CANADIAN THESES

THÈSES CANADIENNES

THE UNIVERSITY OF ALBERTA

EFFECT OF ROW COVERS ON MATURITY AND YIELD OF FIELD TOMATOES

by

GERALD IVANOCHKO

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

IN

HORTICULTURE

DEPARTMENT OF PLANT SCIENCE

EDMONTON, ALBERTA

SPRING, 1987

ISBN 0-315-37759-3

THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR GERALD IVANOCHKO

TITLE OF THESIS EFFECT OF ROW COVERS ON MATURITY AND YIELD OF FIELD TOMATOES

DEGREE FOR WHICH THESIS WAS PRESENTED MASTER OF SCIENCE

YEAR THIS DEGREE GRANTED SPRING, 1987

(SIGNED) G. Ivanochko

PERMANENT ADDRESS:

BOX 775,

LA RONGE, SASK.

DATED DEC. 9 1986

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled EFFECT OF ROW COVERS ON MATURITY AND YIELD OF FIELD TOMATOES submitted by GERALD IVANOCHKO in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in HORTICULTURE.

....
Supervisor

....

....

....

Date Dec. 5/86

ABSTRACT

Tomato (*Lycopersicon esculentum* Mill.) plants were grown under various row covers to compare the effect on maturity and yield with the effect of hot tents. Two supported polyethylene row cover treatments with different percentages of perforations (Poly 25 and 45) and two floating row cover treatments, Xiro and Reemay, were examined. A clear polyethylene mulch was used in conjunction with the hot tent and row cover treatments. Two tomato cultivars ('Hybrid 31' and 'Brookpact') were used in adjacent plots. The research was conducted in 1985 at the Alberta Horticultural Research Center in southeastern Alberta.

Mean daily maximum temperature during the period of row cover use was close to the 30 year average but the mean daily minimum temperature was 2.5°C below average. The total number of hours of sunshine recorded was the second highest in 33 years.

Maturity was found to be significantly delayed with the use of row covers in one cultivar, Brookpact. In the other cultivar, Hybrid 31, early yields were not significantly affected by the two supported polyethylene row cover treatments.

Only the Poly 25 treatment significantly increased the final total yields. The Poly 25 treatment also produced the highest per plant dry weight. Mean air and soil temperatures were also significantly higher under this treatment.

However, the minimum air temperature was found to be significantly lower than in all the other treatments.

The lowest yields were produced by the floating row cover treatment, Xiro. Yields were significantly reduced below the hot tent treatment in one cultivar, Hybrid 31. Xiro was also found to significantly delay maturity in both cultivars.

The various row covers and hot tents did not have a significant effect on percentage of culls or fruit size.

None of the row cover treatments offered frost protection comparable to the hot tent treatment.

The results of the preliminary experiment on time of row cover removal suggest that this is a critical factor in increasing the yields obtained.

Acknowlegements

The author wishes to express his sincere appreciation to Dr. W.T.Andrew and Dr. Paul Ragan for their valuable advice and assistance in the preparation of this thesis.

The author would also like to express his thanks to the Alberta Horticultural Research Center (AHRC) and the University of Alberta, Plant Science Department for their joint sponsorship.

Table of Contents

LIST OF TABLES

Table Page

LIST OF FIGURES

I. Introduction

Climate is one of the major factors limiting vegetable production in the prairie provinces of Canada. A short production period, characterized by low heat unit accumulation early in the season, has restricted expansion of the industry.

In order to increase production, several avenues have been investigated. Research studies have concentrated primarily on developing suitable cultivars and methods of production to reduce the climatic constraints. The breeding of early maturing cultivars has been an important development in obtaining increased production. As a result, tomato cultivars that are able to set fruit at low temperatures have made a dramatic impact on production in northern climates.

Improvements in cultural methods of production have also been extensively studied. For several decades various types of hot tents have been used in the horticultural industry. There have been some minor changes in the size and type of materials used but basically the design has remained unchanged. In Alberta, the use of hot tents continues to be the preferred method of production for warm season crops and their use is still the recommended practice for tomato production in the province (1).

A more recent development has been the use of plastics in horticulture. The use of polyethylene mulches and row covers became the established practice in the United States more than a decade ago (14). Yield responses and earliness have been improved for several crops, with the vine crops showing the largest increases in yield and maturity (47).

The use of polyethylene mulches and row covers has not been as widely accepted in Canada for several reasons, the main factor being economics. Also, research conducted in Alberta on the use of these materials has produced varying results (17, 18). Although polyethylene mulches and perforated row covers produced earlier and higher yields in the vine crops, results indicated that lower yields and delayed maturity occurred in tomatoes.

The development of new row cover materials for creating a suitable microclimate for plant growth has renewed the interest in row cover use on less responsive crops. "Floating" row covers which do not require structural support but are laid directly on the seedbed or plants have been developed in Europe. These include slitted polyethylene or porous light weight materials which are laid with sufficient slack to allow for plant growth. Mechanical installation of floating row covers is facilitated through the use of a modified mulch applicator.

If increased market garden and commercial tomato production are to be achieved in Alberta a suitable method of production must be developed using or modifying techniques currently available. The use of hot tents has allowed producers to obtain earlier and higher yields but their high labor requirement has restricted their use.

Mechanically applied row covers which increase earliness and yields in vine crops need to be investigated more closely on tomato production in Alberta.

Therefore, research was conducted in southern Alberta to determine the effects of hot tents and various types of row covers on maturity and yield of tomatoes. Hot tents and row covers were used in combination with clear polyethylene mulches. In addition, a preliminary experiment also investigated the effect of time of row cover removal on yield of tomatoes.

II. Literature Review

1 Terminology

Row covers are defined by Wells and Loy (48) as flexible, transparent coverings which are installed over single or multiple rows of vegetables for the purpose of enhancing plant growth and yield. Synonymous terms for row covers include cloches, plastic tubes, tunnels and low tunnels. The size and shape of the row covers may vary but they are generally oval-shaped and 40-50 cm in height.

Row covers are placed over single or multiple rows whereas hot caps are placed over individual plants. The hot tent is a larger version of the hot cap and allows for more plant growth to occur before removal.

The row cover may or may not be supported with wire hoops. Row covers which are designed to be supported by the plants are termed "floating" row covers. These covers are applied loosely over the row, leaving sufficient slack to accommodate the growth of the plants.

2. Early development of row covers

The use of plastics in horticulture has increased dramatically over the last four decades. This is due largely to the need for more intensive production techniques attributed to increased land values, land shortages and rising production costs which necessitated higher returns. The development of polyethylene film in the 1940's enabled increased use of plastics in agriculture. In the United States, Emmert in 1955 (10) developed many of the principles on the use of plastics in greenhouses, mulches and row covers.

Early row cover experiments on cantaloupe production during the winter months in California were done by Shadbolt and McCoy (37) and Shadbolt, McCoy and Whiting (38). They investigated the effects of various row cover materials and compared them with the conventional practice of using glassine paper caps. The continuous row covers were found to produce earlier and higher yields.

Hall (12) conducted some of the early research on the use of row covers for tomato production in California. Various materials, shapes and venting methods of row covers were examined. Polyethylene row covers were found to force tomato plant growth much faster than paper caps.

The work of Shadbolt *et al.* (37,38) and Hall (12) led to large scale commercial use of row covers in the late 1960's in California (14). However, the adoption of row cover use did not spread to other parts of the U.S. and Canada until the 1970's.

In Canada, some of the earliest research on mulches and row covers was done by Harris (16) in Alberta on beans and corn. Unperforated clear polyethylene row covers were found to produce high air temperatures and humidity which promoted top growth more than root growth. Campbell (6), in Manitoba, found that unperforated polyethylene row covers significantly increased tomato yields. Wiebe's research (49) in Ontario demonstrated that perforated polyethylene row covers produced earlier and higher yields of muskmelons.

In the mid 1970's research on the effects of various mulches and row covers on vegetable production began at the Alberta Horticultural Research Center (AHRC) in Brooks. Research indicated that these materials could increase both earliness and yield, especially in the vine crops (17, 18).

The use of mulch and row covers by market gardeners and commercial vegetable producers in Alberta has only begun in the last two or three years and production under plastic is still very limited.

3. Row cover materials

Thermoplastics, in the form of film, are the principal materials used in plasticulture. Polyethylene is the usual material used for most of the plastic films. The addition of enrichments to the basic polyethylene resin increases the durability of the film, its transparency to visible light and its absorption of long infrared radiation.

Low density polyethylene is the most commonly used plastic film, followed by plasticized polyvinyl chloride (PVC) and then vinyl acetate polyethylene (EVA) (9). More recent technology has also provided nonwoven, spunbonded nylon, polyester and polypropylene materials.

Manufacturers generally use the same resin with different adjuvants to produce low density polyethylene films. However, the manner in which extrusion is accomplished and the nature and quantity of the stabilizing substances (mainly UV absorbants) result in films whose lifetime may vary greatly even under the same weather conditions (32).

The popularity of PVC films for row covers is due to their greater degree of frost protection than polyethylene films. Bowman (4) found that at night, the radiation loss under the PVC row cover was less than under the clear polyethylene row cover due to the low thermal (or infrared) transmittance of the PVC film. However, PVC film is more costly than polyethylene.

EVA films consist mainly of polyethylene enriched with vinyl acetate, which has the property of increasing the absorption of the long infrared radiation through the film without reducing its transparency to UV, visible and infrared radiation of short wavelengths.

The use of spunbonded nylon and polyester materials is increasing amongst producers in Europe and the United States because these products are lightweight and can be applied directly over the plants without the need for support by hoops.

Future technology may provide new row cover polymers which change properties according to temperature. Wells and Loy (48) state that the problem with materials used for row covers to date has been that they are industrial polymers which have been adapted for agricultural use, rather than polymers that were designed for specific row cover application.

Selection of row cover materials must be based upon the creation of a suitable microclimate for plant growth. Shadbolt and McCoy (37) described the desired environmental modifications to be created by row covers. These include: a suitable increase in daytime air temperature; maximum increase in nighttime air temperature, providing protection from frost; increase in soil temperature; maintainence of relative humidity at moderate levels and also protection from wind and blowing sand. However, the effectiveness of the row covers is dependent upon the type of material used and on the local environmental conditions. Plant responses to row covers vary with the plant's ability to respond to the modified climatic conditions. Different species and cultivars, therefore, may be expected to produce different results.

4. Microclimatic factors affected by row covers

4.1 Air exchange

Early research by Shadbolt *et al.* (37,38) indicated that ventilation of continuous row covers was essential shortly after emergence of the plants. Cantaloupes growing under unperforated covers were observed to be severely stunted when compared to those grown under perforated covers. Low carbon dioxide levels under the nonperforated covers were suspected but research did not indicate below normal levels of carbon dioxide during the day or night. Therefore, it was speculated that the high temperatures under the unperforated row covers were responsible for the stunted growth. Hall (13) also suggested that stunting of tomatoes in his studies may have resulted from the high temperatures obtained under the row covers. It was suggested that special venting techniques be used.

Jensen and Sheldrake (23) confirmed the importance of ventilation in polyethylene row covers. In their research, ventilation was provided by the movement of air with fans through air-supported row covers. Various other methods of ventilation have been used over the years. The most common method was a system where one side of the row cover was raised to provide air circulation. This opening was increased in size as the season progressed until finally the covers were removed completely. Another system, used by Hall (12) and others, consisted of using two separate polyethylene sheets which were laid over hoops, covered along the edges by soil, and joined at the top of the row by clothes pins. The covers were opened during warm, sunny weather and closed at night or during periods of cold or windy weather. These systems had a high cost of operation or labor requirement, leading to the development of perforated polyethylene covers.

Slitted plastic row covers, which were developed in New Hampshire, proved to be a good type of perforated polyethylene row cover. They greatly reduced the labor required for installation and the slits eliminated the need for manual ventilation (47). This type of cover is the most commonly used row cover in the United States today.

Shadbolt *et al*. (37, 38) investigated the effects of perforations in polyethylene row covers. High relative humidity (90%) was noticed under unperforated row covers. Perforations in the film reduced the humidity slightly. Shadbolt *et al*. (37,38) postulated that high relative humidity, in conjunction with higher soil temperatures, may result in the production of tender,succulent plants and these plants would be more susceptible to disease, frost injury or sudden exposure to sun and wind.

Maurer and Frey (31) obtained different results in their study of microclimate modifications resulting from row cover use. Relative humidity was found to decrease during the day within the tunnels to a greater extent than in the open. However, at night, when the ambient relative humidity was close to 100%, the tunnels also had close to 100% relative humidity. No reasons are hypothesized for the lower relative humidity under the row covers during the day.

High humidity may also result in condensation of water on the undersurface of the polyethylene covers. This condensation has been shown by Loy and Wells (28) to decrease light transmittance. It has also been shown by Waggoner (44) to serve as a heat barrier. Since water is opaque to long wave radiation and has a high heat capacity, condensation may serve in heat retention and frost protection. The high relative humidity recorded by Shadbolt and McCoy (37) may have been due to the absence of a plastic soil mulch under the row cover.

The limited air movement under row covers, as recorded by Wiebe (49), demonstrates the importance of row covers in providing wind shelter to the young plants.

4.2 Air temperatures

Row covers exert their greatest effect upon the air temperature within the row covers. The increase in temperature depends upon several factors. These include the properties of the row cover materials (28,30,31,42), proportion of perforations in the row cover (38,43), presence or absence of plastic mulches (13,27), and weather conditions (5,35,42).

Loy and Wells (28) found mean daytime temperatures 15 cm above the soil surface covered with black polyethylene under slitted row covers to be 2°C higher than that under the polyester cover plus the same mulch and 7°C higher than the ambient air temperature over bare soil. Nighttime temperatures under slitted polyethylene row covers and polyester row covers were similar and about 1.5°C higher than the ambient air temperature. Maurer, Frey and Gaye (30) recorded similar temperature increases (25 cm above soil surface), with slitted polyethylene row covers producing temperature increases of 5.6°C and polyester covers (3.6°C) above ambient air temperatures.

Tan, Papadopoulous and Liptay (42), using 80 cm high row covers, observed large variations in air temperatures under various types of plastic row covers. Daytime air temperature increases (measured at 25 cm) were highest under clear polyethylene cover with black polyethylene mulch (10°C increase). Nighttime temperatures were highest under the PVC row cover with black polyethylene mulch, Nighttime air temperature under clear polyethylene without mulch was found to be 1°C higher than the same treatment with black polyethylene mulch. Row covers made of clear polyethylene recorded greater temperature fluctuations than the other materials tested and minimum air temperatures were often slightly lower than those outside. Brun (5) also reported lower than ambient air temperatures under perforated polyethylene row covers in southern France during the winter season. Savage (35) noticed that temperatures may drop below ambient air temperature under polyethylene covers shortly after sunset. Maurer and Frey (31) postulate that on clear nights, the outgoing radiation from polyethylene covered tunnels lowered air temperature below that of ambient.

Hemphill and Mansour (19) investigated the effects of floating row covers on air temperatures. These types of row covers were found to increase the mean minimum air temperatures by 1 to 2°C and mean maximum temperatures by as much as 14°C. The temperatures were recorded at a height of 2.5 cm above the soil surface or mulch.

Research has shown that the daytime temperature under row covers can be controlled by the proportion of perforations found in the covers (34,38). Shadbolt *et al*. (38) found that daytime temperatures were generally reduced, particularly near the ground level, when perforations were present. However, perforations in the polyethylene covers had only a slight effect on the minimum air temperatures. Tesi, Graifenberg and Notartommaso (43) using PVC row covers over black polyethylene mulch also found that temperatures under the covers were closely related to the percentage of perforation. Fructos (11) has shown that the location of the perforations can also play an important role in temperature modification. Maximum air temperatures were reduced 2-4°C with top perforations compared to side perforations. Minimum temperatures were not affected by the location of the perforations. No reasons are given by Fructos (11) for the lack of response.

Hall (13) and others (27,41,42) found that polyethylene soil mulches can increase the daytime air temperature inside the row covers. However, minimum air temperatures are reduced by mulches. Jensen and Sheldrake (23) noticed that tomato plants over polyethylene mulch treatments and covered with row covers were more severely damaged by frost than the plants on the no mulch treatment with polyethylene row covers. Loy and Wells (27) confirmed that row covers alone provided slightly better frost protection than the row covers plus black polyethylene mulch. This difference in frost protection was attributed to the heavier condensation of moisture on the underside of the row covers over the moist, bare soil compared to row covers over plastic mulch.

4.3 Soil temperatures

Clear polyethylene mulches have consistently increased soil temperatures more than have black polyethylene mulches (8,21,22,36). In some instances, soil temperatures under black polyethylene mulches have been lower than bare soil temperatures (16,22,42). The difference in soil temperatures between the two mulches has been explained by Hopen (22). Black polyethylene can exchange large quantities of energy by absorbing solar radiation and re-radiating it to the atmosphere resulting in relatively small changes in soil temperature. This is supported by Hill, Hankin and Stephens (21) who observed a 2°C increase in daytime air temperature above the black polyethylene film. De Vries (8) reported similar findings. Clear polyethylene mulch transmits solar radiation more effectively to the soil surface and the soil is heated strongly during the day. De Vries (8) states that the consequence of this increased heat flow rate into the soil is that at night more heat can be delivered to the surface.

The soil temperature under the polyethylene mulch varies according to the season, type of soil, intensity and duration of sunshine and the moisture content of the soil (9). At night, the difference in temperature between covered and uncovered soil is less but clear polyethylene mulches still have higher minimum temperatures than the black mulches (16, 21).

The effect of row covers on soil temperatures is mainly dependent upon the air temperatures achieved under the covers (20). Therefore, row covers which produce higher air temperatures, due to the material used or amount of ventilation, generally produce higher soil temperatures (28,29).

It is findings such as these that have shown that the combined effects of row covers plus mulches tend to increase soil temperatures more than row covers alone. Loy and Wells (28) recorded higher soil temperatures under clear polyethylene row covers plus black polyethylene mulch than polyethylene row covers with no mulch. However, Tan *et al.* (42) found soil temperatures to be similar using the same treatments. Harris (16) offers an explanation for this discrepancy. Poor contact between the soil and the black polyethylene mulch can create an insulating layer of air which may reduce the transfer of heat from the mulch to the soil. Tan *et al.* (42) confirms this hypothesis by stating that the black polyethylene mulch in their research studies was not placed in close contact with the soil.

Polyester row covers tend to produce lower maximum soil temperatures than polyethylene due to the lower air temperatures achieved under the polyester material (28,30,31). The floating row cover, Xiro, which is a polyethylene film cut to form slits that open progressively as plant growth takes places, produced the highest soil temperatures in research by Maurer *et al.* (30) and Mansour, Hemphill and Riggert (29).

4.4 Soil moisture

Higher moisture levels in mulched than in unmulched soils have been reported by many researchers (16,22,36,45). However, high soil temperatures underneath the clear polyethylene mulch have been observed to produce a high evapotranspiration rate and a continuous decline in soil moisture at lower levels (25,36). The result can be much lower soil moisture under clear polyethylene than black polyethylene mulches or even the unmulched soil. Knavel and Mohr (25) suggest that the high temperatures under clear polyethylene influenced the moisture levels under these mulches.

Polyethylene row covers act in a similar manner as polyethylene mulches by preventing water from reaching the soil surface. The effectiveness of the polyethylene row covers in reducing the amount of water entering the soil to rain or irrigation depends on the proportion of perforations in the covers. However, the low percentage of perforations normally found in polyethylene row covers results in most of the water being shed. Soil moisture from rain or irrigation must therefore move laterally from the sides of the row covers unless a drip irrigation system is used. Highly perforated floating row covers allow the water to penetrate through the covers. Porous spunbonded polyester also allows the rain or irrigation water to pass through this material.

4.5 Solar and thermal radiation

Light transmittance through the row covers is affected by the type of material used. Loy and Wells (28) measured light transmittance of photosynthetically active radiation (PAR) (400-700 nm) in slitted polyethylene and a spunbonded polyester material on sunny and cloudy days. With both covers, light transmittance was decreased more on cloudy than on sunny days. The polyethylene covers had lower levels of light transmittance than did the polyester covers on cloudy, humid days. This was attributed to condensation of water on the undersurface of the polyethylene covers. On sunny days, the polyester material reduced light transmittance by 23% compared to a decrease of 14% by the slitted polyethylene. Maurer *et al.* (30) obtained an 18% reduction in light transmittance for both slitted polyethylene and the polyester material on sunny days. The observed reduction in light transmission through row cover materials observed (28,30) should not limit growth of young plants in full or partial sun, since the photon flux density of full sun is well above the light saturation point for crop plants (48).

A more important effect of row cover materials is upon the long wavelength infrared radiation or thermal transmission. Dubois (9) reports a value of about 71% transmittance for polyethylene compared to a value of 4.4% for glass. This fact is responsible for the rapid cooling, during the evening and night, of the air and soil under the polyethylene row covers and mulches. This prevents the "greenhouse effect" (9) from occurring under the row covers. However, if condensation occurs, a greenhouse effect may occur due to the reduction in the long infrared radiation through the water layer. This was demonstrated by Waggoner (44).

Nisen, Nijskens, Deltour and Coutisse (32) gave a long infrared transmittance value of 26.1% for polyester films. Therefore, these materials have better insulating properties than polyethylene; but since the spunbonded materials are relatively porous, much of the heat transfer from inside to the outside of the covers occurs by air mixing (48).

4.6 Disease and insect control

No problems with disease or insects have been reported in research studies on row cover use even though some of the row covers can produce high levels of humidity as measured by Shadbolt and McCoy (37).

Mansour *et al.* (29) observed that insect movement and damage was eliminated under all floating row covers tested. Loy and Wells (28) did not encounter any disease or insect problems with the row cover materials used in their research. Wells (46) reported control of root damage in radish from maggots and also control of flea beetles with the use of spunbonded polyester. Both insects were controlled by excluding them from the crop under the cover.

Loy and Bushnell (26) observed that row covers over summer squash and muskmelon provided protection against cucumber beetles and aphids which are both vectors for harmful pathogens.

5. Use of soil mulches in conjunction with row covers

5.1 Advantages

Loy and Wells (27) listed several advantages of using a row cover-mulch combination as compared to the row cover alone. The advantages of the mulch include: continued higher soil temperatures after row cover removal, reduction in loss of N through leaching after row cover removal and also weed control if a black polyethylene mulch is used. Daytime air temperature under the polyethylene row cover-black mulch combination was also found to be higher than under the row cover alone. However, the row cover alone afforded slightly better frost protection than the row cover-polyethylene mulch treatment. Jensen and Sheldrake (23) observed that row covers plus mulch treatment produced the highest yields of tomatoes. The black polyethylene mulch treatments produced more than the clear mulch treatments and this was attributed to better weed control.

5.2 CO2 levels

It is not known to what extent the polyethylene mulches affect the carbon dioxide levels under the row covers as suggested by Sheldrake (40). This author does not know of any research that has been conducted to measure carbon dioxide levels under polyethylene row cover-mulch combinations. However, as previously mentioned, attempts by Shadbolt and McCoy (37) to measure carbon dioxide levels under polyethylene row covers alone suggested normal levels were present.

5.3 Soil nitrate concentrations

Mulches have been shown to increase the nitrate concentrations in the soil (3,7,24,25). Shadbolt and McCoy (37) measured the nitrate-nitrogen content of the cantaloupe plants grown under polyethylene row covers and hot tents. A higher nitrate content of plants grown under polyethylene row covers was found. A high correlation between nitrate content and moisture content of the plant was discovered indicating that greater nitrate uptake occurred in the fast-growing, more succulent plants. Row covers alone may act in a similar manner as mulches in reducing the leaching losses of nitrogen. Therfore, the combination row cover-mulch may not be required unless a highly water permeable row cover is used. Also higher nitrate concentrations may be due to the warmer soil temperatures and higher soil moisture which would encourage nitrification.

6. Response of tomatoes to row cover use

Hall (12) in 1965 conducted some of the earliest research on the use of row covers for tomato production. His findings indicated that vented polyethylene row covers increased early plant growth and yields of early spring tomatoes grown in California. Polyethylene row covers quickly replaced the use of hot caps in that area of the country (14). However, the adoption of row cover use for tomato production in other parts of the United States and Canada has not been as widespread.

For row covers to be effective, they must be managed according to the temperature requirements or limitations of the crop (48). Extreme temperatures, which may be experienced under row covers, can limit fruit set. Temperatures above 30°C (the exact limits depending on the cultivar) are detrimental to one or more of the processes leading to fruit set (33).

Wells and Loy (48) obtained improved yield of tomatoes with row covers in 1982, whereas in 1983 the yield was drastically reduced under high ambient temperature conditions. This may explain why the response of tomatoes to row covers has been so variable. Therefore, adequate ventilation and proper time of removal of the row covers are essential.

When ambient air temperatures are not excessive, row covers have been shown to increase early and total yields. Wells and Loy (48) found that both slitted polyethylene and spunbonded polyester improved total yields above the bare soil or black plastic mulch treatments. The slitted polyethylene row cover produced significantly higher early yield than all the other treatments and also higher total yield than the polyester row cover. Taber (41), in Iowa, obtained higher early and total yields of tomatoes with clear polyethylene mulch plus slitted row cover than with black polyethylene mulch plus slitted row cover. The slitted polyethylene row cover without mulch produced higher early yields but similar total yields compared to the uncovered bare ground treatment.

In Alberta, Hausher (17) obtained inconclusive results with his research on row cover and mulch use for tomato production. Increased vegetative growth and delayed maturity were observed.

More research is required about row cover use for tomatoes. Methods must be found to reduce the yield variability that has been obtained. Some of the research aspects that require more investigation are degree of ventilation, types of row cover materials to use and time of row cover removal.

III. Materials and Methods

Experiments were conducted in the summer of 1985 at the Alberta Horticultural Research Center (AHRC) in Brooks which is located in southeastern Alberta. This region experiences a continental type of climate with semiarid conditions. Mean annual precipitation is about 335 mm, with two thirds of that occurring during the growing season. The frost-free period is about 116 days. The soils at the Research Center are derived from a fine loamy, moderately calcareous fluvial or lacustrine material and belong to the Chin soil series. This series is an orthic Brown Chernozemic soil with a silt loam texture. The soils are mild to moderately alkaline (pH 7.8-8.2) and contain a low organic matter content (<2.0%).

Four row cover treatments and one hot tent treatment were tested on two cultivars of tomatoes. The cultivars were tested separately on adjacent plots. A randomized complete block design consisting of five replications on each cultivar was used. The five treatments studied were :

(1) hot tents which were the control

(2) clear polyethylene row cover with 25 holes per m^2

(3) clear polyethylene row cover with 45 holes per m^2

(4) a spunbonded polyester floating row cover, Reemay[1]

(5) a slitted polyethylene floating row cover, Xiro,[2] with 35,000 slits (8 mm in length) per m^2.

----

[1] Reemay is a lightweight, porous, spunbonded polyester material manufactured by Du Pont Canada Inc.

[2] Xiro is a polyethylene film with small slits which open as the plants grow and is manufactured by Xiro Ag. in Fribourg, Switzerland.

Hot tents were used as the control based on research findings by AHRC staff that this method of production produced higher marketable yields and earlier maturity than uncovered or row cover production (1,17,18).

All row cover treatments were applied manually over a clear polyethylene mulch. Research at Brooks (AHRC) has indicated that better yields are obtainable with the use of clear polyethylene than bare soil or black polyethylene (17,18). The polyethylene row covers and mulches were 0.050 mm thick. The holes in the polyethylene row covers were 26 mm in diameter resulting in 1.3% and 2.4% perforation in the two polyethylene row cover treatments, Poly 25 and Poly 45 respectively. The holes were spaced 20x20 cm in the polyethylene with 25 holes per m² and 11x20 cm in the polyethylene with 45 holes per m².

The polyethylene mulch was 1.2 m wide and was applied in rows using a commercial mulch applicator. The rows were 10 m in length and when applied the exposed mulch measured 60 cm in width. The rows were spaced 1.8 m apart, center to center. A north-south row orientation was used because of the sprinkler irrigation system design.

The slitted polyethylene floating row cover, Xiro, was 1.5 m wide while all the other row covers were 1.8 m wide. Support for the polyethylene row covers was provided using galvinized #9 wire (1.8 m long) which was bent into hoops and placed at the edge of the mulch. The wire hoops were spaced 1.5 m apart and the polyethylene rows covers were laid tightly over the wire hoops and secured at the base and row end with soil. These row covers were approximately 40 cm high at the middle of the row and 60 cm wide at the base. The two floating row covers, Reemay and Xiro, were laid directly over the tomato plants allowing sufficient slack for plant growth and secured with soil. The hot tents, which measured 37 by 46 cm, were set on top of the plastic mulch and were anchored around the base with soil. At the time of setting, a 5 cm slit was cut on the upper leeward side of the hot tents to provide some ventilation. This slit was increased to 20 cm on June 12 and then the tents were completely opened on June 21, 1985.

Two tomato cultivars which have produced good results in the Brooks area were selected. The cultivars were also selected on the basis of their different growth characteristics. The 'Brookpact' which was developed at the AHRC in Brooks produces a moderately erect plant with vigorous foliage. The fruits are large, round to flat-round, very fleshy and weigh from 170-250 grams. The other cultivar, 'Hybrid 31', developed by Peto Seeds in California, produces a taller plant with a longer internodal length. The fruits are very firm, round to oval, and smaller in size than the Brookpact. Both cultivars are early maturing and have a determinate growth habit.

Land preparation consisted of rototilling the plots. The soils were treated with a preemergence herbicide, trifluralin (Treflan 545 EC), which was applied at a rate of

0.82 kg/ha a.i. on May 2, 1985. The herbicide was incorporated into the soil at the time of rototilling. In Plot A, on which the cultivar Hybrid 31 was tested, a clear polyethylene mulch was laid on May 6, 1985 using a commercial mulch applicator. Plot B (Brookpact) was rototilled a second time on May 13, 1985 and the same type of mulch was applied immediately afterward.

Six-week old transplants from the greenhouse were planted in the field on May 21, 1985. This is the normal time of planting this crop in southern Alberta. The Brookpact seedlings were 10 cm in height and the Hybrid 31 seedlings 15 cm in height at the time of field setting. The transplants, which were grown in soil blocks, were hand planted in the field. Slits approximately 10 cm in length were made in the polyethylene mulch to permit placement of the transplants. The plants were spaced 90 cm apart within the row and 1.8 m between rows. Each 10 m row contained 10 tomato plants.

One-half litre of starter solution (10-52-10 at 1.25 g/l) was applied to each transplant. Plants were fertilized again on June 6, 1985 with one litre to each plant of a water soluble urea solution (46-0-0 at 1.0 g/l). Fertilizer application was done at this time due to the late arrival of soil test results which indicated low levels of nitrogen. Nitrogen levels were 6-8 ppm while phosphorus ranged from 72-101 ppm and potassium was 350-452 ppm.

Seedlings which did not survive the first transplanting were replaced from the original lot of transplants. In addition, a killing frost occurred on June 1, 1985. Severely affected and killed plants were replaced from the original lot of transplants on June 4. Each transplant again received a 0.5 litre of starter solution of the same concentration as at the original planting.

Irrigation was carried out as required using a solid set sprinkler irrigation system. Time of irrigation was determined with the use of irrometers placed at a depth of 15-20 cm. Supplemental hand watering was done on June 12, 1985 for the two supported polyethylene row cover treatments when the plants showed some signs of stress. The plants under these two treatments were given one litre of water each.

The row covers were completely removed on July 1, 1985 during a period of hot weather. The two supported polyethylene row cover treatments were split open at the top on the previous day to permit the plants to acclimatize.

Harvesting of tomatoes began August 9 and was conducted at weekly intervals up to September 20, 1985. A total of six harvests was carried out. Total and marketable yields were recorded during the harvest period.

A preliminary experiment was also conducted on time of row cover removal for one of the row cover treatments. Five 5 m rows were used for each of the two cultivars. Five transplants per row using the same spacing as in the previous experiment were planted in rows covered with a clear polyethylene mulch. The polyethylene row cover with 25 holes per m^2 was applied over the rows. One row cover was removed at weekly intervals for each cultivar beginning on June 24, 1985 and extending to July 22, 1985. There were no replications in this experiment. The same harvesting procedure as outlined in the replicated trials was followed. The yield data were recorded using all five plants within each row.

Data Recorded

1. Temperatures

Temperature measurements under each of the five treatments were recorded during the period of row cover use (40 days) from May 22 to July 1, 1985. Four replications were made. Temperatures were only recorded in Plot A where the cultivar Hybrid 31 was grown.

Maximum and minimum air temperatures using Brennan minimum/maximum thermometers were recorded at 20 cm above the mulch inside the row covers and hot tents. For comparison, ambient air temperature at 20 cm above bare soil was also recorded.

Soil temperatures at a depth of 10 cm were recorded twice daily (0700-0730 h and 1530-1600 h) using a Lab-line Instruments soil thermometer.

Air and soil temperatures were also recorded over one 24-hour period at two hour intervals on June 17-18, 1985.

2. Soil moisture

Soil moisture at a depth of 15-20 cm was recorded using irrometers. Measurements were recorded daily from three replications in Plot A. Soil moisture levels in bare soil were also measured, however, only at one location.

3. Light Transmittance

Photosynthetically active radiation (PAR) was measured under all the row cover treatments using a LI-COR, Inc. Model 185A light meter and a LI-190S quantum sensor (400-700 nm). Six measurements were made for each row cover treatment from 1300-1400 h, June 19, 1985 which was a clear, sunny day.

4. Fresh and dry weights

One plant from each replication of each treatment for each cultivar was collected during the morning of July 2nd, the day after row cover removal. The samples consisted only of the above ground portion of the plants (less roots). The samples were weighed on a balance and then dried for 53 hours at 70-75°C in a forced-air oven. The dry samples were then weighed again on a balance to record dry weight. The percentage of dry matter per plant was then determined.

The samples were randomly selected but precautions were taken to ensure that the late transplants (due to frost) were not included in the sampling.

5. Yield

Yields were recorded in kg per plant and were generally obtained from the yield of seven plants within each row. The first and last plant in each row were discarded.

Harvesting began on August 9, 1985 and was done manually at weekly intervals. Only ripe and pink fruits were harvested. Harvested tomatoes were sorted into marketable or culled fruit. The culls consisted of small, cracked, deformed or rough-skinned fruit. The percentage culls by weight was recorded. The total and marketable yields and total number of fruit harvested were recorded at each harvest date. Harvest continued until the first killing frost which occurred on September 20, 1985. A strip harvest was done on the final harvest date. All the fruit , except the very small fruit (less than 3-4 cm in diameter), was harvested and weighed. Mature green fruits on the last harvest date were included in the final total yield.

Early maturity was measured by the yield of the first three harvests (August 9 to August 23, 1985).

No harvesting was done in the week of September 13 due to cool, wet weather which delayed ripening. On the final harvest date, no measurement of marketable yield was done due to the volume of the harvest and the poor weather conditions at the time.

IV. Results and Discussion

1. Air temperatures

Maximum temperatures were greater than the ambient air temperature under all the row cover and hot tent treatments (Tables 1 and 2). Maximum air temperature increases ranged from 6.2 under Reemay to 14.2°C under Poly 25. The large increases were probably due to the cooler but sunny weather conditions which prevailed during the time of row cover use in the 1985 growing season (Table 3).

At the time of transplanting unusually high temperatures were experienced. Also during June, the total hours of sunshine recorded, was the second highest in 33 years. Although the mean daily maximum temperature recorded during June was close to the 30 year average, the mean daily minimum temperature was 2.4°C cooler.

The largest increase in maximum air temperature (14.2°C) occurred under the polyethylene row cover with 25 holes per m^2 (Poly 25). An approximate 10°C increase in temperature occurred under the Poly 45, Xiro and hot tent treatments. The hot tent treatment initially produced similar temperature increases to the Poly 25 treatment, however, further slitting of the tents on June 12, 1985 reduced the temperatures recorded after that date. Reemay produced the lowest temperature increase (6.2°C).

Minimum air temperatures within the covers were similar to the ambient air temperature (all measured at 20 cm

Table 1. Effect of various row covers on air and soil temperatures.[1]

	AIR TEMP. °C[2]			SOIL TEMP. °C[2]		
Treatment	Min.	Max.	Mean	A.M.	P.M.	Mean
Hot Tents	6.2a[3]	36.3b	21.3b	13.6c	20.4d	17.0d
Poly 25	3.9c	40.2a	22.1a	14.2ab	26.6a	20.4a
Poly 45	4.9b	36.1b	20.5b	14.0b	25.3bc	19.7bc
Reemay	5.4b	32.2c	18.9c	14.5a	24.7c	19.6c
Xiro	5.1b	36.0b	20.6b	14.2ab	26.1ab	20.2ab
Clear mulch	--	--	--	13.2d	26.3a	19.8bc
Amb. air or bare soil	6.3	26.0	16.2	12.1e	20.9d	16.5d

[1] Temperatures were recorded from May 22 - June 30, 1985.

[2] Air temperatures were measured 20 cm above the mulch and soil temperatures at 10 cm depth.

[3] Mean separation in columns by Duncan's multiple range test, 5% level

Table 2. Temperature deviations from the ambient air and bare soil temperatures under various row covers.[1]

	AIR TEMP. DEVIATIONS °C			SOIL TEMP. DEVIATIONS °C		
Treatment	Min.	Max.	Mean	A.M.	P.M.	Mean
Hot Tents	-0.1a	+10.3b	+5.1b	+1.5b	-0.5d	+0.5c
Poly 25	-2.4c	+14.2a	+5.9a	+2.1a	+5.7a	+3.9a
Poly 45	-1.4b	+10.1b	+4.3b	+1.9a	+4.4b	+3.2b
Reemay	-0.9b	+6.2c	+2.7c	+2.4a	+3.8c	+3.1b
Xiro	-1.2b	+10.0b	+4.4b	+2.1a	+5.2ab	+3.7a

[1] Ambient air temperatures were 6.3°C minimum and 26.0°C maximum while bare soil temperatures were 12.0°C at 0700h and 20.9 °C at 1530h.

[2] Mean separation in columns by Duncan's multiple range test, 5% level.

Table 3. Climatic data recorded at Brooks, Alberta (altitude 758 m) for 1985 and 30 - year average (1951-80).

		MONTH				
		May	June	July	Aug.	Sept.
Mean daily max. temp. (°C)	30 yr avg	18.4	22.5	26.2	24.9	19.2
	1985	20.9	22.8	27.6	22.9	13.4
Mean daily min. temp. (°C)	30 yr avg	3.8	8.6	11.0	9.7	4.4
	1985	4.5	6.2	11.6	9.0	3.0
Mean daily temp. (°C)	30 yr avg	11.1	15.6	18.6	17.3	11.9
	1985	12.7	14.5	19.6	16.0	8.2
Mean precip. (mm)	30 yr avg	38.3	65.7	32.2	40.1	33.8
	1985	13.2	22.0	38.8	53.4	65.5
Degree days above 10°C	30 yr avg	71.4	169.8	266.8	228.1	87.2
	1985	83.8	135.3	299.5	183.0	40.0
No. of hours of sunshine	30 yr avg	269.9	287.1	341.7	304.1	201.2
	1985	294.2	354.5	348.5	251.7	129.3
Total no. of frost free days	30 yr avg	116				
	1985	94				

height) only under the hot tent treatment. In all the row cover treatments, the minimum temperatures dropped below the ambient air temperature which was measured over bare soil. The Poly 25 treatment decreased minimum temperatures (2.4°C) below the ambient air temperature. This was the largest decrease recorded. The Poly 45 treatment, which had a greater percentage perforation, decreased the minimum air temperature 1.4°C below ambient air temperature.

An increase in percentage perforation in the supported polyethylene row covers tended to decrease the maximum air temperatures and increase the minimum temperatures recorded. The temperature differences from ambient, both minimum and maximum, measured under these two treatments were significant (Table 2). The minimum air temperature difference between the two supported polyethylene treatments was unexpected and it is difficult to explain. It is perhaps due to the different humidity levels and rates of air exchange.

Minimum air temperatures lower than the ambient air temperature under row covers have been reported by other researchers (5,15,31,35,41,42). However, the degree and consistency of the temperature decreases observed in this experiment were surprising. The temperature difference between inside and outside has not been fully studied by researchers investigating the effects of row covers.

Maurer and Frey (31) found that the temperature under slitted polyethylene tunnels was decreased approximately 2°C below the ambient air temperature on clear nights early in the season. They did not speculate on the cause of the reduced temperatures. Hansen (15) attributed the difference in temperature to the lack of downward transport of sensible heat by the turbulent motion of the wind outside the greenhouse. Savage (35) found that the air under plastic tunnels was cooler than the outside air shortly after sunset. The inside air temperature was found to decrease more rapidly than the outside air. However, after a few hours, the temperatures were again equal and then finally warmer inside the tunnel than outside. Savage (35) attributed this to the fact that the sudden decrease in air temperature causes an increase in the inside relative humidity and then it is possible that condensed water would form on the inside. This condensed water could then act as a heat barrier reducing the cooling rate of the air inside the plastic tunnel (44).

In this experiment, air temperatures were recorded at two-hour intervals over a 24-hour period on June 17-18 (Figure 1). Temperatures increased to a greater extent under the Poly 25 and hot tent treatments. Temperature increases and decreases were least dramatic under the Reemay treatment. These results correspond to the findings of Maurer and Frey (31). The air temperatures were found to be below the outside temperature shortly after sunset (Figure 1). However, in contrast to Savage's results (35), air temperatures continued to be below the ambient air temperature throughout the night. Maurer and Frey (31) obtained similar results early in the season (May) when the temperature under the slitted polyethylene decreased below the ambient at approximately 2030 h and continued so until 0800 h. The lower temperatures did not occur later in the season when temperatures over a 24 hour period were again recorded in late June. These findings are in contrast to the results obtained in the present research where lower minimum air temperatures under the polyethylene row covers continued throughout the period of row cover use.

A 14°C decrease in air temperature in Poly 25 was recorded between 2100 h and 2300 h. Meanwhile, only a 5.5°C decrease in ambient air temperature occurred. Minimum air temperatures were recorded shortly before 0500 h (near

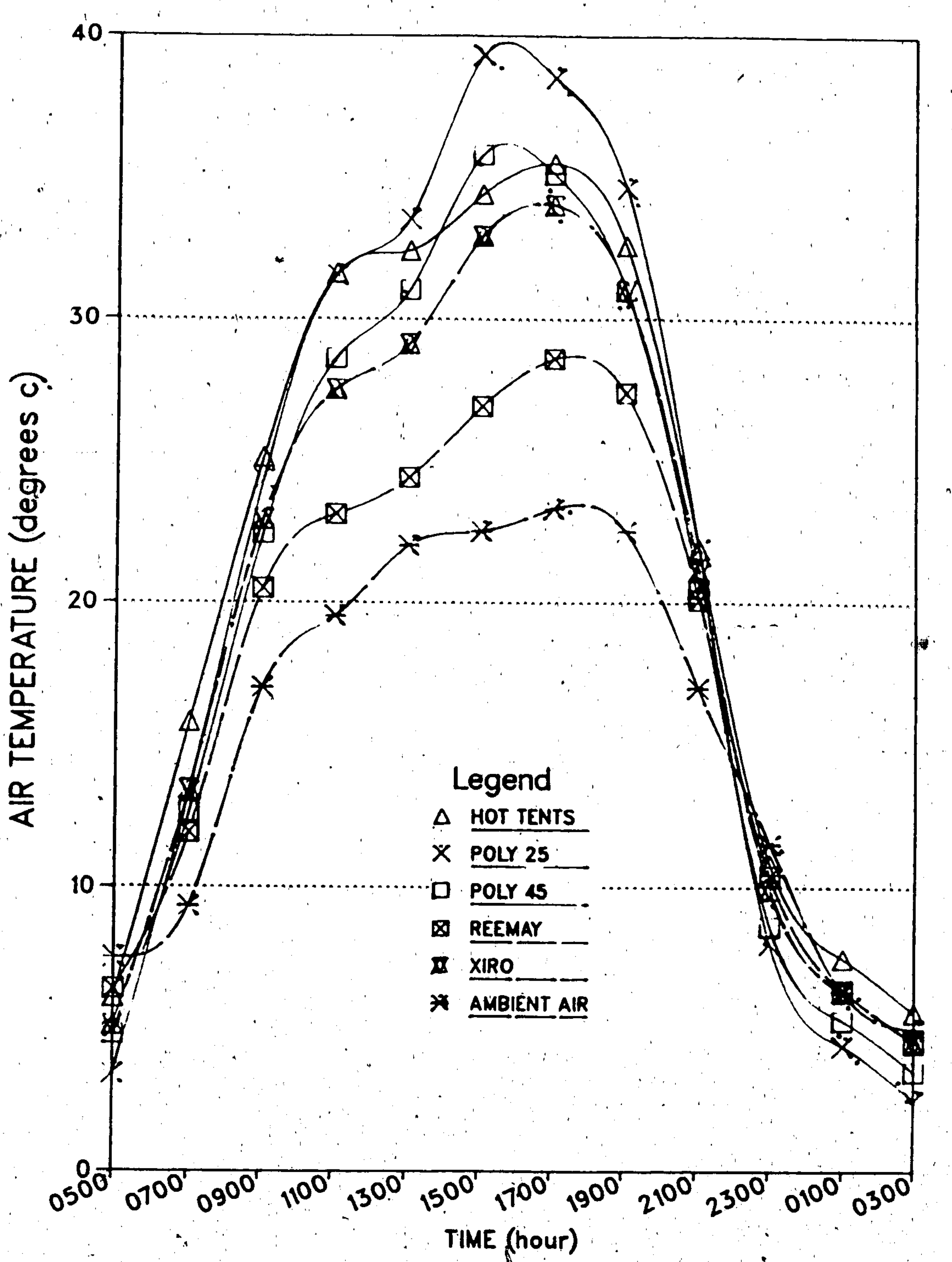

Fig. 1. Air temperatures recorded under various row covers over a 24 hour period (June 17-18, 1985).

sunrise). Similar trends were observed by Maurer and Frey (31) but the decrease in temperatures was not as dramatic.

A possible explanation for lower air temperatures inside than outside the row cover has been postulated by Wells and Loy (48). They state that when the humidity under covers is so low that the dew point is not reached at low temperatures, then temperatures may be lower inside than outside the row covers. Therefore, low humidity levels under the covers in the present experiment may have produced the lower minimum temperatures under the covers. Unfortunately, humidity levels were not recorded in my experiment. However, research conducted by Maurer and Frey (31) would seem to indicate that the relative humidity at night should be equal to or higher than the ambient relative humidity. Their research indicated that when the ambient relative humidity was low at night, the relative humidity under the slitted polyethylene tended to be higher than the ambient.

It is also speculated that heat lost by the soil was being trapped under the clear polyethylene mulch. It was noticed that condensation on the undersurface of the mulch occurred and this could have acted as a heat barrier. The result would be less heat being dissipated from the soil to the air in the row cover. Meanwhile, heat moving up from the bare soil could have increased the ambient air temperature outside the row cover. It was observed (Figure 2) that soil temperatures under the row covers were higher than the bare soil.

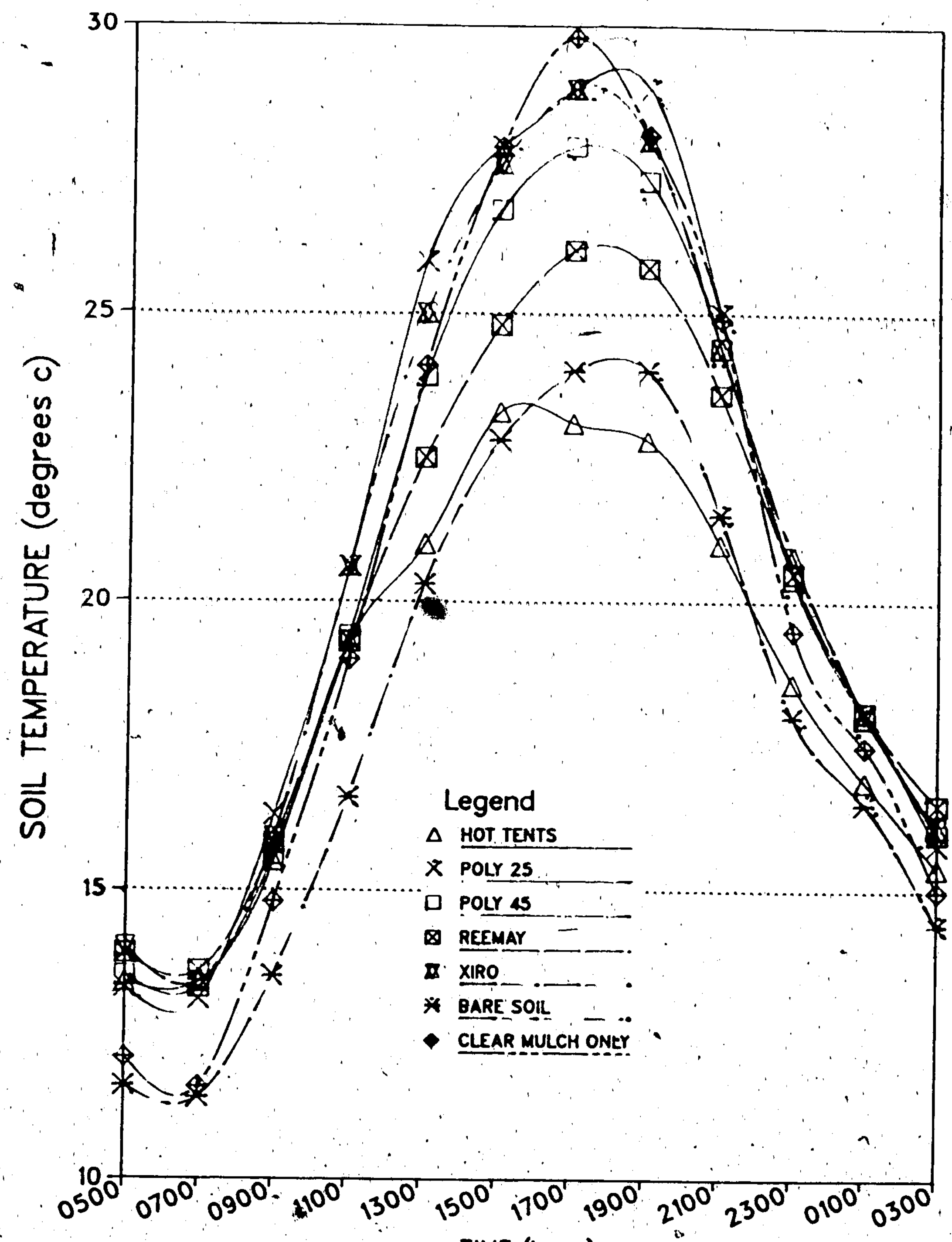

Fig. 2. Soil temperatures recorded under various row covers over a 24 hour period (June 17-18, 1985).

Frost was recorded on June 1, 1985, when the ambient air temperature at 20 cm above the bare soil was -1.5°C. Temperatures recorded on that day under all the row cover and hot tent treatments were below the ambient air temperature. The Poly 25 treatment resulted in the largest decrease (4.0°C) below the ambient air temperature. The hot tent treatment experienced the smallest decrease in temperature (1.3°C below ambient). These results are different from those reported by some researchers who have suggested that row covers offer some frost protection. Wells and Loy (48) reported 1 to 2°C frost protection with slitted or perforated row covers and the spunbonded polyester, Reemay.

Frost damage to plants under the various treatments was recorded (Table 4). The largest number of plants affected was under the two floating mulch treatments (Reemay and Xiro). However, the lowest temperatures were recorded under the two supported polyethylene treatments (Poly 25 and Poly 45). The plants under the Xiro treatment were the most severely affected with approximately 75% of the plants in the Hybrid 31 cultivar being damaged.

Wells and Loy (48) have observed that plant foliage in direct contact with Reemay material is more susceptible to frost damage than supported row covers. They speculate that moisture forms more readily on leaf surfaces in contact with the covers, and that heat is more readily re-radiated from the surface of the row cover to the atmosphere, resulting in

Table 4. Degree of frost injury to tomato plants under various row covers.[1]

	% of Plants Affected		% of Plants Killed or Severely Affected	
Treatment	Hybrid 31	Brookpact	Hybrid 31	Brookpact
Hot Tents	0	0	0	0
Poly 25	26	12	18	4
Poly 45	28	8	20	6
Reemay	54	12	12	0
Xiro	76	40	22	0
Mean	37	14	14	2

[1] Frost injury was measured on June 1, 1985 when the minimum ambient air temperature reached -1.5°C.

rapid frost formation on the leaf surface. Similar conditions may be produced with Xiro, resulting in increased frost damage with this floating row cover also. In the case of Reemay, it is also possible that this material enhances ice nucleation on the leaf surfaces with which it is in direct contact. It has been observed (48) that at 0°C, ice forms readily from moisture condensed within the pores of spunbonded fabrics.

The number of plants which had to be replaced was quite similar in the supported and floating polyethylene row cover treatments for the Hybrid 31 cultivar. However, none of the plants of either cultivar under the hot tent treatment were affected by frost.

Other researchers have stated that row covers are not effective in protecting plants from frost especially if the row cover is coupled with a polyethylene mulch (27,41,42,45). The use of hot tents offers a distinct advantage to producers in areas such as Alberta where the danger of frost is more prevalent. It also offers the potential to plant the crop earlier than would normally be possible with row covers.

A large difference in frost tolerance between the two cultivars was observed (Table 4). The Hybrid 31 cultivar had 37% of the plants affected and 14% of the plants killed or severely damaged by the frost. In the adjacent plot, only 14% of the Brookpact plants were affected and only 2% were killed or severely damaged. The difference in frost tolerance between the two cultivars may be due to the different selection criteria that were used to develop these cultivars. Brookpact is a cultivar that was produced locally.

Freezing temperatures were recorded under the row cover treatments on four other days after the June 1 killing frost. However, no frost damage to the plants was observed. The last freezing temperature under the row covers was recorded on June 11, 1985.

2. Soil temperatures

Soil temperatures did not change as dramatically as air temperatures but increases in temperature at a 10 cm depth were observed (Tables 1 and 2). A significant 5-6°C increase in afternoon soil temperature above the bare soil temperature was observed in the Poly 25, Poly 45 and Xiro treatments. Slightly smaller but still significant temperature increases (3.8°C) were measured under the Reemay treatment. The reduction in soil temperature increases with Reemay has been reported by other researchers (28,30,31).

Afternoon soil temperature under the hot tent treatment was slightly below the bare soil temperature but not significantly. The effect of the clear polyethylene mulch was probably negated by the method of laying the hot tents on the mulch. Soil was used to secure the edges of the hot tents on the mulch and this resulted in lower soil temperatures being produced due to the shading of the mulch.

Morning soil temperatures, which were measured near the time when minimum soil temperatures occurred, were increased 1.5-2.4°C above the bare soil temperature by the row cover and hot tent treatments which were all in combination with the clear polyethylene mulch. Soil temperature under clear polyethylene mulch with no row or plant cover was measured on sections of the hot tent treatment to determine the effect of the mulch. Clear polyethylene mulch alone increased the morning soil temperatures 1.1°C above the bare soil temperature.

Soil temperatures recorded over a 24-hour period at two-hour intervals on June 17-18, 1985 (Figure 2) indicate that the row cover plus mulch combination maintained higher soil temperatures during the night. Soil temperatures during the night did not decrease as rapidly under the row cover plus mulch combinations as with the clear mulch with no row cover. Row covers were found to increase the nighttime soil temperatures approximately 1°C above that of the clear mulch only.

3. **Light transmittance**

Photosynthetically active radiation (PAR) was measured under the row covers during a clear sunny day and was compared to PAR in the open. The spunbonded polyester row cover, Reemay, transmitted less light than the polyethylene row covers (Table 5). The Reemay reduced light transmittance 22% compared to 17% and 13% for the Poly 25 and Poly 45 respectively while Xiro reduced transmittance 10%.

PAR was also measured under the hot tents using only 15 cm of the one meter quantum sensor and this measurement was converted to a one meter reading. Light transmittance in the hot tents was found to be reduced approximately 60%. The hot tents were slit open 20 cm in length by this date.

The reduced light transmittance resulting from the use of various row covers corresponds to the findings of other researchers (28,30). Wells and Loy (48) state that the reduction in light transmittance should not limit the growth of young plants under row covers since the photon flux density of full sun is well above the light saturation point of crop plants. It is not known if the greatly reduced light

Table 5. Transmittance of photosynthetically active radiation (PAR) through row covers on a sunny day (June 19, 1985).

	PAR Readings[1]	
Row Cover	$uEm^{-2}s^{-1}$	% of Control[2]
Hot Tents	630[3]	39
Poly 25	1330	83
Poly 45	1395	87
Reemay	1250	78
Xiro	1440	90

[1] Each value represents mean of 6 measurements made with a LI-COR, Inc. Model 185A light meter and a LI-190S quantum sensor (400 to 700 nm).

[2] PAR measured in the open.

[3] Measured using only 15 cm length of quantum sensor and measurement converted to a 1m reading.

transmittance under the hot tents could affect plant growth, particularly if extended periods of cloudy weather occurred.

4. Fresh and dry weights

In both cultivars, the highest mean per plant fresh and dry weights were obtained in the Poly 25 treatment (Tables 6 and 7). In the Hybrid 31 cultivar, plant dry weight was significantly higher in the Poly 25 treatment than in all the other treatments (Table 6). In Brookpact, the two supported polyethylene row covers (Poly 25 and Poly 45) had significantly higher dry weights than the hot tent treatment

Table 6. Per plant fresh and dry weights (less roots) for Hybrid 31 tomato cultivar at time of row cover removal.[1]

	PER PLANT WEIGHT		
Treatment	Fresh Wt.(g)	Dry Wt.(g)	% Dry Wt.
Hot tents	203.3	25.6b[2]	12.9a
Poly 25	416.5	47.4a	11.4b
Poly 45	201.1	24.4b	12.3ab
Reemay	139.8	17.4b	12.5ab
Xiro	123.7	16.4b	13.4a

[1] Fresh weight samples were collected and weighed in the morning of July 2, 1985.

[2] Mean separation in columns by Duncan's multiple range test, 5% level.

Table 7. Per plant fresh and dry weights (less roots) for 'Brookpact tomato cultivar at time of row cover removal.[1]

	Per Plant Weight		
Treatment	Fresh Wt.(g)	Dry Wt.(g)	% Dry Wt.
Hot Tents	201.7	22.8b[2]	12.0a
Poly 25	583.1	59.8a	10.6b
Poly 45	490.8	51.1a	10.5b
Reemay	389.6	43.2ab	11.3ab
Xiro	293.5	34.8ab	12.0a

[1] Fresh weight samples were collected and weighed in the morning of July 2, 1985.

[2] Mean separation in columns by Duncan's multiple range test, 5% level.

(Table 7).

Plant growth is affected by the air and soil temperatures. Although the air temperatures recorded under the supported polyethylene row covers and hot tents were quite similar, there was a significant difference between mean soil temperatures. Mean soil temperatures under the polyethylene row covers were approximately 3°C higher than the hot tent treatment and this factor would seem to account for the increased plant growth under these covers in at least one cultivar, Brookpact. In contrast, Hybrid 31 exhibited large differences in plant growth between the two supported polyethylene row covers (Poly 25 and Poly 45). Although mean air temperature was 1.6°C higher under the Poly 25 than the Poly 45 treatment, the mean soil temperature was only 0.7°C warmer. These differences in air and soil temperatures resulted in almost twice as much growth occurring under the Poly 25 treatment in Hybrid 31.

Dry matter content of the plants in the different treatments was also determined (Tables 6 and 7). The dry matter content of plants under the Poly 25 treatment was found to be significantly lower than for the hot tent and Xiro treatments in both cultivars. In Brookpact, Poly 45 also produced significantly lower dry matter content in tomatoes than did the hot tent or Xiro treatments.

Benoit (2) reported that the relative dry matter content of lettuce plants decreased with the length of time during which the plants were covered with perforated polyethylene. Shadbolt *et al.* (37) also found significantly higher moisture contents in cantaloupes grown under polyethylene covers compared to hot tents.

Several factors have been suggested to account for the difference in relative dry matter contents. Shadbolt *et al.* (37) attributed it to high soil temperatures which caused increased root growth and physiological activity in cantaloupes and this resulted in increased uptake of water and nitrate-nitrogen in the plants. Benoit (2) found that lettuce covered with unperforated polyethylene contained a higher percentage of dry matter than those covered with perforated polyethylene. This was attributed to the reduced transpiration under the unperforated polyethylene.

Temperature and CO2 levels have also been suggested by Benoit (2) to affect the dry matter content of plants. Higher temperatures may cause dissimilation to increase while reduced CO2 levels under unperforated polyethylene may produce smaller plants with higher dry matter contents.

In this experiment, it is difficult to speculate which factors contributed to the reduced dry matter content under the polyethylene row covers since the CO2 levels and relative humidity under the row covers were not measured.

A correlation was done to determine if there was a relationship between the dry weight of tomato plants at the time of row cover removal and the early total and final total yields (Table 8). The two tomato cultivars produced

Table 8. Correlation (r) between per plant dry weight (less roots) and early total yield and final total yield.

	CULTIVAR	
	Hybrid 31	Brookpact
Fruit Yield	r	r
Early total yield	+0.71 **	+0.06 n.s.
Final total yield	+0.66 **	+0.64 **

n.s. - non significant correlation

** - significant correlation at p = 0.01

different results. In Hybrid 31, positive correlations between dry weight and the early total and final total yields were found to be highly significant.

In Brookpact, final total yields had a highly significant correlation but early total yields showed no correlation to the plant dry weight at the time of row cover removal.

5. Early maturity

Early maturity was assessed as the yield of fruit picked at the first three harvests (August 9 to August 23). None of the row covers significantly increased early yields compared to the hot tent treatment (Tables 9 and 10).

In the cultivar, Brookpact, maturity was delayed by all the row cover treatments. The hot tents produced a significantly higher total and marketable early yield than

Table 9. Effect of row covers on marketable, total and total plus strip harvest yields of Brookpact tomatoes.

	CUMULATIVE FRUIT YIELDS AT HARVEST : (kg/plant)					
	Marketable		Total		Final Total Yield	Total + Strip Harvest
Treatment	Aug.23	Sept.6	Aug.23	Sept.6	Sept.20	Sept.20
Hot Tents	0.62a[1]	2.38a	1.09a	3.10b	4.32b	8.27b
Poly 25	0.26b	2.90a	0.58b	4.64a	7.34a	12.78a
Poly 45	0.33b	3.18a	0.65b	4.48a	7.16a	13.08a
Reemay	0.26b	3.23a	0.40b	4.45a	6.61a	11.53a
Xiro	0.15b	1.18b	0.33b	1.77c	3.71b	11.92a

[1] Mean separation in columns by Duncan's multiple range test, 5% level.

Table 10. Effect of row covers on marketable, total and total plus strip harvest yields of Hybrid 31 tomatoes.

	CUMULATIVE FRUIT YIELDS AT HARVEST : (kg/plant)					
	Marketable		Total		Final Total Yield	Total + Strip Harvest
Treatment	Aug.23	Sept.6	Aug.23	Sept.6	Sept.20	Sept.20
Hot tents	0.23ab[1]	1.73c	0.45a	2.22b	4.60b	9.72bc
Poly 25	0.41a	2.59a	0.68a	3.46a	6.06a	11.37a
Poly 45	0.32a	2.45ab	0.50a	3.11a	5.16ab	10.04b
Reemay	0.11b	1.87bc	0.12b	2.20b	4.13b	8.49c
Xiro	0.02c	0.72d	0.02b	0.86c	2.49c	8.45c

[1] Mean separation in columns by Duncan's multiple range test, 5% level.

the row covers (Table 9). In Hybrid 31 (table 10), the two supported polyethylene row covers produced slightly higher total and marketable early yields than did hot tents, but the differences were not significant.

Results with the floating row cover treatments, Xiro and Reemay, varied between the two cultivars. The floating row covers produced significantly lower early total yields than did the other treatments in Hybrid 31. However, in Brookpact, no significant differences in yield were obtained between the floating row covers. The yield differences obtained between the two cultivars may be explained by their different growth habits. Hybrid 31 produces a plant with less foliage and with a longer distance between internodes. The result was that the plant support of the floating row cover was not as good as that of Brookpact. This resulted in poor plant growth and some flower abortion. Similar growth problems occurred in Brookpact but the damage was not as severe as in Hybrid 31.

The constant winds that occur in southern Alberta produced stunted plants due to the abrasion between the floating row cover and the plants. In some cases, the tomato plants wore holes through the Reemay material. However, the plants in both cultivars made a rapid recovery in the two floating row cover treatments once the covers were removed. Similar observations have been made by Taber (41) in Iowa, where winds produced growth problems.

In Brookpact, Reemay produced a significantly larger fruit size than the Poly 25 treatment for the early yield whereas no difference in fruit size was noticed in the Hybrid 31 (Table 11). The exposure of pollen to high temperature can have adverse effects on fertilization or on the processes which immediately precede or follow it (33). Since final fruit size is influenced by the number of seeds (33), row covers which produce extremely high temperatures at time of fruit set may produce smaller sized fruit.

No significant difference in percentage of culls in Brookpact was observed among the treatments (Table 12). However, in Hybrid 31, the Reemay treatment produced a significantly lower percentage of culls than the two supported polyethylene row cover and hot tent treatments. The reduced percentage of culls in the Reemay and Xiro treatments may be due merely to their delayed maturity in this cultivar.

6. Final yields

The harvest period extended from August 9 to September 20, 1985. Cumulative yields were recorded over this period (Tables 9 and 10). Cool, wet weather during the harvest period delayed maturity (Table 3). In the cultivar, Brookpact, Reemay and the two supported polyethylene row covers (Poly 25 and Poly 45) produced significantly higher final total yields than the hot tent and Xiro treatments (Table 9). For Hybrid 31 (table 10), only the Poly 25

Table 11. Effect of various row covers on fruit size.

	AVERAGE WEIGHT OF FRUIT[1] (g)			
	HYBRID 31		BROOKPACT	
Treatment	Aug.23	Sept.6	Aug.23	Sept.6
Hot Tents	83a[2]	78a	167ab	146ab
Poly 25	90a	77a	145b	140b
Poly 45	87a	79a	171ab	150ab
Reemay	87a	76a	192a	160a
Xiro	---[3]	75a	161ab	146ab

[1] Based on total number of fruit harvested up to that harvest date inclusive.

[2] Mean separation in columns by Duncan's multiple range test, 5% level.

[3] Negligible harvest.

treatment produced significantly higher final total yields than the two floating row cover and the hot tent treatments. Marketable yields were not measured on the last harvest date.

The higher final total yields appear to be due to the higher air and soil temperatures recorded under the row covers except for the Xiro treatment. It is difficult to explain the difference in yields obtained with Xiro since the air and soil temperatures measured under this treatment were similar to those obtained with the Poly 45 treatment. The explanation for the difference observed may be in the method used to measure the air temperature. Thermometers

Table 12. Effect of various row covers on percent culls.

	AVERAGE PERCENT CULLS[1] (%)			
	HYBRID 31		BROOKPACT	
Treatment	Aug.23	Sept.6	Aug.23	Sept.6
Hot Tents	49a[2]	22ab	43a	24a
Poly 25	39a	25a	55a	35a
Poly 45	36a	21ab	49a	29a
Reemay	12b	15c	36a	28a
Xiro	---[3]	16bc	54a	31a

[1] Percent culls on a weight basis.

[2] Mean separation in columns by Duncan's multiple range test, 5% level.

[3] Negligible harvest.

were placed on wooden stakes and the temperature was measured at a height of 20 cm above the soil. The wooden stakes held up the Xiro at this point and created more openings of the small perforations in this material than were present over the tomato plants.

Mansour *et al.* (29) observed excessive heat buildup with Xiro in their research on floating row covers. The lower final total yields with the Xiro treatment observed in this experiment may therefore have been due to excessively high air temperatures. The excessive temperatures appeared to delay maturity only since total production (final total yield plus strip harvest) equalled the production of some other row covers (Tables 9 and 10).

The lower yields obtained in the hot tent treatment appear to be due to the lower soil temperatures especially for the cultivar, Brookpact, since similar air temperatures to the supported polyethylene row covers were recorded. An approximate 3°C increase in mean soil temperature resulted from the use of supported polyethylene row covers in comparison to hot tents.

Cumulative marketable yields were recorded to September 6, 1985. In Brookpact, marketable yields were significantly lower in the Xiro treatment (Table 9) compared to all the other treatments. With Hybrid 31 (table 10), the Poly 25 and Poly 45 treatments produced significantly higher marketable yields than in the hot tent and Xiro treatments. The Xiro treatment again produced significantly lower yields than in all the other treatments.

No significant difference in percentage of culls in Brookpact was observed. However, in Hybrid 31, Reemay produced a significantly lower percentage of culls than the two supported polyethylene row cover and hot tent treatments (Table 12).

Fruit size was not affected by row cover treatment in Hybrid 31 but in Brookpact, Reemay produced a significantly larger fruit size than the Poly 25 treatment (Table 11).

A strip harvest was done on the final harvest date. Final total yields including the strip harvest showed dramatic differences between cultivars(Tables 9 and 10). In

Brookpact, total production was significantly lower in the hot tent treatment compared to all other treatments. For Hybrid 31, the Poly 25 treatment produced significantly higher total production than all the other treatments. Total production in the two supported polyethylene treatments was significantly higher than the two floating row cover treatments, Xiro and Reemay.

The difference in total production between the two cultivars under the floating row covers is possibly due to their different growth habits which were discussed earlier. The two floating row covers had more of a detrimental effect on Hybrid 31.

7. Time of row cover removal

The highest marketable and total yields for both cultivars were obtained from the earliest cover removal date (June 24, 1985) (Table 13). The yields shown in Table 13 are the cumulative yields to September 20, 1985 which was the last harvest date. Yields decreased 300-350% from the first removal date to the last removal date. These results seem to indicate that the time of row cover removal is an important factor to consider with the polyethylene row cover treatment. This may be due to the high temperatures occurring under this row cover treatment later in the season which would limit the fruit set (33,39).

Since this experiment was not replicated, it is difficult to draw any firm conclusions. However, it would

Table 13. Effect of time of row cover removal on fruit yields of tomatoes.[1]

	FRUIT YIELDS[3] (kg/plant)			
Date of	HYBRID 31		BROOKPACT	
Cover Removal[2]	Marketable	Total	Marketable	Total
June 24	6.28	7.49	6.61	9.05
July 1	4.25	5.36	4.38	6.31
July 8	2.73	3.33	3.81	5.45
July 15	1.65	2.01	2.26	3.49
July 22	1.90	2.13	1.76	3.05

[1] Preliminary expermiment--no replication of experiment was done.

[2] Polyethylene row cover with 25 holes/m² was used in all cases.

[3] Fruit yields are cumulative to Sept. 20, 1985.

appear that more research with earlier removal dates is required.

Time of cover removal for Reemay may not be as critical since excessively high temperatures are not as common with this material.

V. Conclusions

Supported polyethylene row covers produced higher total yields in both tomato cultivars. Yields were increased more in Brookpact than in Hybrid 31. Final total yields in Brookpact were increased 66-70% above the control (hot tents) while in Hybrid 31, final total yields were increased 12-32% by the supported polyethylene row covers (Poly 25 and Poly 45). Air and soil temperatures appear to be the major factors influencing yields. The highest yields were obtained in the Poly 25 treatment which produced the highest mean air and soil temperatures.

Plant responses to row or plant covers vary with the plant's ability to respond to the modified climatic conditions. Brookpact responded more favorably than Hybrid 31. This may be due to the fact that Hybrid 31 is a hybrid and therefore tended to be less tolerant to environmental extremes produced under the covers. Hybrids have a more uniform genetic compostion and are therefore not as adaptable to different environmental conditions as open-pollinated cultivars.

The two floating row covers, Xiro and Reemay, decreased final total yields compared to the control in Hybrid 31. In Brookpact, Reemay increased final total yields 53% above the control, whereas, Xiro decreased yields 14%. Generally, the two floating row covers did not perform well under conditions found in southern Alberta. Wind generated abrasion of the plants by the floating row covers and tended to stunt plant growth and cause some flower abortion. However, in one cultivar, Brookpact, the Reemay did increase the final total yields. Increased yields in the Reemay treatment were possibly due to the growth habit of Brookpact. Presently, the high cost of Reemay does not seem to justify its use. It has been argued that Reemay is reuseable but from observations in this experiment, it proved to be very difficult to remove the material without some damage occurring.

Although final total yields were increased significantly with the supported polyethylene row covers, in Brookpact, maturity was delayed. Early marketable yields in the hot tent treatment were approximately double the other row cover treatments.

In Hybrid 31, the hot tent treatment produced lower total early yields than the two supported polyethylene row covers but the differences were not significant. Early marketable yields were 40-80% higher in the supported polyethylene treatments than in the hot-tent treatment.

There was no significant difference in yields between the two supported polyethylene row covers. But, final total yields were higher in the Poly 25 treatment especially with the Hybrid 31. The highest maximum air temperatures and mean soil temperatures were recorded under this treatment.

Although some of the row covers did increase yields above the control, none of them offered similar frost protection to the hot tents. Air temperatures were found to be lower than the ambient air temperature under all of the row covers. Therefore, row covers do not allow the producer to plant any earlier than normal.

More research is required on the use of different types of polyethylene materials which do offer some frost protection. These materials do not lose soil and air heat as rapidly as the low density polyethylene material used in this experiment. Materials such as infra-red polyethylene, polyvinyl chloride (PVC) and ethylene-vinyl acetate (EVA) can reduce heat losses during the night. Materials which offer some frost protection are very important for the type of climate that is experienced in southern Alberta.

Another important aspect of row cover use that will require more research is the time of row cover removal. From the preliminary research carried out in this experiment, the time of row cover removal has an important effect on yields produced. Marketable and total yields for both cultivars were reduced with increasing lengths of row cover use.

It appears that previous research carried out at Brooks, Alberta (17) which indicated polyethylene row covers did not increase yields above that of hot tents may have been due to the time of row cover removal. It was reported that the plants produced excessive vegetative growth under the row covers. Similar observations were made in this experiment with row cover treatments that were removed at later dates. Findings in this experiment appear to indicate that if the polyethylene row covers are removed at the proper time final yields may be increased more than with hot tents.

VI. Literature Cited

1. Alberta Hort. Advisory Comm.,1984. Alberta vegetable production guide. Alberta Agriculture.

2. Benoit, F. 1975. Effects of flat plastic film covering and tunnel protection on the development of early lettuce. Scientia Hort. 3: 405-415.

3. Black, A.L. and B.W. Greb. 1962. Nitrate accumulation in soils covered with plastic mulch. Agron. J. 54: 366.

4. Bowman, G.E. 1963. A comparison of greenhouses covered with film and with glass. Proc. XVI Int. Hort. Congr., Brussels, p. 551.

5. Brun, R. 1968. Utilisation des films plastiques souples perfores dans le sud-est de la France. Acta Hort. 9: 203-209.

6. Campbell, J.D. 1972. Growing vegetables in plastic tunnels. Proc. 28th Western Can. Soc. for Hort.,Saskatoon,Sask. ,p.72-74.

7. Clarkson, V.A. 1960. Effect of black polyethylene mulch on soil and microclimate temperatures and nitrate level. Agron. J. 52: 307-309.

8. De Vries, H.C. P. 1968. The influence of mulching on temperature and heat flux in the soil and temperature just above the ground in connection with night frost protection. Acta Hort. 9; 163-164.

9. Dubois, P. 1978. Plastics in agriculture. Applied Sci. Pub. London.

10. Emmert, E.M. 1955. Results of research in 1955. 68th Annual Rpt. Kentucky Agr. Expt. Sta.

11. Fructos, D. 1974. Aeration des tunnels plastiques de semi-forcage. Effet de l'emplacement des perforations. Acta. Hort. 42: 273-289.

12. Hall, B. J. 1965. Tomato and cucumber plastic tube shape and construction. Proc. Natl. Agr. Plast. Cong. 6: 113-123.

13. Hall, B.J. 1967. Polyethylene mulches on tomato and cucumber row covers. Proc. Natl. Agr. Plast. Cong. 7: 56-63.

14. Hall, B.J. and S.T. Besemer. 1972. Agricultural plastics in California. HortScience 7: 373-378.

15. Hanson, K.J. 1963. The radiative effectiveness of plastic films for greenhouses. J. Appl. Meteorol. 2: 793-797.

16. Harris, R.E. 1965. Polyethylene covers and mulches for corn and bean production in northern regions. Proc. Amer. Soc. Hort. Sci. 87: 288-294.

17. Hausher, L. 1979. Plastic mulch trials in Alberta. Proc. 35th Western Can. Soc. Hort. ,Lethbridge, Alta., p.140-148.

18. Hausher, L. 1980. Tunnel and plastic mulch trials of vine crops. Proc. 36th Western Can. Soc. Hort., Winnipeg,Man., p.81-88.

19. Hemphill, Jr., D.D. and N. S. Mansour. 1984. Response of muskmelons to three floating row covers. Oregon State Univ. Agric. Exp. Stn. Tech. Paper.

20. Henriksen, K. 1981. Influence of temporary covering with plastic on timing, yield and quality of Iceberg lettuce. Acta Hort. 122: 61-75.

21. Hill, D.E., L. Hankin, and G.R. Stephens. 1982. Mulches: their effect on fruit set, timing and yields of vegetables. Conn. Agr. Exp. Sta. Bull. 805, 15 pp.

22. Hopen, H.J. 1965. Effects of black and transparent polyethylene mulches on soil temperature, sweet corn growth and maturity in a cool growing season. Proc. Amer. Soc. Hort. Sci. 86: 415-420.

23. Jensen, M. and R. Sheldrake. 1965. Concluding results of air supported row covers for early vegetable production. Proc. Natl. Agrl. Plast. Cong. 6: 100-112.

24. Jones, T. L., U.S. Jones and D. O. Ezell. 1977. Effect of nitrogen and plastic mulch on properties of Troup loamy sand and yield of "Walter" tomatoes. J. Amer. Soc. Hort. Sci. 102(3): 273-275.

25. Knavel, D.E. and H.C. Mohr. 1967. Distribution of roots of four different vegetables under paper and polyethylene mulches. Amer. Soc. Hort. Sci. 91: 589-597.

26. Loy, J.B. and B. Bushnell. 1984. Comparison of polyethylene and spunbonded fabric row covers over muskmelon and summer squash. Proc. Natl. Agr. Plast. Cong. 18: 171 - 180.

27. Loy, J.B. and O.S. Wells. 1975. Response of hybrid muskmelons to polyethylene row covers and black polyethylene mulch. Scientia Hort. 3: 223-230.

28. Loy, J.B. and O.S. Wells. 1982. A comparison of slitted polyethylene and spunbonded polyester for plant row covers. HortScience 17(3): 405-407.

29. Mansour, N.S., D.D. Hemphill, Jr., and C. Riggert. 1984. An evaluation of floating row covers in the production of cool and warm season vegetable crops. Proc. Western Wash. Hort. Assoc. p. 19-26.

30. Maurer, A.R., B.M. Frey, and M.M. Gaye. 1985. Response of zucchinis and bell peppers to mini tunnels and floating mulches. Proc. Can. Soc. Hort. Sci., Charlottetown, P.E.I.

31. Maurer, A.R. and B.M. Frey. 1986. Modification to microclimate resulting from row cover application to some vegetable crops. Proc. Can. Soc. Hort. Sci., Saskatoon, Sask.

32. Nisen, A., J. Nijskens, J. Deltour, and S. Coutisse. 1984. Determination des proprietes radiometriques des materiaux plastiques utilises en couverture des serres. Acta. Hort. 154: 19-32.

33. Picken, A. J.F. 1984. A review of pollination and fruit set in the tomato (*Lycopersicon esculentum* Mill.). J. of

Hort. Sci. 59(1): 1-13.

34. Rylski, I. 1965. Vegetative development, flower formation and fruit setting in cucumbers cultivated in plastic tunnels with different perforation. Acta. Hort. 4: 70-75.

35. Savage, M.J. 1980. Plastic tunnels: a study of air temperatures. Agrochemophysica 12: 5-13.

36. Schales, F.D. and R. Sheldrake. 1966. Mulch effects on soil conditions and muskmelon response. Proc. Amer. Soc. Hort. Sci. 88: 425-430.

37. Shadbolt, C.A. and O.D. McCoy. 1960. Temperature and plant responses to paper and plastic protectors on cantaloupes. Hilgardia 30: 247-266.

38. Shadbolt, C.A., O.D. McCoy, and F.C. Whiting. 1962. The microclimate of plastic shelters used for vegetable production. Hilgardia 32: 251-266.

39. Shelby, R.A., W.H. Greenleaf, and C.M. Petersen. 1978. Comparative floral fertility in heat tolerant and heat sensitive tomatoes. J. Amer. Soc. Hort. Sci. 103(6): 778-780.

40. Sheldrake, R. J. 1963. Carbon dioxide levels in the micro-climate as influenced by the permeability of mulches. Proc. Natl. Agr. Plast. Conf. 4: 93-96.

41. Taber, H.G. 1983. Effect of plastic soil and plant covers on Iowa tomato and muskmelon production. Proc. Natl. Agr. Plast. Conf. 17: 37-45.

42. Tan, C.S., A.P. Papadopoulous, and A. Liptay. 1984. Effect of various types of plastic films on the soil and air temperatures in 80-cm high tunnels. Scientia Hort. 23: 105-112.

43. Tesi, R., A. Graifenberg, and M. Notartommaso. 1973. The influence of P.V.C. tunnels and ventilation on strawberry culture. Acta, Hort. 27: 240-248.

44. Waggoner, P.E. 1958. Protecting plants from the cold. The principles and benefits of plastic shelters. Conn. Agric. Expt. Sta. Bul. 614.

45. Waggoner, P.E., P.M. Miller and H.C. De Roo. 1960. Plastic mulching-principles and benefits. Conn. Agric. Expt. Sta. Bul. 634.

46. Wells, O.S. 1984. Evaluation of spunbonded polyester (Reemay) as a row cover for the production of

horticultural crops. Univ. of New Hampshire, Dept. of Plant Sci. Research Report.

47. Wells, O.S. and J.B. Loy. 1981. Slitted plastic row covers for vegetable production. Proc. Natl. Agr. Plast. Cong. 16: 124-128.

48. Wells, O.S. and J.B. Loy. 1985. Intensive vegetable production with row covers. HortScience 20(5): 822-826.

49. Wiebe, J. 1973. Tunnel covers and mulches for muskmelon production. Can. J. Plant Sci. 53: 157-160.