered and uncovered lettuce in 1988. (A) fresh weight (B) dry weight.

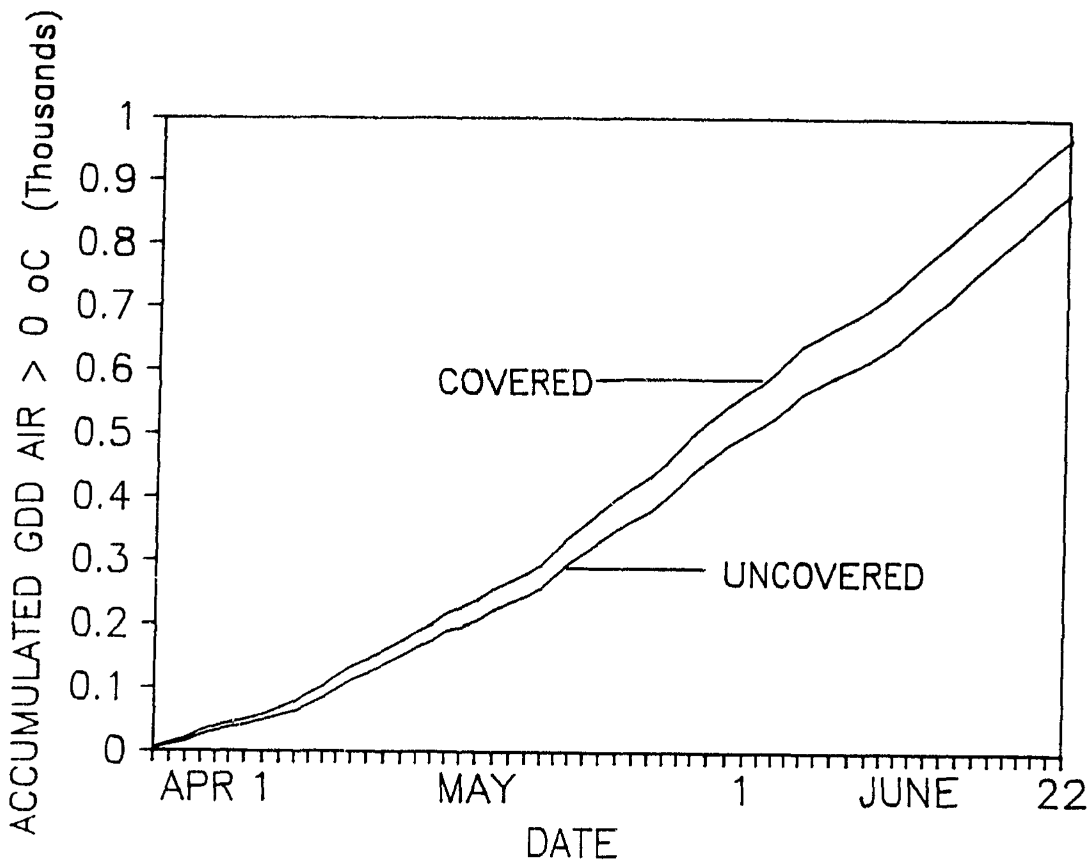

Fig. 4.15: Accumulated growing degree-days for covered and uncovered lettuce plots in 1988.

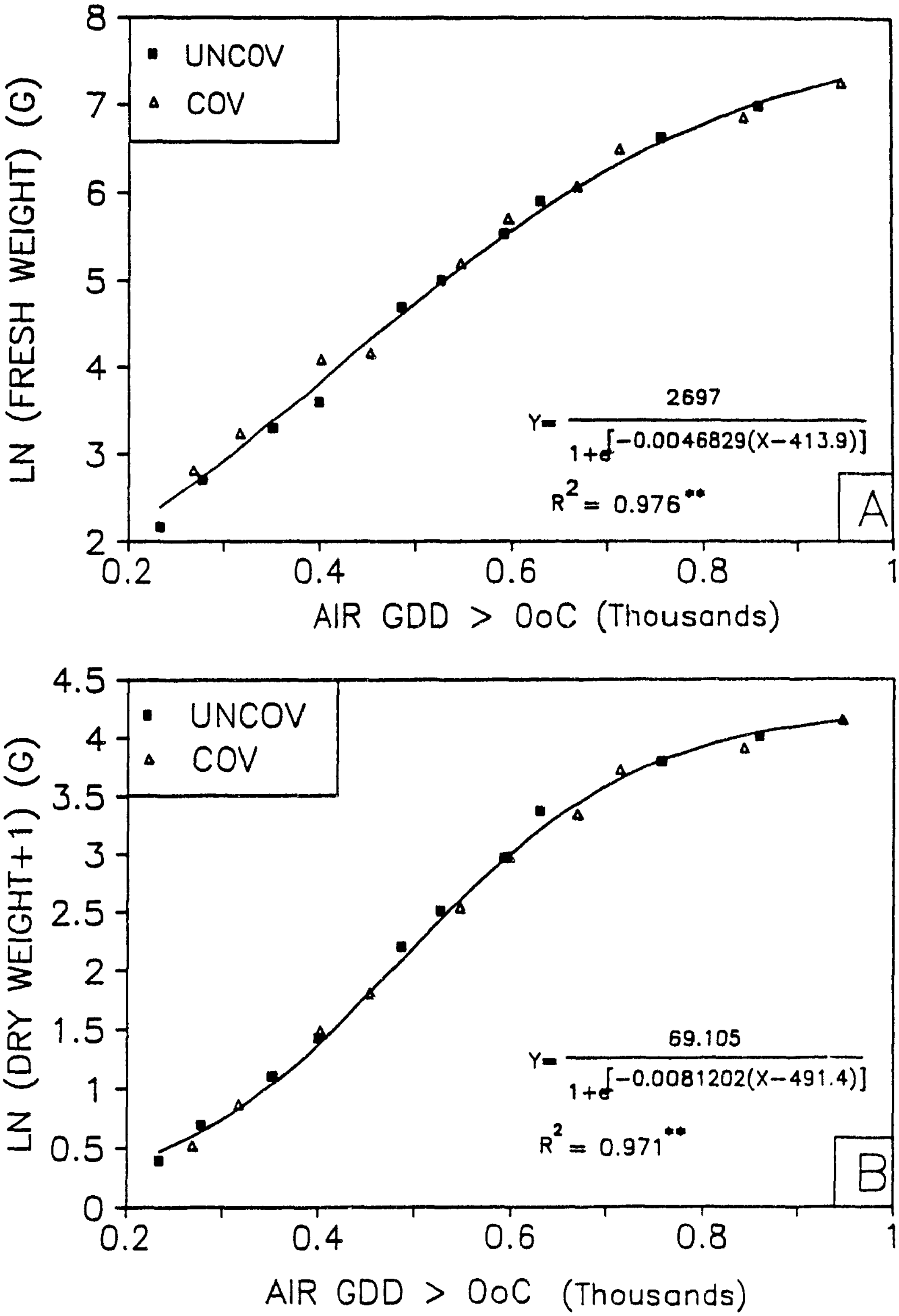

Fig. 4.16: Change in plant weight with accumulated air growing degree-days above 0 oC for covered and uncovered lettuce in 1988. (A) fresh weight (B) dry weight.

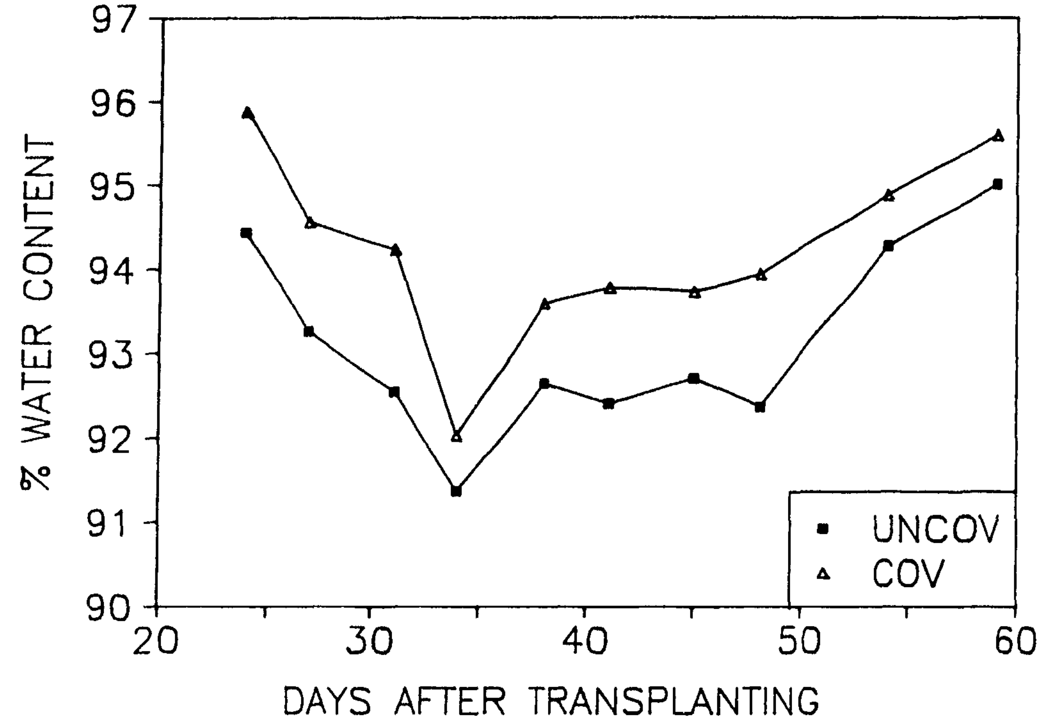

Fig. 4.17: Effect of a floating row cover on water content of lettuce during the growing season of 1988.

degree-days under the floating row cover from transplanting of lettuce until harvest compared to a no cover situation (Fig. 4.15). When accumulated air growing degree-days at a base temperature of 0 ^{o}C were used as a time scale, both growth curves could be fitted to a common regression line following a logistic equation (Fig. 4.16 A and B).

Finally, the percentage water content of covered lettuce was consistently higher compared with that of uncovered lettuce during entire 1988 growing season (Fig. 4.17).

4.3 DISCUSSION

4.3.1 The wide cover experiment

Although not directly affecting the results of the 1987 trial, it must be noted that a frost occured early in the season and more severely affected covered lettuce than uncovered ones (Plate 4.4). There have been suggested two main reasons for such a phenomenon.

Firstly, the plants, particularly those on the edge of the cover, were in close contact with the cover material. MAFF (1984 b) suggested that the cover could create an artificial ground level; therefore, plants in contact with the cover could be at the cover temperature . Wells and Loy (1985) suggested that at 0^{o}C, water trapped in the pores of agrotextiles freezes and consequently enhances ice nucleation on the leaf surface which can lead to frost damage. A second factor which may work in conjunction with the first is wind damage. Wind causes the row cover to flap. This flapping action causes abrasion to the leaf surface which increases its vulnerability to frost damage. It is also possible that inversion of temperature occurred, particularly if the night was clear and calm. However, the damage was essentially localized in the edges of the cover and the two first explanations are more likely. As a consequence, it may be profitable to use longer row cover to reduce the number of edges.

The greatest influence of the row cover appeared to occur between transplanting and soil cover with increases in fresh weight of 31 % and 20 % compared to the control in 1987 and 1988, respectively (Table 4.1). Bierhuizen, Ebbens and Koomen (1973) studied the growth of lettuce at plant densities of 20 by 20 cm under 9 greenhouse temperature regimes in early spring. They showed that the time to reach 100 % soil cover depended primarily on temperature and not on total radiation or time. They concluded that it may be useful to induce a high temperature in a greenhouse to reach the soil cover stage as soon as possible and thereafter to lower the temperature because radiation was shown to become the most important factor affecting final fresh weight. Similarly, the increase in temperature brought about by the row cover in this experiment resulted in heavier lettuce heads in both 1987 and 1988. On the other hand, van Holsteijn (1980 a,b) found that although temperature effect on soil cover rate is evident, neither temperature or radiation alone exclusively determined the soil cover process in spring and fall greenhouse experiments. Furthermore, the correlation between plant growth characteristics and the fresh weight in an early stage of growth and those at harvest were low and decreased as the length of the growth period increased.

The percentage of firm lettuce tended to increase with longer covering time up to the hearting stage in both 1987 and 1988 (Fig. 4.5). Maasswinkel and Welles (1987) studied the effect of soil and air temperatures on head formation for several cultivars of iceberg lettuce in controlled environments. They found that maintaining the root temperatures at levels higher than 14 °C throughout the growing season resulted in a low percentage of open heads, that is when no head was formed. Increasing numbers of open heads were observed when low temperatures of 6 and 10 °C were applied until head formation followed by higher temperatures thereafter (10 to 18 °C). In the 1988 experiment, mean soil temperatures from April 24 (after transplantation) to May 28 (soil cover stage) were 11.1 and 9.7 °C for covered and uncovered plots, respectively. From this period until harvest, mean soil temperatures rose to 16.8 °C in both covered and uncovered plots. The lower soil temperatures found in uncovered plots during early growth may then explain the smaller percentage of firm heads of uncovered lettuce. Further, lettuce growing under cooler temperatures developed more slowly and might be expected to have less firm heads.

In both years, the percentage of firm lettuce tended to decrease when the row cover was kept on after the stage hearting plus one week, suggesting that keeping the row cover until later days increases the percentage of loose heads. Henriksen (1981) also observed that iceberg lettuce heads covered with polyethylene (500 holes/m^2) from 6 to 7 weeks were looser than when the cover was applied for 4 weeks or not covered. Working with butterhead lettuce, Benoit and Ceustermans (1980) have reported that an extensive covering period induced development of an excessive number of leaves on relative small stalks and with a low width to length ratio which in turn resulted in looser heads.

The percentage of small lettuce tended to decrease with longer covering time (Fig. 4.6) and this is probably related to a greater number of leaves formed under the row cover (Fig. 4.10 and 4.12).

Figures 4.7 A and 4.8 show that leaving the row cover longer than the stage 'soil cover' increased tipburn damage from 23 to 57 % and sunscald from 7 to 13 % in 1987. These results are not surprising since maximum air temperatures at 2-4 cm above soil level reached 50 °C for 2 days (Fig. 4.1). In Denmark, Henriksen (1981) also observed that a prolonged period of covering (more than 5-6 weeks) of iceberg lettuce resulted in fewer marketable heads due to physiological disorders such as tipburn. It is generally accepted that tipburn is a result of a localized calcium deficiency which results from an increased growth rate of the lettuce plant (Ashkar and Ries, 1971; Cox, McKee and Dearman, 1976; Misaghi and Grogan, 1978). Cox et al. (1976) and Misaghi and Grogan (1978) have shown that high temperatures enhance the growth rate of the plant, so that nutrient uptake cannot match tissue requirements and deficiency symptoms appear. Yanagi and Bullock (1983) found a high positive correlation (R^2=0.95 significant at the 0.01 level) between tipburn incidence and monthly mean maximum air temperatures. These authors reported that the incidence of tipburn increased from 13 to 90 % starting from May when monthly mean maximum temperature were above 29.4 °C in Hawaii. This is in agreement with the present results. In 1988, the percentage of lettuce with tipburn increased from 57 to 87 % between the stage soil cover and beginning of hearting (Fig. 4.7 B), period during which the mean maximum temperature was 31.6 and 29.3 in covered and uncovered plots, respectively.

The greater percentage of diseased lettuce found under the Agronet in 1987 (Fig. 4.9 A) and in 1988 when the cover was left after heart stage (fig. 4.9 B) was probably due to the greater humidity usually found under floating row covers (CTIFL, 1987). When soil moisture content was determined under covered and uncovered conditions in the mini carrot experiment of 1988, the covered soil had 2.0-67.6 % higher moisture (Fig. 3.5). It is therefore possible that a similar situation would exist in the lettuce experiment. In fact, with the closer plant canopy of the lettuce crop, humidity levels would be expected to be even higher. Disease levels in 1988 was less compared to 1987 probably due to the drier spring. Climatological data from Ste-Clothilde meteorological station (about 30 km away from the lettuce field) indicated that the amounts of rainfall that fell between May 1 to June 22 were 145.6 mm and 58.2 mm in 1987 and 1988, respectively.

For the conditions experienced during the spring 1987, the stage of growth 'soil cover' appeared to be a critical stage for the removal of the floating row cover. Even though larger and firmer lettuce heads were obtained with longer covering periods (Fig. 4.5, 4.6), head quality decreased as levels of tipburn (Fig. 4.7), sunscald (Fig. 4.8) and disease (Fig. 4.12) rose with prolonged covering.

4.3.2 The narrow cover experiment

Basset (1975) defined a "heading" plant as one in which "each successive leaf in the heading position of the plant folds over and largely covers its predecessor, thus forming a firm head". During the heading or hearting of a head lettuce (CV Capitata that includes crisphead and butterhead), a few folded leaves dictate quite early the final outer shape of the lettuce head and the final firm and compact head is the outcome of the accumulation of additional leaves inside this cover (Bensik,1971). As indicated by Dullforce (1962), hearting is not a monofactorial effect, but should be considered as the ultimate result of different processes operating simultaneously. Hearting seems to depend upon a relatively high rate of leaf production, slow rate of stem elongation, large size of individual leaves and a relatively short length of the petiole. Then, hearting is characterized by a conspicuous surplus of mesophyll development relative to midrib elongation which causes folding and crinkling of the lamina, in particular along the lower part of the midrib (Bensik, 1971). The slower growth of the midrib compared with the lamina is associated with an increase in width to length ratio of the leaves which is regarded as an essential element of hearting (Bensik, 1971; Basset, 1975).

In this experiment, measurements were recorded on the 13th leaf, which, at maturity, corresponded to a wrapper leaf, that is a frame leaf close to the head. It was found that the 13th leaf of covered lettuce plants developed faster in length and in width (Fig. 4.11 A, B). The width to length ratio of the 13th leaf of the covered plants was greater in early stages, i.e. up to the stage hearting plus one week, and indicated an earlier hearting process under the row cover (Fig. 4.11 C).

Gray and Morris (1978) suggested that variation in head weight was due to environmental conditions affecting frame size, that is the size of leaves produced before hearting occurs. Wurr and Fellows (1984) found a positive relationship between the length of leaves 11-15 and head weight of Ithaca at maturity. Indeed, covered lettuce had at harvest time a longer 13^{th} leaf and heavier heads compared with uncovered lettuce on the same day. However, it would have been very interesting to make the comparison with uncovered lettuce plants at maturity. Wurr, Fellows and Morris (1981) found that warmer soil conditions brought about by soil mulching with clear polyethylene increased the length of leaves up to leaf 11 and reduced the length of subsequent leaves. Similarly, Gray and Steckel (1981) observed that early shading of lettuce increased the length of early leaves and reduced the length of later leaves. In both experiments, the reduction in leaf length of later leaves was attributed to competition between leaves for photosynthate and ultimately resulted in reduced head weights. Bensik (1971) showed that leaf shape , associated with head formation, was affected by both radiation and temperature. In particular, at light intensities of 80 W/m^2, both leaf width and leaf length tended to increase with increasing temperature in the range from 10 to 30 ^oC. However, Bensik worked with low light intensities in the range of 20 to 100 W/m^2 corresponding to light levels encountered during winter greenhouse production of lettuce in the Netherlands.

Growth in early stages prior to hearting was most likely to be largely affected by higher temperature found under the row cover since all leaves were probably light saturated under normal spring conditions (Gaastra, 1959; Gray and Morris, 1978 ; Gray and Steckel, 1981). Nothman (1976) working with romaine lettuce also found that higher soil temperature accelerated matu~ing of the lettuce head.

During the growing season, the number of leaf initials and leaves forming the head was significantly greater for covered lettuce in early stages, although the greater number of total leaves after the stage 'soil cover' was more a result of a larger number of leaves forming the heart (Fig. 4.12). This is a fact of importance since the number of leaves making up the head, determined by the rate at which the leaves are initiated and the rate at which they grow out, substantially contribute to head formation. Bensik (1971) showed that leaves were produced at a higher rate than at which they expand and young leaves tend to accumulate in the course of time. He concluded that the more the rate of outgrowth of leaves matches the high rate of initiation, the better the conditions are for head formation.

At harvest time, the heavier, larger and firmer lettuce heads found under the row cover resulted from a greater number of leaves forming the heart (Fig. 4.10). Although the uncovered lettuce nad more frame leaves (Plate 9), the difference was not significant (Fig. 4.10). Basset (1975) studying the inheritance of heading in lettuce found that the larger number of frame leaves of F2 lettuce plants was a result of the delayed initiation of head formation compared with the iceberg parent 'Minetto'.

The pattern of increase in fresh and dry weight of lettuce plants were logistic in form and there were differences in the parameters of the logistic equation between covered and uncovered treatments (Fig. 4.14 A, B). Scaife and Jones (1976) in controlled environment, and Wurr and Fellows (1984) under field conditions also used the logistic model to describe growth of lettuce. Dullforce (1962) found that in a constant environment, the growth of lettuce was almost exponential for at least half of the crop's life. During this phase, leaves overlap little, spring grown lettuce plants are probably light saturated (Gaastra, 1959) and competition for nutrients and water unlikely (Sale, 1966). The form of the curve after the inflexion point was then determined by genetic factors controlling plant habit and ultimate size, together with competition between plants for water, nutrients and light (Scaife, 1973).

Higher fresh and dry weights were obtained under the floating row cover during the whole season (Fig. 4.14 A, B). As the rate of production of lettuce leaves and their expansion was largely determined by temperature (Bensik, 1971), a time scale based on temperature was used. The growth curves for covered and uncovered lettuce were similar when chronological time was replaced by a time scale based on accumulated growing degree-days above 0 ^{o}C. The rate of leaf production was 10.5 leaves per 100 GDD above 0 ^{o}C which is higher than the rate of leaf production of iceberg lettuce of 6.6 leaves per 100 GDD > 0 ^{o}C found by Wurr and Fellows (1984). This difference might be attributed to factors other than temperature, like soil type since the authors were using a coarse sandy loam. These results suggest that air growing degree-day with a base temperature of 0 ^{o}C is a good scale to predict growth for iceberg lettuce. In England, Wurr and Fellows (1984) showed similar results and could predict growth for different iceberg lettuce cultivars and different sowing dates.

However, this was in contrast with the base temperature of 4.4 ^{o}C (Edey, 1980) for lettuce production in Canada, 4 ^{o}C for iceberg lettuce in Denmark (Kristensen, Friis, Henriksen and Mikkelsen, 1987) and 6 ^{o}C for butterhead lettuce in England (Gray and Morris, 1978). As pointed out by Kritensen et al. (1987), these estimated optimum base temperatures depend both on the experimental data and the statistical method used and may differ from the true physiological minimum temperature for growth of iceberg lettuce. Another interesting point was the surprisingly good fit of growth curves for both covered and uncovered lettuce in spite of the very high temperature levels found under the row cover, greater than 35 ^{o}C for several days at a time (Fig. 4.2). Indeed, the range of temperatures suitable for growing iceberg lettuce was found to be 17-28 ^{o}C during the day and 3-12 ^{o}C during the night (Kimball, Sims and Welch, 1967) and temperature outside these ranges are not considered suitable for the production of a good quality lettuce (United States Department of Agriculture, 1974). In particular, Richard, Sundstrom and Grimes (1985) found that Ithaca optimum temperature range for maximum head diameter, head weight and yield was 17.4-18.1 but yield was more constant than other iceberg cultivar over the range studied (16.4 to 22.9 ^{o}C seasonal temperature).

One reason for such a good fit with GDD based on air temperatures above 0 °C is that air temperature was recorded near the plants at a height of 2-4 cm which corresponded to the growing point of lettuce. Watts (1973) working with Zea mays showed that growth rates in early stage of growth depended on the temperature of the apical meristem. Another reason is that Ithaca was bred in Eastern USA for resistance to bolting under high temperatures in summer production (Ryder 1979 as cited by Wurr and Fellows, 1984).

As it was found for mini carrots, the water content of lettuce leaves was greater in covered plots compared to uncovered (Fig. 4.17). Bierhuizen, Ebbens and Koomen (1973) working with greenhouse lettuce at 9 different temperature regimes found a tendency toward a higher dry weight percentage at lower temperatures. Benoit (1975) for butterhead lettuce, Henriksen (1981) for iceberg lettuce and Abbes, Hemphill and Mansour (1987) for romaine lettuce also found a greater succulence for plants covered with polyethylene or agrotextiles. Benoit (1975) suggested that lower CO_2 levels and higher temperatures caused increased respiration under the row cover may have accounted for this lower dry matter content in covered lettuce leaves. On the other hand, Scaife (1973) found that increasing temperature resulted in a significant increase in dry matter percentage, the mean percentages for whole plants (average of 5 butterhead and 1 iceberg lettuce cultivars) being 7.1, 7.5, 8.0 and 8.1 (S.E.=0.35) at 10, 14, 18 and 22 °C, respectively However, this temperature range was usually inferior to the temperatures encountered under row covers.

4.4 CONCLUSION

The row cover increased mean air temperature by 2 °C and mean soil temperature by 1 °C. Very high air temperatures of 50 °C or more were encountered under the row cover in 1987 whereas in 1988, maximum air temperatures reached 40 °C.

The results indicate that covering lettuce with Agronet increased length and width of the 13th leaf during the growing season and resulted in a higher width to length ratio earlier in the season. These leaf modifications resulted in an earlier hearting process and in a larger number of firm heads at harvest time of the row covered lettuce. The higher number of leaves forming the head resulted in larger heads and contributed to the firmness of the heads. However, these plant modifications brought about by the row cover did not appear to affect mean fresh weight to the same extend and there was variation in earliness from year to year. Early lettuce is a transplanted crop and therefore did not benefit from the microclimate of the row cover during early growth as did direct seeded crops. Also, as a leafy crop, lettuce was more susceptible to abrasion effect of the row cover and the use of long row covers is desirable in order to reduce edge effects. Further, weed growth was enhanced under the row cover, but there are no efficient herbicides for lettuce grown on muck soils. Removing the row cover for weeding was much less practical than spraying an herbicide on top of the row cover as it is the case for carrot production. Nevertheless, the present work has shown that row covering improves the size and firmness of lettuce heads. However, it is suggested to remove the material at the stage 'soil cover'. Keeping the row cover longer resulted in less marketable yield caused by pathological as well as physiological disorders such as tipburn and sunscald.

5. SUGGESTIONS FOR FUTURE RESEARCH

Use of row cover is still a new technique for early vegetable production in Quebec. From the present results, the following suggestions could be made:

1) Studies on micrometeorological aspects of the row covers should be carried out, especially in terms of modification of radiation, temperature and water balance. The effect of row covers on soil physical properties should be also further investigated.

2) Since mini carrot has a shorter growing season compared with standard carrot cultivars, the latters should be tried using row covers to determine if they respond in a similar manner. In this regard, special attention should be made to response of the bunching type of carrot.

3) Potential physiological changes , such as water and carotene content of carrot plants under the row cover should be studied.

4) Attempts should be made to assess the suitability of row covers as protectors against carrot weevils and other pests.

5) Ithaca is a bolting resistant cultivar which responded fairly well to the very high temperatures found under the row cover during both 1987 and 1988 springs. However, it may not be the case for other cultivars or other types of lettuce, like romaine or butterhead, and these should be tested

6) Investigation on whether the storage life of the vegetable is affected by row covers should be performed.

7) The economic aspects of using floating row covers on vegetable crops should be addressed, as well as the potential of re-use of the material for a second growing season.

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APPENDIX A1

Analysis of variance: Germination of mini carrot (section 3.3)

1. Percent emergence (angular transformation)

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	79.79	19.95	0.93	0.5468	6.70
Error	3	64.51	21.51			
Corrected total	7	144.31				

Source	df	SS	F
Block	3	44.60	0.69
Treatment	1	35.20	1.64

2.Mean emergence time (days)

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	5.24	1.31	8.41	0.0557	3.78
Error	3	0.47	0.16			
Corrected total	7	5.71				

Source	df	SS	F
Block	3	0.19	0.40
Treatment	1	5.06	32.43*

3. Standard deviation of emergence times

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	1.09	0.27	4.39	0.1272	12.99
Error	3	64.51	21.51			
Corrected total	7	1.28				

Source	df	SS	F
Block	3	0.02	0.09
Treatment	1	1.07	17.27*

* = significant at P=0.05
** = significant at P=0.01
*** = significant at P=0.001

APPENDIX A2

Analysis of variance:
Mini carrot data during the 1988 growing season
by stage (section 3.3)

1. Leaf number

a. 25 days after seeding

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.82	0.20	25.74	0 0117	3 11
Error	3	0.02	0 01			
Corrected total	7	0.84				

Source	df	SS	F
Block	3	0.03	1.42
Treatment	1	0.78	98.68**

b. 32 days after seeding

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.60	0.15	2.50	0.2388	6.53
Error	3	0.18	0 06			
Corrected total	7	0.78				

Source	df	SS	F
Block	3	0.10	0.56
Treatment	1	0.50	8.33

c. 39 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.38	0.09	2.27	2.2630	3.79
Error	3	0.12	0.04			
Corrected total	7	0.50				

Source	df	SS	F
Block	3	0.34	2.78
Treatment	1	0.03	0.76

d. 46 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.37	0 09	6 43	0.0791	1 94
Error	3	0 04	0.01			
Corrected total	7	0.42				

Source	df	SS	F
Block	3	0.09	2.14
Treatment	1	0.28	19.29*

e. 53 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.45	0.11	1.35	0.4192	4.51
Error	3	0.25	0.08			
Corrected total	7	0.70				

Source	df	SS	F
Block	3	0.13	0.52
Treatment	1	0.32	3.84

f 60 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.78	0.19	1.28	0.4367	5.41
Error	3	0.45	0.15			
Corrected total	7	1.23				

Source	df	SS	F
Block	3	0.76	1.68
Treatment	1	0.01	0.07

2. Length of the longest leaf (cm).

a. 25 days after seeding

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.80	0.20	6 56	0 0771	3.69
Error	3	0.09	0.03			
Corrected total	7	0.90				

Source	df	SS	F
Block	3	0.19	2.11
Treatment	1	0.61	19.92*

b. 32 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	13.51	3.38	10.96	0.0390	6.73
Error	3	0.92	0.31			
Corrected total	7	14.43				

Source	df	SS	F
Block	3	0.20	0.21
Treatment	1	13.31	43.21**

c. 39 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	33.06	8 26	2 26	0.2642	14.69
Error	3	10.96	3 65			
Corrected total	7	44.01				

Source	df	SS	F
Block	3	1.49	0.14
Treatment	1	31.56	8.64

d. 46 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	78.99	19.75	10.06	0.0438	6.25
Error	3	5.88	1.96			
Corrected total	7	84.88				

Source	df	SS	F
Block	3	2.98	0.51
Treatment	1	76.01	38 74**

e. 53 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	101.20	25.30	8.11	0.0585	6.34
Error	3	9.36	3.12			
Corrected total	7	110.56				

Source	df	SS	F
Block	3	21.19	2.26
Treatment	1	80.01	25.63*

f. 60 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	181.81	45.45	26.23	0.0114	3.65
Error	3	5.20	1.73			
Corrected total	7	187.00				

Source	df	SS	F
Block	3	7.52	1.45
Treatment	1	174.28	100.60**

3. Leaf to total fresh weight ratio

a 18 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.01	0.003	3.48	0.1668	4.95
Error	3	0.002	0.001			
Corrected total	7	0.01				

Source	df	SS	F
Block	3	0.01	3.49
Treatment	1	0.003	3.46

b 25 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.002	0.0006	4.51	0.1230	1.54
Error	3	0.0004	0 0001			
Corrected total	7	0.003				

Source	df	SS	F
Block	3	0.001	2.59
Treatment	1	0.001	10.27*

c. 32 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.0002	0.00004	0.23	0.9056	1.51
Error	3	0.0005	0.0002			
Corrected total	7	0.0007				

Source	df	SS	F
Block	3	0.0002	0.29
Treatment	1	0.00001	0.04

d. 39 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.005	0.001	5.39	0.0989	2.05
Error	3	0.001	0.0002			
Corrected total	7	0.006				

Source	df	SS	F
Block	3	0.005	6 41
Treatment	1	0.001	2.35

e. 46 days after seeding

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.002	0.001	1.97	0.3027	2 80
Error	3	0.001	0.0003			
Corrected total	7	0.003				

Source	df	SS	F
Block	3	0.001	0.75
Treatment	1	0.001	5.62

f. 53 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.01	0.002	5.12	0.1055	4.47
Error	3	0.001	0.0004			
Corrected total	7	0.01				

Source	df	SS	F
Block	3	0.01	0.88
Treatment	1	0.01	17.82*

g. 60 days after seeding.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.0003	0.0001	0.34	0.8363	3.92
Error	3	0.0007	0.0002			
Corrected total	7	0.001				

Source	df	SS	F
Block	3	0.0002	0.35
Treatment	1	0.00007	0.31

* = significant at P=0.05
** = significant at P=0.01
*** = significant at P=0.001

APPENDIX A3 Analysis of variance:
mini carrot data at harvest (1988)
(section 3.3)

1. Coefficient of variability of root fresh weight (%)

Source of variation	df	SS	MS	F	Pr>F	CV
Model	7	1127.90	161.13	5.93	0.0037	10.61
Error	12	325.96	27.16			
Corrected total	19	1453.86				

Source	df	SS	F
Block	3	122.53	1.50
Treatment	4	1005.38	9.25**

2. Mean root fresh weight (g)

Source of variation	df	SS	MS	F	Pr>F	CV
Model	10	106763	10676	4.91	0.0010	11.78
Error	21	45671	2174			
Corrected total	31	152435				

Source	df	SS	F
Block	3	4196	0.64
Treatment	7	102567	6.74***

3. Mean leaf fresh weight.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	10	20388	2039	3.85	0.0044	10.14
Error	21	11110	529			
Corrected total	31	31498				

Source	df	SS	F
Block	3	2257	1.42
Treatment	7	18131	4.90**

4 Yield (g per 2 meter row)

a. marketable

Source of variation	df	SS	MS	F	Pr>F	CV
Model	10	1431464	143146	5.46	0.0005	13.13
Error	21	551048	26240			
Corrected total	31	1982511				

Source	df	SS	F
Block	3	53221	0.68
Treatment	7	1378242	7.50***

b. large roots (>19 mm in diameter)

Source of variation	df	SS	MS	F	Pr>F	CV
Model	10	2144381	214438	6.59	0.0001	32.79
Error	21	682968	32522			
Corrected total	31	2827350				

Source	df	SS	F
Block	3	337868	3.46*
Treatment	7	1806512	7.94***

c. Roots infested by carrot weevils.

Source of variation	df	SS	MS	F	Pr>F	CV
Model	10	225732	22573	4.10	0.0031	62.05
Error	21	115535	5501			
Corrected total	31	341267				

Source	df	SS	F
Block	3	6433	0.39
Treatment	7	219299	5.69***

* = significant at P=0.05
** = significant at P=0.01
*** = significant at P=0.001

APPENDIX B

Analysis of variance:
lettuce data during the 1988 growing season
by stage (section 4.2.3)

1. Leaf length (cm)

a. soil cover

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	24.78	6.20	7.08	0.0699	25.45
Error	3	2.63	0.88			
Corrected total	7	27.41				

Source	df	SS	F
Block	3	2.47	0.94
Treatment	1	22.31	25.50*

b. start of hearting

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	156.54	39.13	13.27	0.0299	12.81
Error	3	8.85	2.95			
Corrected total	7	165.38				

Source	df	SS	F
Block	3	3.41	0.39
Treatment	1	153.13	51.93**

c hearting plus one week

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	158.99	39.75	7.85	0.0610	10.04
Error	3	15.19	5.06			
Corrected total	7	174.18				

Source	df	SS	F
Block	3	7.79	0.51
Treatment	1	151.20	29.85*

d harvest

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	57.69	14.42	1.85	0.3205	8.85
Error	3	23.40	7.80			
Corrected total	7	81.09				

Source	df	SS	F
Block	3	10.06	0.43
Treatment	1	47.63	6.11

2. leaf width (cm)

a. Soil cover

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	21.04	5.26	6.61	0.0763	34.57
Error	3	2.39	0.80			
Corrected total	7	23.42				

Source	df	SS	F
Block	3	2.80	1.17
Treatment	1	18.24	22 93*

b. start of hearting

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	344.99	86.25	12 96	0.0310	17 97
Error	3	19.97	6.66			
Corrected total	7	364.96				

Source	df	SS	F
Block	3	12.42	0 62
Treatment	1	332.56	49.96**

c. hearting plus one week

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	366.62	91 65	13 63	0.0288	9 35
Error	3	20.17	6 72			
Corrected total	7	386.79				

Source	df	SS	F
Block	3	14.17	0.70
Treatment	1	352 45	52 43**

d. harvest

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	11.10	2 78	0.95	0 5386	4.82
Error	3	8.76	2 92			
Corrected total	7	19.86				

Source	df	SS	F
Block	3	10.44	1.19
Treatment	1	0.66	0.23

3. Width to length ratio

a. soil cover

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.11	0.03	49.43	0.0045	3.64
Error	3	0.002	0.0006			
Corrected total	7	0.11				

Source	df	SS	F
Block	3	0.02	9.88*
Treatment	1	0.09	168.09 **

b. start of hearting

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.20	0.05	9.28	0.0488	7.24
Error	3	0.02	0.005			
Corrected total	7	0.22				

Source	df	SS	F
Block	3	0.04	2.50
Treatment	1	0 16	29.63*

c. hearting plus one week

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.03	0.007	3 82	0.1498	3.41
Error	3	0.005	0.002			
Corrected total	7	0.03				

Source	df	SS	F
Block	3	0.0003	0.06
Treatment	1	0.03	15.11*

d. harvest

Source of variation	df	SS	MS	F	Pr>F	CV
Model	4	0.08	0.02	0.97	0.5301	13.06
Error	3	0.07	0.02			
Corrected total	7	0.15				

Source	df	SS	F
Block	3	0 03	0 45
Treatment	1	0.06	2.54

* = significant at P=0.05
** = significant at P=0.01
*** = significant at P=0.001