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TARC Report

Effects of Row Cover on the Growth of Leafy Vegetables in Summer in the Subtropical Zone of Japan

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Abstract
The environmental conditions under row covers are characterized by the attenuation of strong radiation, the alleviation of the increase of the soil temperature and the maintenance of the soil moisture and atmospheric humidity in comparison with the conditions prevailing in open fields. The wind-breaking effect and the effect on the preservation of the soil and air moisture were more conspicuous under direct cover as compared with floating cover. However, the increase of the soil and air temperature was significantly suppressed and the damage caused by pests was less pronounced with the floating cover. Germination and early growth of Pak-choi were promoted by covering. Plant height and leaf area of Pak-choi increased, while the dry matter decreased under the covers, resulting in a more etiolated plant growth. The quality of the products was satisfactory. The optimum environmental conditions for the growth of Pak-choi were as follows: air temperature, 25°C; soil temperature, 25°C; soil moisture, pF 1.25-1.75; wind velocity, 0.4-1.4 m/s and higher relative humidity (80%). Row cover appears to be suitable for use in the tropics as well as in the subtropics.

Discipline: Crop production/Agricultural environment
Additional key words: cheese-cloth, direct cover, floating cover, Pak-choi, wind-break net

Introduction

Climatic conditions, characterized by strong solar radiation, high temperature, drought, frequent occurrence of typhoons as well as outbreaks of pests and diseases represent a major constraint on vegetable production in summer in the subtropical zone of Japan.

In the Okinawa Prefecture in Japan, which is located in the subtropical Pacific region, there is a shortage of vegetable products in summer and the shipment of costly vegetables from mainland Japan is a serious economic problem.

Under such conditions, the use of row covers colloquially known as "Betagake", was promoted by local farmers to increase the self-sufficiency rate of vegetable products.

Initially cheese-cloth was used as row cover immediately after its release in the agricultural market as a material for the protection from pests and typhoon attacks. At present wind-break nets and several types of petrochemical fabrics are commonly used. They were laid as floating covers at first, but later as direct covers, and nowadays various types are being used, as shown in Fig. 1.

The practice has been disseminated throughout Japan recently along with the release of light and

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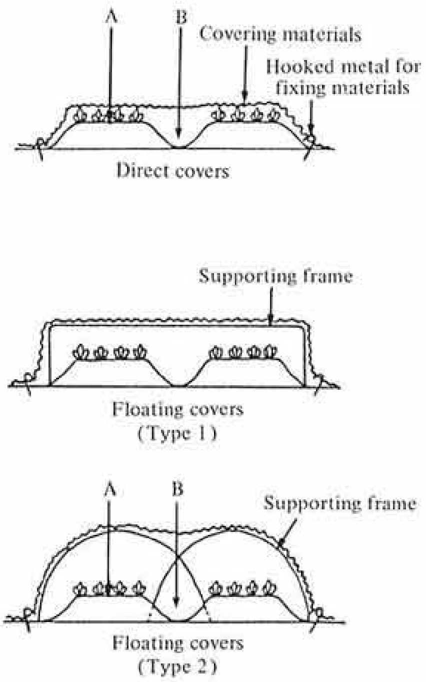

Fig. 1. Types of row covers for leafy vegetable cultivation in Okinawa, and measuring spots for environments under direct covers and floating covers
A: Soil temperature (at 1, 10 cm depth), soil moisture (at 10 cm depth).
B: Light transmission, air temperature and relative humidity (at 10 cm height above soil surface).

cheap materials. The area under row covers is estimated at between 4,000 and 5,000 ha at present in Japan. Row covering has been reported to be a common practice in the United States of America through the development of unwoven fabrics for the past years[8,9,13,14], and this practice has also been introduced into Europe.

The purpose of row covers in the temperate regions differs from that in the subtropical regions. In the temperate regions, row covers are used for protection from cold[5], frost[5], hail[7], wind[5,6], bird[6] and insect attacks[6,12], suppression of transpiration[7] and promotion of germination[3], growth and yield[2,10]. On the other hand, their main purpose in the subtropics is to protect the crops from typhoons, pests, and for the attenuation of strong solar radiation and drought.

Since row covering is a relatively new technique, most of the studies conducted so far have been restricted to the increase of yield in the temperate regions and little progress has been made to analyze their effects in the subtropical environment.

Therefore, several experiments were carried out in the field of Okinawa Branch, Tropical Agriculture Research Center, Ishigaki Island, Okinawa Prefecture, to investigate the growth response of leafy vegetables under row covers in relation to the environmental conditions.

The present contribution deals with (1) the determination of several meteorological parameters under row covers, (2) growth of leafy vegetables under row covers, (3) determination of optimum environmental conditions for the growth of leafy vegetables.

Materials and methods

1) Determination of meteorological parameters under row covers

The experimental plot 11.2 m^2 in area was covered with cheese-cloth (white, 1.4 mm mesh, 75 g/m^2 weight, vinyl fabric) or a wind-break net (blue, 2 mm mesh, 110 g/m^2 weight, polyethylene product) as either direct cover or floating cover (with supporting frame) as shown in Fig. 1.

Meteorological parameters, i.e. air temperature (ventilated thermocouple), relative humidity (ventilated thermocouple), soil temperature (thermocouple, 0.3 mm), solar radiation (radiometer), soil moisture (tensiometer), wind velocity (hot-wire anemometer) and amount of evaporation (water loss from a dish 14.6 cm in diameter filled with 200 ml water) were determined for the experimental plots and the control in open field.

The experiments were carried out in the summer of 1987 and 1988.

2) Growth of leafy vegetables under row covers

Pak-choi cultivar (*Brassica campestris* L.) was used for the experiments. Seeds were sown on beds (1.4 m in width and 4 m in length) and the beds were covered with cheese-cloth or a wind-break net as direct covers and floating covers (50 cm in height) as indicated in Fig. 1. Compound fertilizer (N 1.5 kg/a, P_2O_5 1.9 kg/a and K_2O 1.7 kg/a) was applied and irrigation (5 mm/day) was carried out except for cloudy and rainy days throughout the experimental period.

Germination rate (emergence of cotyledon), plant height, leaf area and dry matter increase (10-day intervals after sowing) and yield (24 and 29 days after sowing in 1986 and 1987, respectively) were determined.

3) Determination of optimum environmental conditions for the growth of leafy vegetables

The effects of environmental factors (light, air temperature, soil temperature, soil moisture, wind velocity and humidity) on the growth response of Pak-choi were investigated under different levels of variables as described below.

(1) Light

Four levels of shading intensity (0, 25, 30 and 47%) were selected. Shading intensities were regulated by the use and combination of samples of white cheese-cloth (25 and 33% shading intensity).

(2) Air temperature

Five levels of constant temperature (20, 25, 30, 35 and 40°C) and three levels of alternate temperature (30–20, 27.5–22.5, 22.5–27.5°C), in the daytime (8:00–18:00) and at night (18:00–8:00) were selected. The air temperature was regulated by the use of an attemperator within the different chambers.

(3) Soil temperature

Five levels of soil temperature (25, 30, 35, 40 and 45°C) were selected. Soil temperatures were regulated by immersing pots in the temperature-controlled waterbath with foamed polystyrene covers to remove the effect of air temperature.

(4) Soil moisture

Six levels of soil moisture tension (pF 1.25, 1.5, 1.75, 2.0, 2.25 and 2.5) were selected. The soil moisture was regulated by irrigation when the pF value of the tensiometer (buried at 10 cm depth underground) exceeded the pre-determined levels.

(5) Wind velocity

Six levels of wind velocity (0.1, 0.4, 0.8, 1.4, 2.5 and 4.0 m/s) were selected. Wind velocity was regulated by the distance from an electric fan.

(6) Relative humidity

Moderate humidity level (60%) and high humidity level (80%) were selected. The humidity level was regulated by using silica gel or drizzling the air inside the chamber.

Pak-choi plants at the fourth leaf stage were used for the experiment after sowing and thinning them into three plants per pot (1/5000 a Wagner pot). The experiment lasted for 10 days. At the end of the treatments, measurements of transpiration rate, plant height, leaf area, and dry matter weight were carried out. Growth analysis (RGR, NAR, LAR) was performed based on the measurements of dry matter and leaf area increase at 10-day intervals after treatment. The transpiration rate was measured by using a steady state porometer at the level of the third leaf.

Results

1) Measurements of environmental variables under row covers

The light transmission under the covers decreased to 65–70% of the incident light (Table 1). By exposure, the light transmission of the covering materials decreased by 2–3% at the end of the experiments.

Table 1. Light transmission percentage and amount of evaporation under covers

Treatment		Light transmission percentage[a)] (%)	Amount of evaporation[b)] (mm)
Covering materials	Covering methods		
Without cover	Control	100	6.11 (100)[c)]
Cheese-cloth	Direct cover	69.1 ± 3.2	3.41 (56)
	Floating cover	67.3 ± 4.5	-
Wind-break net	Direct cover	59.5 ± 2.4	3.54 (58)
	Floating cover	59.2 ± 2.2	-

a): Measured at every hour between 10:00 and 16:00 on July 4, 1987.
b): Measured from 9:00 on July 7 until 9:00 July 8, 1987.
c): Numerals in parentheses indicate the percentage against control (without cover).

The air temperature under the covers was 1–3°C higher than the open field temperature in the daytime, while little difference was observed at night (Fig. 2). It was also noticed that the increase of the temperature in the daytime under covers became attenuated when it was windy and the ventilation was enhanced.

The soil temperature under the covers decreased by 3–6°C at 1 cm depth and 1–3°C at 10 cm depth, respectively from the open field temperature (Fig. 3). The attenuation of the increase of the soil temperature by the covers was less evident at the later stage

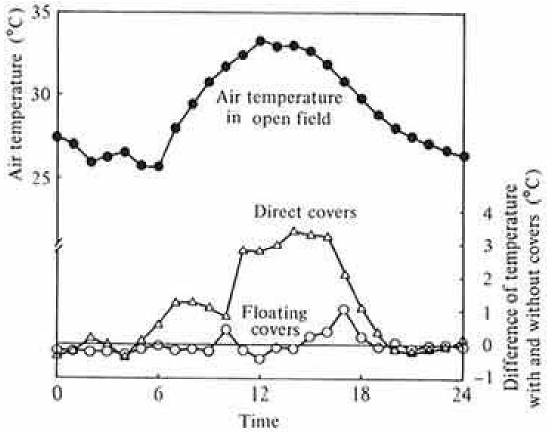

Fig. 2. Diurnal fluctuation of air temperature in open field and difference of temperature with and without row covers during 24 hr period, fine day

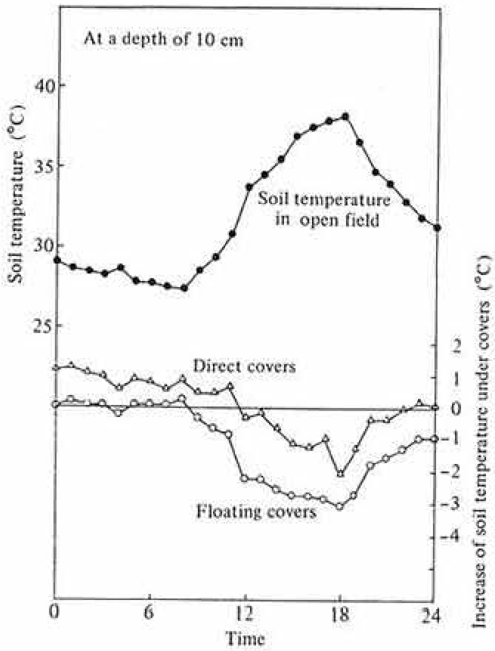

Fig. 3. Diurnal fluctuation of soil temperature in open field and increase of soil temperature under covers during 24 hr period, fine day

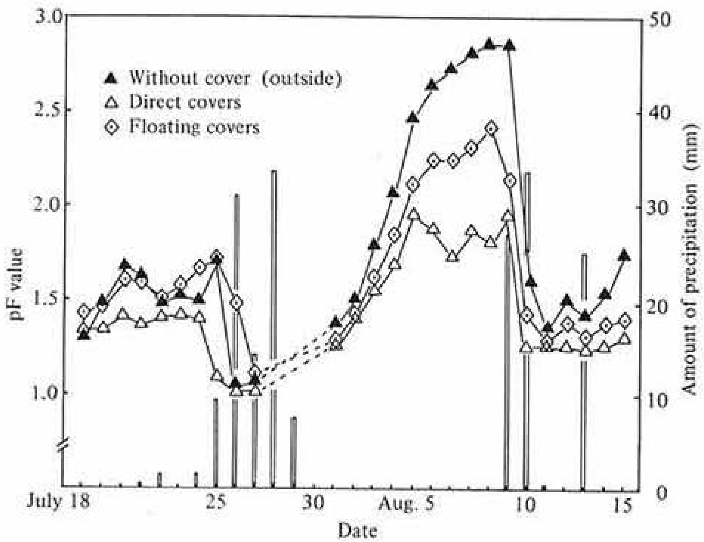

Fig. 4. Fluctuation of soil moisture (pF value) with and without covers
Measured at 9:00 every day.
Data from July 28 to July 30 are lacking.

of growth due to the expansion of the plant canopy.

The soil moisture was retained over a longer period of time (low pF values) under the covers. Although the pF value increased subsequently by rainfall, the increase was less conspicuous under the covers (Fig. 4). The evaporation under the covers was also suppressed to 56–58% of the values of the uncovered plot (Table 1).

Wind velocity under the covers decreased to as much as one fifth of the open field value. The rate of reduction depended on the kinds of materials, especially their mesh-size (Fig. 5).

The relative humidity under the covers was always higher than that in open field, regardless of the time of the day. The difference in the relative humidity was as large as 10% in the daytime (Fig. 6).

As for the covering methods, floating covers provided more favorable ventilation conditions than direct covers. The measurements of the wind velocity, air temperature, soil moisture and relative humidity under floating covers showed intermediate values between those for direct covers and open field, although the light transmission did not differ between the covering methods. However, the soil temperature under floating covers was lower than that under direct covers in the daytime.

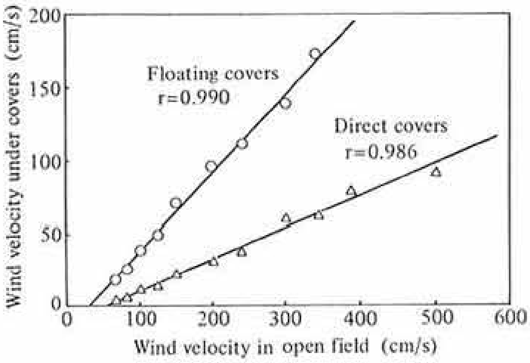

Fig. 5. Decrease of wind velocity under different row covers

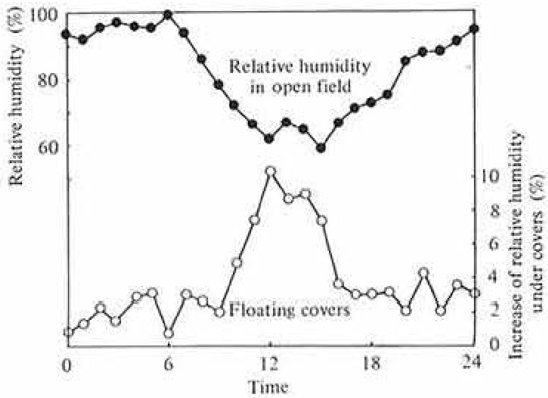

Fig. 6. Diurnal fluctuation of relative humidity in open field and increase under floating covers during 24 hr period, fine day

Table 2. Effect of row covers on germination, growth and yield of Pak-choi

Treatment		Frequency of	Germination percentage[a]		Plant height[b]		Fresh weight[b]		Dry matter	Yield[c]	Damage by pests[d]
Covering materials	Covering methods	insecticide spraying	3 (%)	6 (%)	10 (cm)	30 (cm)	10 (g)	30 (g)	(%)	(kg/m²)	
None		0	42.6	58.9	2.5	19.4	0.29	21.1	7.5	2.50	+++
		5	-	-	2.6	25.3	0.28	44.6	6.2	5.20	+
Cheese-cloth	Direct cover	1	77.2	89.8	4.1	27.1	0.46	43.8	5.1	4.22	+
	Floating cover	1	66.0	77.2	4.5	27.9	0.74	59.7	4.7	5.73	-
Wind-break net	Direct cover	1	-	-	3.7	21.6	0.32	22.0	5.9	3.10	++
	Floating cover	1	-	-	4.4	24.2	0.54	32.9	5.2	4.73	+
LSD (0.05)			-	-	0.5	1.6	0.07	5.2	-	0.66	

a): Measured 3 and 6 days after sowing.
b): Measured 10 and 30 days after sowing.
c): Measured 24 days after sowing and harvested 24 days after sowing.
d): Classified as -; none, +; slight, ++; moderate, +++; severe.
Seeds were sown on July 1, 1986.

As for the materials, ventilation was better when materials with a larger mesh-size (2 mm, wind-break net) than with a smaller one (1.4 mm, cheese-cloth) were used.

2) Growth of leafy vegetables under row covers

The results of the experiments carried out in 1986 and 1987 were similar. The germination percentage of Pak-choi under covers was higher than that without covers. The growth parameters, i.e. plant height, leaf area and fresh weight also showed higher values at the early stage under covers. However, the fresh weight of Pak-choi under covers was inferior to that of the plants grown without covers at the growth stage of 20 days after sowing due to the etiolated growth associated with dense population (Table 2).

The yield was the lowest in the control treatment (no spraying and without covers). The yield under floating covers was almost equivalent or slightly superior to the treatment with frequent spraying without covers. However, the yield under direct covers was lower because the later growth of Pak-choi was remarkably inhibited.

The damage by pests (holes on leaves caused by larvae) which was significantly reduced by the covers was comparable to the treatment consisting of five sprays without covers (Table 2). The main pests observed were the diamondback moth (*Plutella xylostella* Linne), cabbage webworm (*Oebia undalis* Fabricius) and striped flea beetle (*Phyllotreta striolata* Fabricius). However, they were unable to migrate inside the covers except for the striped flea beetle. For the pest prevention, the use of cheese-cloth was more effective than that of wind-break net and the use of floating covers was more efficient than that of direct covers.

3) Determination of optimum environmental conditions for the growth of leafy vegetables

(1) Light

Relative growth rate (RGR) and net assimilation ratio (NAR) of Pak-choi decreased as the shading intensity increased from 0 to 47% (Table 3). Shading affected the growth of the roots significantly and increased the leaf area rate (LAR), reflecting the reduction of leaf thickness under the shade.

(2) Air temperature

Higher air temperature inhibited the growth. Pak-choi showed wilting in the second day, and died 5 days after the treatment at the temperature of 40°C. Moderate wilting was observed even during the treatment at the temperature of 35°C, while growth was normal at temperatures below 30°C.

The transpiration rate increased with the increase of the air temperature (Table 4).

In the constant temperature treatments, plant height, leaf area, RGR and NAR showed the highest values at the temperature of 25°C and they exhibited a decreasing trend below and above 25°C.

In the temperature treatments with day and night alternation (average temperature at 25°C), the values for plant height, leaf area, RGR and NAR were maximum for the treatment of 27.5–22.5°C. A difference of temperature around 5°C was found to be favorable for the growth of Pak-choi.

(3) Soil temperature

At the soil temperature of 45°C, Pak-choi showed wilting on the day when the treatment started, and the lower leaves began to dry up on the third day. The plants eventually died on the fifth day.

Wilting was also observed on the third day when

Table 3. Effect of shading on the growth of Pak-choi

Shading intensity (%)	RGR[a]				NAR[a]	LAR[a]	Dry matter (%)
	Leaf	Petiole	Root	Total			
0	100	100	100	100	100	100	9.1
25	97	94	82	93	82	114	7.9
33	96	92	68	90	76	119	7.6
47	80	81	56	79	56	140	6.4

a): RGR, NAR and LAR were calculated from the measurements of dry matter and leaf area 20 and 30 days after sowing, each.
Data show the index number against control (0% shading intensity).
Seeds were sown on July 18, 1988.

the soil temperature was 40°C, while normal growth was obtained at a soil temperature below 35°C.

The transpiration rate decreased as the soil temperature increased (Table 5).

The values for plant height, leaf area, RGR, NAR and dry matter were maximum at the soil temperature of 25°C and they decreased when the soil temperature exceeded 25°C.

(4) Soil moisture

Plant height and leaf area showed the highest values for a soil moisture of pF 1.25–1.75. The values for the dry matter, RGR and NAR were maximum when the soil moisture reached a pF of 1.5 (Table 6). The transpiration rate was also the highest at pF 1.25–2.0 and the values decreased significantly as the soil moisture decreased.

(5) Wind velocity

The transpiration rate was higher when the values of the wind velocity ranged from 0.4 to 1.4 m/s (Table 7). Maximum values of RGR, NAR and leaf area were also obtained in this range. The increase of the wind velocity above 1.4 m/s resulted in the

Table 4. Effect of constant and alternate air temperature on transpiration rate and growth of Pak-choi

Air temperature (°C)	Trans. rate ($\mu g/cm^2/s$)	Plant height a) (cm)	Leaf area a) (cm^2)	RGR b)	NAR b)	Dry matter (%)
Constant						
20	9.0	17.0	230	87	88	5.8
25	10.1	17.2	300	100	100	5.6
30	13.5	14.5	210	87	93	6.6
35	14.9	12.0	114	70	91	8.7
40	-	8.9	46	5	5	-
LSD (0.05)	3.5	1.4	31	-	-	-
Alternate						
30–20	-	18.1	217	119	130	5.6
27.5–22.5	-	18.4	237	121	125	5.3
25	-	16.8	203	100	100	5.8
22.5–27.5	-	15.8	232	115	125	6.9
LSD (0.05)	-	1.4	NS	-	-	-

a): Measured 10 days after initiation of treatments.
b): Index number against 25°C in constant temperature and 25–25°C in alternate temperature treatments.
Treatments were carried out for 10 days using Pak-choi at the 4th leaf stage.

Table 5. Effect of soil temperature on transpiration rate and growth of Pak-choi

Soil temperature (°C)	Trans. rate ($g/dm^2/hr$)	Plant height a) (cm)	Leaf area a) (cm^2)	RGR b)	NAR b)	Dry matter (%)
25	8.7	16.6	193	100	100	5.5
30	9.2	14.9	140	89	94	6.0
35	8.7	13.1	116	85	98	7.2
40	5.9	10.5	59	51	59	8.3
45	-	6.3	-	9	11	-
LSD (0.05)	0.5	1.6	41	-	-	-

a): Measured 10 days after initiation of treatments.
b): Index number against 25°C.
Treatments were carried out for 10 days using Pak-choi at the 4th leaf stage.

decrease of the growth of Pak-choi.

(6) Relative humidity

The transpiration rate was higher at a high humidity than at a moderate humidity and this trend was more obvious in the chamber at 30°C than at 25°C (Table 8). The high humidity level resulted in higher values of plant height, leaf area, RGR and NAR. However, the dry matter percentage was lower at a high humidity level than at a moderate one.

Table 6. Effect of soil moisture on transpiration rate and growth of Pak-choi

Soil moisture (pF)	Trans. rate ($g/dm^2/hr$)	Plant height[a] (cm)	Leaf area[a] (cm^2)	RGR[b]	NAR[b]	Dry matter (%)
1.25	9.1	17.9	185	92	85	4.7
1.5	8.5	17.8	190	100	100	5.1
1.75	8.4	17.0	177	94	92	5.4
2.0	8.6	15.6	137	86	89	5.5
2.25	7.9	13.9	110	77	82	6.0
2.5	4.2	11.5	84	65	71	7.0
LSD (0.05)	0.6	1.8	27	-	-	-

a): Measured 10 days after initiation of treatments.
b): Index number against pF = 1.5.
Treatments were carried out for 10 days using Pak-choi at the 4th leaf stage.

Table 7. Effect of wind velocity on transpiration rate and growth of Pak-choi

Wind velocity (m/s)	Trans. rate ($\mu g/cm^2/s$)	Plant height[a] (cm)	Leaf area[a] (cm^2)	RGR[b]	NAR[b]	Dry matter (%)
0.1	8.7	16.1	256	100	100	6.2
0.4	13.7	15.8	270	105	111	6.4
0.8	14.0	16.1	276	108	116	7.3
1.4	17.3	14.5	242	108	123	7.8
2.5	11.3	13.8	201	97	111	7.9
4.0	9.3	13.8	206	95	109	7.9
LSD (0.05)	2.6	0.6	37	-	-	-

a): Measured 10 days after initiation of treatments.
b): Index number against wind velocity of 0.1 m/s.
Treatments were carried out for 10 days using Pak-choi at the 4th leaf stage.

Table 8. Effect of relative humidity on transpiration rate and growth of Pak-choi

Relative humidity	Variation of actual measurements (%)	Trans. rate		Plant height[a] (cm)	Leaf area[a] (cm^2)	RGR[b]	NAR[b]	Dry matter (%)
		25°C ($\mu g/cm^2/s$)	30°C ($\mu g/cm^2/s$)					
Moderate	61.1±6.8	6.5	3.8	16.1	249	100	100	6.0
High	79.0±7.0	9.7	10.5	18.0	296	113	114	5.7
LSD (0.05)	-	NS	5.6	NS	NS	-	-	-

a): Measured 10 days after initiation of treatments.
b): Index number against moderate humidity.
Treatments were carried out for 10 days using Pak-choi at the 4th leaf stage.

Discussion

1) Row covers in the subtropics

The use of row covers has been recognized to be an effective measure for the stabilization of vegetable production in Okinawa, which is located in the subtropical region of Japan, and this practice has been disseminated rapidly throughout the country recently. However, little progress has been made in the study of its effects on the modification of the growing environment.

The environmental conditions under row covers are characterized by the attenuation of strong radiation, the alleviation of the increase of the soil temperature, and the preservation of the soil moisture and atmospheric humidity in comparison with the conditions prevailing in open fields. These effects are considered to contribute to the stabilization of leafy vegetable production in summer in the subtropics.

As for the covering methods, the wind-breaking effect and the effect on the preservation of the soil and air moisture were more conspicuous under direct cover. However, the increase of the soil and air temperatures was significantly suppressed and the damage caused by pests was less pronounced under floating covers. Therefore, the use of floating covers was considered to be more suitable for creating optimum environmental conditions for the cultivation of leafy vegetables.

As for the materials, the use of cheese-cloth was more effective for the alleviation of the increase of the air temperature than that of a wind-break net, presumably due to the difference in the chemical properties of the covering materials. Since there are many kinds of covering materials commercially available, care should be exercised in their selection, by determining whether they are adapted to particular climatic conditions.

As for the influence on the growth of Pak-choi, germination and early growth were promoted by covering. However subsequent growth was not as much promoted as it was in the early stage. The growth in the later stage was significantly suppressed under direct covers with the use of a wind-break net. This phenomenon was attributed to the small buffer space under direct covers, resulting in the increase of the air temperature in the daytime and mechanical pressure build-up on the plants.

Direct covers are more likely to rub plants, which may induce the production of endogenous ethylene causing stunted growth of plants[1,4]. The amount of ethylene induction under row covers should be estimated. On the other hand, growth suppression under floating covers was minimal.

Plant height and leaf area of Pak-choi increased, while the dry matter content decreased under covers, resulting in more luxuriant plant growth. The quality of the products was satisfactory and the use of floating covers with cheese-cloth was recommended for leafy vegetable production in the subtropics.

In conclusion, the selection of covering methods and materials in accordance with the growth stage and growing season should be further studied.

2) Growth response of Pak-choi to environmental conditions

Since the covering practice modifies the micro-environmental factors in complex ways, experiments aiming at the control of some of the variables involved were conducted to evaluate their effects on plant growth independently. The optimum combination of environmental factors evaluated through the experiments can be summarized as follows.

Comparison of RGR values showed that shading up to 33% of the incident light did not affect the growth of Pak-choi. The optimum air temperature was 25°C with 5°C of temperature difference between day and night. The optimum soil temperature was 25°C and the growth decreased as the soil temperature increased. A soil moisture tension of pF 1.25–1.75 was optimum in the range of pF 1.25 to 2.5. The optimum range of wind velocity was 0.4–1.4 m/s and higher relative humidity (80%) resulted in better growth than moderate relative humidity (60%).

In the summer season in the subtropical zone of Japan, the light intensity exceeds 150 klux, the air temperature is above 30°C, the soil temperature exceeds 45°C and 30°C at a depth of 1 cm and 10 cm, respectively, the soil moisture tension reaches a pF value of 2.5, the relative humidity decreases to 50–60% in the daytime, the wind blows normally at the velocity of 4–5 m/s, and the anticipated number of typhoon attacks is 3–4.

These climatic conditions are not suitable for leafy vegetable cultivation. Therefore, the modification of the micro-climate obtained by row covering offers a great potential for alleviating vegetable scarcity there. This measure may enable to control, among others, the light intensity, soil temperature and moisture level, and the rate of ventilation in a crop community.

The main problems include the improvement of product quality and the control of pests and diseases under row covers. Elongation of leaves and deterioration of the quality of the products caused by inadequate air ventilation could be alleviated by adjusting the sowing and planting density or by improving the air conductivity of the materials. Furthermore, the population dynamics of pests and diseases under covers also needs to be investigated in collaboration with entomologists and pathologists.

Row covers could be used in the tropics as well as in the subtropics. Vegetable farmers are using coconut leaves for the purpose of shading. In addition, overdose of chemicals (insecticides, fungicides, etc.) for the control of pests and diseases is causing serious social and environmental problems in the tropics at present. Therefore the introduction of row covering, after identifying appropriate materials and methods with regard to its purpose, based on sound economic assessment, may enable to solve some of the problems in vegetable production in the tropics.

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