THE EFFECT OF MULCHING AND ROW COVERS ON VEGETABLE PRODUCTION

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ABSTRACT

Plastic mulches have various beneficial effects on crop production in temperate regions, including an increase in soil temperature; the conservation of soil moisture, texture and fertility; and the control of weeds, pests and diseases. However, mulching with fresh leaves gave better yields than plastic films in summer in the subtropics, since plastic mulching produced a marked increase in soil temperature.

Row covers, using plastic nets and non-woven fabrics, also increased the yield of vegetables, especially that of leafy vegetables, in the tropics and the subtropics. The yield increase was the combined result of shading, suppression of soil temperature increase, conservation of soil moisture, and protection from wind and pests.

INTRODUCTION

Protected vegetable cultivation started in Japan at the beginning of the 17th century. The first records describe the use of greasy paper for forcing cultivation in Shizuoka, so that early vegetables could be shipped to Tokyo (Edo).

However, it was after the commercial production of plastic films in 1951 that protective methods of vegetable cultivation became widespread in Japan. At first, various materials were used as covers for forcing cultivation during the cold season. Later, they came into use as mulches, rain shelters and row covers throughout the year.

With regard to the use of plastic materials for vegetable production, there are currently five types of protective cultivation carried out in Japan (Fig. 1). The area under protective vegetable cultivation using these methods reached 160,163 ha in 1987, comprising 26% of the total area under vegetable cultivation (617,600 ha in 1987). The use of plastic materials for vegetable cultivation, for e.g. mulches, row covers and rain shelters, seems also to be applicable to vegetable production in the tropics and subtropics. The effect and feasibility of mulching and row covers are discussed in the paper, with regard to their effect in stabilizing vegetable production in both temperate and tropical climates.

MULCHING

Effect of Mulching in Temperate Regions in Japan

Yield Increases and Early Harvest

There are many reports confirming the stimulation of growth and consequent yield increases by the use of plastic mulches. Their effects are particularly noticeable in early spring. For example, Fig. 2 shows groundnut yields with and without mulching at various experimental stations in the Kyushu district in Japan (Iguchi 1977). Although the experiments were carried out under different climatic conditions, soils and years, mulching was always found to be effective in producing a yield increase. The practice of mulching also shortened the growth period. Mulching thus stabilized production by eliminating various constraints, and made possible more intensive multiple cropping by advancing the harvest (Fig. 3) (Iguchi 1977).

Reasons for Yield Increases with Mulching

Increase in Soil Temperature

Polyethylene mulch raises the soil temperature. This effect derives mostly from the suppression
Fig. 1. Five types of protected vegetable cultivation using plastic materials, and the extent of their use in Japan

<table>
<thead>
<tr>
<th>Type of protected vegetable cultivation</th>
<th>Extent of use in Japan (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mulching</td>
<td>120,322</td>
</tr>
<tr>
<td>Hot cap</td>
<td>?</td>
</tr>
<tr>
<td>Row cover</td>
<td>4,225</td>
</tr>
<tr>
<td>Rain shelter</td>
<td>4,750</td>
</tr>
<tr>
<td>Frame-house</td>
<td>30,856</td>
</tr>
</tbody>
</table>
Fig. 2. Yields of groundnut with and without mulching at various locations in Kyushu district, Japan. Results from the years 1971 (a), 1972 (b) and 1973 (c).

Source: Iguchi 1977
of latent heat loss through evaporation. The extent of the increase in soil temperature depends on the color of the film and the intensity of solar radiation. Soil temperatures with and without mulching were monitored in a field of carrots sown on April 27 (Fig. 4). The penetration of sunlight and the increase in soil temperature was most marked when transparent film was used, while black film was not as effective in raising soil temperatures. The difference in soil temperature between mulched and bare soil in early May reached 7°C with transparent film and 5°C with black film. However, this increase in soil temperature diminished later, as the canopy of carrot leaves began to cover the mulch.

Conserving the Soil Moisture and Texture

The soil moisture content of bare soil in the carrot fields fluctuated as rainfall occurred. However, it was quite stable in soil under mulch. The soil moisture was always higher under black mulch than under transparent mulch (Fig. 5).

Although some rainfall penetrates the holes in the mulch and soaks into the soil, the moisture content of soil under mulch becomes lower in the long term, as there is not much supplementary water accumulation under mulch after covering. The soil temperature and soil moisture content monitored in soybean fields with and without mulch are shown in Fig. 6 (Onuma et al. 1971). It is apparent that the conservation of soil moisture under mulches lasts only during the early stage of growth.

Rainfall onto bare soil leads to the destruction of the soil structure. The distribution of onion roots in soil with and without mulch is shown in Fig. 7. The texture of the soil under the mulch remained porous, which contributed to root growth expansion.

Conserving Soil Fertility

Mulching prevents the leaching of fertilizer, because it acts as a physical barrier to rainfall. Fluctuations in the nitrate and ammonium content in the soil of carrot fields with and without mulch are shown in Fig. 8. Compound fertilizers of N-P-K: 220-210-200 kg/ha were applied as a basal dressing. The amount of nitrate was highest in the soil under transparent film, followed by black film, and was lowest in bare soil. The amount of ammonium showed the same trend, except that there was little difference between soil under black film mulch and bare soil.

The movement of water is directed up-
Fig. 4. Fluctuations in soil temperature (5 cm below surface) in carrot fields with and without mulch

Source: Takahashi and Chiba 1971

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Fig. 5. Fluctuations in soil moisture in carrot field with and without mulch

Source: Takahashi and Chiba 1971
Fig. 6. Fluctuations in soil temperature and soil moisture in soybean fields with and without mulch (Measurement was carried out at a depth of 10 cm at 10 a.m.)

Source: Onuma et al. 1971

Fig. 7. Distribution of roots of onion grown with and without mulch

Source: Kawaguchi 1974
wards in soil under plastic mulch, which results in the accumulation of salts on the soil surface beneath the film. The electric conductivity of the soil was markedly higher under mulch. The content of exchangeable cations was also higher under transparent mulch during the middle stage of growth, while both transparent and black mulch gave a higher cation content at the final growth stage (Table 1). However, the pH value was lower by 0.2-0.5 in soil under mulch compared to bare soil (pH 6.1), which indicates that anions such as nitrate, sulfate and chloride also remain in the soil without being leached out. The amount of nutrients (N, P, K, Ca, Mg) absorbed by the plant from the soil was 1.4-1.5 times higher in soil under mulch than in bare soil.

Weed Control

Black polyethylene film gives effective weed control by cutting down solar radiation by more than 90%, resulting in etiolated growth and the eventual death of weeds under the film. Transparent film, on the other hand, has no effect on weed control unless the film is coated with weedicides.

Green plastic film was innovated as a mulch to combine the effects of black film in terms of weed control, and transparent film in terms of increased soil temperature. Although the increase of soil temperature under green film was almost comparable to that under transparent film, the effect of green film on weed control was inconsistent. Green film was found to be quite effective in controlling weeds such as *Portulaca oleracea* L., but did not control the growth of *Cyperus difformis* L. or *Digitaria adscendens* Henr. (Table 2). A wavelength of around 520 nm has a selective effect in inhibiting the germination and growth of plants (Fig. 9). The effect on weed control of green film, which permits a wavelength of 500-600 nm to pass through, is rather dependent on the species of weed concerned.

Control of Pests and Diseases

Silver film was developed as a mulch to suppress the increase in soil temperature and to control pests and diseases. The silver color acts as a repellent to aphids which transmit viruses. The number of aphids and the occurrence of virus symptoms in melons grown with and without silver mulch is shown in Fig. 10. At an early stage of growth, the repelling effect of the silver color on aphids was observed even when it covered only 10% of the soil surface. Later this effect disappeared, as plant leaves began to cover the mulch. Silver film was also found to be effective in reducing attacks by *Aulacophora* spp. on melons.

With regard to diseases, there is a report that sclerotinia rot of lettuce was reduced by mulching, due to the prevention of direct contact between the leaves and the soil (Nishitani 1979).

Effect of Mulching in Summer in the Subtropics

Experiments were carried out at the Okinawa branch of the Tropical Agricultural Research Center (TARC) to investigate the effect of mulching during summer in the subtropics.

Soil Temperature under Mulches

Diurnal fluctuations in soil temperature at a depth of 0 cm (surface), -10 cm and -30 cm under various mulching materials during summer are shown in Fig. 11. Plastic films (transparent, green, black and silver), white non-woven fabrics and freshly cut Napier grass (*Pennisetum purpureum* Schum.) were used for the field tests, and compared to the control. The surface temperature of the bare soil rose to 56°C. Green, transparent and black films increased soil temperature more than the control, to a level of 70°C under black film. On the other hand, a slight decrease in soil temperature was observed under white fabrics and a significant decrease under silver film, while freshly cut Napier grass suppressed any soil temperature increase so completely that the temperature remained almost constant throughout the day. Soil temperatures became lower with greater soil depth (-10 cm and -30 cm), but the same trends were still observed in the effect of the various mulching materials on increased soil temperatures, regardless of soil depth.

Reasons for Increased Soil Temperature under Plastic Mulch

In view of this extreme increase in soil temperature under plastic mulch, especially with black polyethylene film, differences in surface temperature in relation to the color of the covering were analyzed, using colored steel plates (black, green, silver and white). The black plate absorbed most solar heat, followed by green and silver. The increase in temperature was least pronounced when the white plate was used (Fig. 12). Evaporation from the surface of mulching materials of various colors followed the same pattern
Fig. 8. Fluctuations in nitrate and ammonium content in soil with and without mulch
Source: Takahashi and Chiba 1971
Table 1. Electric conductivity and exchangeable cations in soil of carrot fields with and without mulch

<table>
<thead>
<tr>
<th>Item</th>
<th>E.C.</th>
<th>Exchangeable cations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of measurement</td>
<td>6.16</td>
<td>7.12</td>
</tr>
<tr>
<td></td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td>CaO (mS/cm)</td>
<td>12.8</td>
<td>359</td>
</tr>
<tr>
<td>MgO (mg/100g soil)</td>
<td>220</td>
<td>53</td>
</tr>
<tr>
<td>K₂O (mg/100g soil)</td>
<td>21</td>
<td>62</td>
</tr>
<tr>
<td>Na₂O (me)</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Total (me)</td>
<td>9.3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>No.</th>
<th>CaO (mg/100g soil)</th>
<th>MgO (mg/100g soil)</th>
<th>K₂O (mg/100g soil)</th>
<th>Na₂O (me)</th>
<th>Total (me)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (bare soil)</td>
<td>0.31</td>
<td>263 24 8</td>
<td>12.8 220 14 4</td>
<td>9.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Black film mulch</td>
<td>1.75</td>
<td>278 35 7</td>
<td>12.6 325 43 8</td>
<td>15.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transparent film</td>
<td>2.10</td>
<td>357 54 35</td>
<td>17.9 359 62 8</td>
<td>17.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Takahashi and Chiba 1971

Table 2. No. and dry weight of weeds under plastic mulch, compared to the control

<table>
<thead>
<tr>
<th>Species of weed</th>
<th>No. (bared soil)</th>
<th>Dry wt. (g/m²)</th>
<th>Transparent film</th>
<th>No.</th>
<th>Dry wt. (g/m²)</th>
<th>Green film</th>
<th>No.</th>
<th>Dry wt. (g/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digitaria adscendens</td>
<td>40</td>
<td>1.46</td>
<td>111</td>
<td>66</td>
<td>2.57</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cyperus difformis L.</td>
<td>28</td>
<td>0.01</td>
<td>29</td>
<td>29</td>
<td>0.22</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portulaca oleracea L.</td>
<td>20</td>
<td>0.08</td>
<td>25</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euphorbia supina RAFIN</td>
<td>21</td>
<td>0.09</td>
<td>30</td>
<td>8</td>
<td>0.06</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatoua villosa NAKAI</td>
<td>12</td>
<td>0.06</td>
<td>11</td>
<td>24</td>
<td>0.21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others</td>
<td>55</td>
<td>1.02</td>
<td>97</td>
<td>18</td>
<td>0.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>176</td>
<td>2.74</td>
<td>303</td>
<td>145</td>
<td>3.17</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Takahashi and Chiba 1971

as the temperature increases under colored plates (Fig. 13).

The soil moisture contents were lower in bare soil and under white fabric mulch (water permeable), than those under plastic film mulches. Among the plastic film mulches, silver film and black film were most effective in maintaining soil moisture, while transparent film was least effective (Fig. 14).

Growth and Yield of Cabbage with Mulching

Cabbages were grown under various mulches (black, transparent and silver polyethylene films, white fabrics and freshly cut Napier grass) and in bare soil. The increase of surface temperature soon caused the black film to shrink and tear, and the transparent film also tore during the experiment. (No data on yields were obtained).

The mulch of freshly cut Napier grass gave the greatest yield and highest harvesting percentage. The yield of cabbages grown under silver plastic mulch was slightly higher than the control; however white fabrics resulted in a lower yield than the control (Table 3).

Similar effects of plastic mulches on vegetable growth in a hot climate have been reported from Burkina Faso, in West Africa.
Black polyethylene mulch yielded 3.3 times higher than soil without mulch in eggplant, and 2.3 times in tomato, when grown during the relatively cool season (sown in September and harvested in January. However, in a trial carried out during the hot season, the use of plastic mulch had an adverse effect on vegetables and decreased their yields significantly (Djigma et al. 1986).

The extreme increase in soil temperatures under plastic mulch seems to indicate that it should not be used in climates where there is high solar radiation.

**PLASTIC ROW COVERS**

In hot climates, the use of plastic film mulches does not seem to be justified. Only mulching with fresh leaves gave higher productivity than the control. Another approach to modify the micro-climate to enhance plant productivity by plastic
Fig. 11. Soil temperatures at a depth of 0 cm, 10 cm and 30 cm under various mulching materials during summer in Okinawa
Fig. 12. Increase in temperature of colored steel plates

Fig. 13. Surface evaporation from different mulching materials
Table 3. Growth and yield of cabbage with and without mulching

<table>
<thead>
<tr>
<th>Mulching material</th>
<th>Shading intensity(%)</th>
<th>Plant weight (kg)</th>
<th>Head weight (kg)</th>
<th>Head/plant weight (%)</th>
<th>Harvesting percentage</th>
<th>Yield (mt/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (bare soil)</td>
<td>0%</td>
<td>0.76</td>
<td>0.46</td>
<td>0.60</td>
<td>90%</td>
<td>10.3</td>
</tr>
<tr>
<td>White non-woven fabric</td>
<td>62</td>
<td>0.99</td>
<td>0.62</td>
<td>0.63</td>
<td>55</td>
<td>8.5</td>
</tr>
<tr>
<td>Silver plastic film</td>
<td>97</td>
<td>1.36</td>
<td>0.89</td>
<td>0.65</td>
<td>65</td>
<td>14.5</td>
</tr>
<tr>
<td>Freshly cut Napier grass</td>
<td>-</td>
<td>1.51</td>
<td>1.11</td>
<td>0.74</td>
<td>100</td>
<td>27.7</td>
</tr>
</tbody>
</table>

Cultivation was carried out during summer in Okinawa, using the various mulches shown above and white cheesecloth row covers.
material is the use of row covers.

Okinawa’s farmers began using plastic nets as row covers for leafy vegetables during the late 1950’s. This practice proved quite effective for vegetable production in a hot climate. The area under row covers has now increased to 4,225 ha in Japan.

Row Covers

Materials Used for Row Covers

Row covers used in vegetable production have different purposes in temperate and tropical regions. In temperate regions, they are used mainly during the cold season to conserve warmth, stimulate germination and early growth, protect plants from frost injury, and improve the quality of the crops. Other beneficial effects, such as maintaining soil texture, and protecting crops from the attacks of birds and pests, can also be expected. For such purposes, especially to minimize heat loss during cold weather, materials such as polyethylene film, or non-woven fabric layer sheets of polyester or polyvinylalcohol, are used.

In the tropics, however, materials used as row covers need to have adequate permeability to air and moisture, to prevent the accumulation of excessive heat inside the covers. The most popular materials used in summer in Okinawa are woven polyester wind-break nets, cheese-cloth, and non-woven fabrics of polyvinylalcohol. Various colors such as transparent, white, silver, blue and black are available. In Okinawa, most farmers prefer to use blue row covers.

Types of Row Cover

Originally, row covers were laid directly on the beds, but recently covers resting on low tunnel hoops or low pipe-framed houses are becoming more popular. Covers resting directly on the plants means that there is little space between the plants and the covering material, and provide a less favorable environment for plant growth than covers stretched over a frame.

Effect of Row Covers in the Tropics and the Subtropics

Yield Increases in the Subtropics (Okinawa)

An experiment was carried out at TARC in Okinawa over the summer. Chinese cabbage of the non-heading type (var. Santousai) was cultivated under row covers resting on a tunnel-shaped framework. Eleven kinds of perforated plastic materials were tested, together with the control (bare soil). The shading intensity given by the covers ranged from 0 to 88%. Compared with untreated control, yields were increased by covers with 5-40% shading intensity. The highest yield was seen in the treatment using black cheesecloth (36% shading intensity), which gave a yield 1.8 times higher than the control (Table 4).

Yield Increases in the Tropics (Malaysia)

Six kinds of vegetables (water convolvulus, radish, cucumber, tomato, French bean and sweetcorn) were grown in Malaysia under covers resting on low wooden frame houses over a two-year period. The shading intensity under the covers ranged from 0 to 98%.

Plant height and leaf weight were the greatest under heavy shading (37-87% shading intensity), but the root weight of radish decreased as shading intensity increased. As for fruit vegetables, maximum yields for cucumber and French bean were obtained under medium shading (20-37% shading intensity), while maximum yields of tomato and sweetcorn were obtained when no covers were used (Fig. 15). The reason why the yields of tomato and sweetcorn declined under row covers may be the photosynthetic characteristic of these crops, both of which have a high saturation point for light intensity.

Quality Improvement

The quality of the product, particularly that of the leafy vegetables, improved under row covers in both Okinawa and Malaysia. The texture of the Chinese cabbage leaves became tender, and the leaves were pale green in color, as is preferred by consumers. The number of larvae and of holes in the leaves was significantly reduced by the use of row covers.

Results of experiments both in the subtropics and the tropics indicated that row covers of plastic net or cheesecloth are an effective measure in vegetable production, especially of leafy vegetables, in a hot climate.
Fig. 11. Soil temperatures at a depth of 0 cm, 10 cm and 30 cm under various mulching materials during summer in Okinawa
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Table 4. Environment and yield of Chinese cabbage under various types of row cover

<table>
<thead>
<tr>
<th>Covering material</th>
<th>Shading intensity</th>
<th>Difference in soil temperature (°C)</th>
<th>Yield (mt/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>0%</td>
<td>-38.7 Max. 25.4 Min.</td>
<td>6.05</td>
</tr>
<tr>
<td>Transparent non-woven fabric</td>
<td>5</td>
<td>+0.6 Max. +1.7 Min.</td>
<td>7.88</td>
</tr>
<tr>
<td>Plastic net (windbreak) (4mm mesh)</td>
<td>19</td>
<td>-1.3 Max. +0.7 Min.</td>
<td>8.00</td>
</tr>
<tr>
<td>White cheesecloth (#300)</td>
<td>21</td>
<td>-1.0 Max. +1.2 Min.</td>
<td>7.26</td>
</tr>
<tr>
<td>White cheesecloth (#100)</td>
<td>30</td>
<td>-2.3 Max. +0.9 Min.</td>
<td>8.47</td>
</tr>
<tr>
<td>Grey cheesecloth (#327)</td>
<td>32</td>
<td>-3.8 Max. +1.0 Min.</td>
<td>8.69</td>
</tr>
<tr>
<td>Black cheesecloth (#610)</td>
<td>36</td>
<td>-3.5 Max. +0.7 Min.</td>
<td>11.12</td>
</tr>
<tr>
<td>Plastic net (windbreak) (2mm mesh)</td>
<td>38</td>
<td>-3.3 Max. +0.4 Min.</td>
<td>9.61</td>
</tr>
<tr>
<td>Silver non-woven fabric</td>
<td>40</td>
<td>-5.5 Max. +1.2 Min.</td>
<td>7.31</td>
</tr>
<tr>
<td>Plastic net (windbreak) (1mm mesh)</td>
<td>57</td>
<td>-4.0 Max. +0.7 Min.</td>
<td>4.92</td>
</tr>
<tr>
<td>Double net (thin)</td>
<td>67</td>
<td>-6.2 Max. +1.2 Min.</td>
<td>4.17</td>
</tr>
<tr>
<td>Double net (thick)</td>
<td>88</td>
<td>-6.0 Max. +1.5 Min.</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Fig. 15. Yield of vegetables in relation to shading intensity in the tropics (Malaysia)
Source: Hanada 1987
Reason for Yield Increases of Leafy Vegetables Grown under Row Covers in a Hot Climate

Both the yield and the quality of leafy vegetables are improved by the use of row covers. To investigate their effects in more detail, several experiments were carried out using leafy vegetables, mainly pak-choi (Chinese mustard, *Brassica rapa* L.).

Effect of Shading

Covering the plants with plastic net or cheesecloth reduced the radiation and prevented scorching or wilting of leaves caused by marked temperature increases within the leaf tissue from strong sunlight.

The Relative Growth Rate (RGR) of 16 leafy vegetables under covers with 0-90% shading intensity was investigated. All leafy vegetables except edible amaranth (*Amaranthus tricolor* L.) and pak-choi showed an increase in RGR under 20-40% shading intensity. Cabbage and Chinese cabbage showed better growth than the control, even under 60% shading intensity (Fig. 16). Shaded environments with 30-40% shading intensity seemed to be suitable for most of the leafy vegetables.

Air Temperature

Air temperature under white cheesecloth (30% shading intensity) increased by 1°C when the material was stretched over a framework, and by 3°C when it was used as a direct cover, at midday compared with the control. The use of less porous covering materials further raised the inside air temperature. At night, there was little temperature difference between treatments with and without covers (Fig. 17).

The ideal air temperature for the growth of pak-choi was found to be 25°C, with a temperature difference of 5-10°C between the daytime and the night. Since the ambient air temperatures in Okinawa at midday in summer exceed 30°C, it is important not to increase air temperatures under the covers.

Soil Temperature

An increase in soil temperature at midday was suppressed by the use of covers. Soil temperatures at a depth of 5 cm were lower by as much as 6°C under covers with a shading intensity of more than 67%, compared to the control. On the other hand, non-woven fabrics with a low shading intensity (5%) gave higher soil temperatures than the control (Table 4).

The growth of pak-choi decreased as the soil temperature increased to more than 25°C (Fig. 18). As soil temperatures reach almost 50°C on the surface and 40°C at a depth of 10 cm in summer in Okinawa, row covers are effective in producing an underground environment more suitable for root growth.

Soil Moisture

Soil was kept moister for a longer period when row covers were used. Direct covers were more effective in retaining soil moisture than covers supported by a framework, although the soil beneath them was apt to become waterlogged after rain (Fig. 19).

The ideal soil moisture content for the growth of pak-choi was found to be P<sub>F</sub> 1.5 (Fig. 20). As the soil in summer is liable to dry out after a short time, row covers also provide a protective environment for plants against water stress.

Protection from Wind

Wind velocity decreased to as little as 1/5 under direct coers, and by 1/2 under covers over a framework, compared to the control. The growth rate of pak-choi was highest at a wind velocity of 0.4-1.4 m/sec (Table 5). As wind usually blows at a velocity of 3-4 m/sec in Okinawa, the effect of row covers in improving yields by protecting crops from wind is important.

Protection from Pests

Row covers made of plastic net or cheesecloth act as a physical barrier against attacks by pests. In experiments in Malaysia, cheesecloth with a mesh size of 1.4 mm gave good control of attacks by pests.

In the case of cruciferous vegetables, covering materials with a larger mesh size of 4.0 mm provide a sufficient barrier against armyworm and cabbage worm, although a mesh of 2.0 mm is needed to protect crops from diamondback moth. Materials with a mesh of 1.0 mm are needed to protect vegetables from yellow-striped flea beetles.
Fig. 16. Relationship between shading intensity and relative growth rate (RGR) on 16 kinds of vegetable.
CONCLUSION

Mulching with appropriate materials has a number of effects: it increases the soil temperature, conserves soil moisture, texture and fertility; and controls weeds, pests and diseases. Various kinds of mulching material are available for vegetable production in temperate regions, depending on their purpose. However, mulching with plastic film caused an extreme increase in soil temperature during summer in the subtropics. Organic matter such as fresh leaves, fresh grass or straw are better mulching materials than plastic in a hot climate.

The effect of row covers, another way of stabilizing vegetable production, was also investigated in the tropics and the subtropics. Covering crops with plastic net or non-woven fabrics, especially when these were supported by a framework, increased the yield of vegetables, especially of leafy vegetables, in both subtropical and tropical areas. These yield increases were found to be the combined results of shading, suppression of increases in soil temperature, conservation of soil moisture, and protection from wind and pests.

The use of plastic nets as row covers and mulching with freshly cut grass seem to be highly promising techniques of vegetable production in the tropics.
Fig. 9. Germination and survival percentages of weeds under radiation of different wave lengths
Source: Inada 1971

Fig. 18. Growth of Pak-choi under different soil temperatures

Fig. 19. Fluctuations in soil moisture (pF value) with and without row covers
Table 5. Effect of wind velocity on the growth of pak-choi

<table>
<thead>
<tr>
<th>Wind velocity (m/s)</th>
<th>Leaf temperature (°C)</th>
<th>Transpiration rate (µg/cm²/s)</th>
<th>Leaf area index</th>
<th>RGR index</th>
<th>Dry matter percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>29.0</td>
<td>8.7±2.3</td>
<td>100</td>
<td>100</td>
<td>6.2</td>
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<tr>
<td>0.4</td>
<td>28.1</td>
<td>13.7±1.8</td>
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<td>105</td>
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<tr>
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<td>108</td>
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</tr>
<tr>
<td>4.0</td>
<td>29.7</td>
<td>9.3±2.7</td>
<td>72</td>
<td>95</td>
<td>7.9</td>
</tr>
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Fig. 20. Growth of Pak-choi under different soil moistures

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