

Effect of Reflective Film Mulching on the Photosynthetic Activity of Carnation

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Abstract

In this report, we examined the influence of reflective film mulching (RFM) on the photosynthetic activity of carnation. In the RFM plot 32% of downward light was reflected while in the black mulching plot, 3%, and the photosynthetic rate increased by 32% on a seedling basis compared with the black mulching plot. However, the photosynthetic rate on a single leaf basis increased by only 16% at most by supplemental illumination. Higher ¹⁴CO₂ fixation in lower leaves was observed in the RFM plot, and a larger amount of assimilation products translocated to roots and folded leaves than in the black mulching plot. It is assumed that the higher photosynthetic activity in the case of RFM was caused by the activation of CO₂ fixation of lower leaves rather than by the increase of CO₂ fixation of each leaf in an individual plant.

Discipline: Horticulture

Additional key words: CO₂ fixation

Introduction

Reflective film mulching (RFM) has been reported to increase the light intensity by reflecting downward light^{5,9}. This effect results in the expansion of the plant community and increase of yield^{2,7,8,11,12,14,15}. In the previous report¹³ we described a combination of RMF and shading treatments during the hot summer season in carnation, and we observed that the treatments promoted vegetative growth under high temperature and subsequently induced early flowering and a 15% increase in yields compared with the plot without mulching and shading. We considered that these effects were caused by the increase of solar radiation brought about by RFM and lower temperature by shading. Although RFM may affect the photosynthesis, there is no report on the effect of RFM on the photosynthesis. In the present work, we attempted to determine how RFM affected the photosynthetic activity in carnation.

Materials and methods

Exp. 1: Effect of RFM on the photosynthetic rate of carnation

(Exp. 1-1) Influence of RFM on the photosynthetic rate on a seedling basis

Seedlings of cv. Pearl Lake were planted in pots (18 cm diameter) in October 1987, and pinched at the 4th node in November 1987. Then the seedlings were transferred into a greenhouse maintained at above 10°C and grown until the measurements were performed. Photosynthesis measurements were conducted from late February until early March in 1988, when the average plant height and primary branch length were 23 and 19 cm, respectively. Seedlings were transferred into a small chamber (volume 65 l) in a phytotron. The relative humidity in the chamber was set at 60%. Apparent photosynthetic rates and leaf temperatures of seedlings were measured when the room temperature ranged from 11 to 32°C and light was supplied with 4 metal halide lamps

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at intensities of 587, 859 and 1,460 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at a 10 cm height from the soil surface. The air stored in an 800 l bag (approx. 360 ppm of CO_2 concentration) was introduced into the chamber containing a seedling at the rate of 20 $\text{l}\cdot\text{min}^{-1}$. Then the CO_2 concentration of the air expelled from the chamber was measured. Apparent photosynthetic rate was calculated from the difference in CO_2 concentration between the air drawn into and the air expelled from the chamber. RFM effect on photosynthesis was also analyzed. Light intensity was set at 495 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (10 cm height from the soil surface), then the soil surface of each of pot was covered with: 1) black mulch film, 2) PolyShine Cloth (aluminized film, Hitachi Condenser, Japan), and 3) Silver Polytop (Tokan Kosan KK, Japan). Room temperature was set at 20°C. Apparent photosynthetic rate was measured as mentioned above. The reflected light intensity at 10 cm above the soil surface was also measured.

(Exp. 1-2) Difference between the photosynthetic activity of leaves illuminated on their adaxial surface and those on their abaxial surface

Seedlings of cvs. Coral, Scania, Pink Barbie, Wiko, and Scarlet Bell were planted in pots 10 cm in diameter on November 18, 1988 and pinched at the 4th node, then transplanted in 12 cm pots 1 month later. Seedlings were placed in a greenhouse maintained at above 15°C until the experiments were conducted. Experiments were carried out in late January, 1989. The magnitude of the photosynthetic rate was measured using a single unfolded leaf at the uppermost position, on both occasions by illuminating the adaxial and abaxial surfaces. SPAD value (value measured with SPAD-501, Minolta), leaf thickness ($\text{gFW}\cdot\text{cm}^{-2}$) and number of stomata per cm^2 were recorded. SPAD values had been shown to be highly correlated with extractable chlorophyll levels³⁾. Photosynthetic rate was measured at 20°C at light intensities of 135 and 410 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ with a halogen lamp using a portable photosynthesis measuring equipment (LI-6700, LI-COR). We used the average of at least 4 replicated values in the measurements.

(Exp. 1-3) Effect of supplemental illumination on the abaxial leaf surface on photosynthetic rate

Carnation cvs. Coral and Scarlet Bell were used. The former recorded the highest photosynthetic rate and the latter the lowest in Exp. 1-2. Seedlings were handled as in Exp. 1-2 until the measurements were performed. Photosynthetic rates were measured as in Exp. 1-2, although light intensities were set at 240,

480, 780 and 1,170 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ on the adaxial surface, and illumination was supplied on the abaxial surface of each leaf at 1/3 intensities of those on the adaxial surface. We used an average of at least 4 replicated values in the measurements.

(Exp. 1-4) Photosynthetic activity on a single leaf basis depending on age

Carnation cvs. Seto no Megumi and Scania were used. Four uniform seedlings per cultivar were planted in pots (12 cm in diameter) and grown in a greenhouse, then pinched at the 4th node. One branch per seedling at visible bud stage was used for the measurements. The seedlings were placed in a phytotron. The room temperature and light intensity were set at 20°C and 380 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, respectively. First, the 4th, 7th and 10th leaves from the neck node were used for the experiment. The air stored in an 800 l bag (approx. 360 ppm of CO_2 concentration) was introduced into the chamber enclosing the test leaf at the rate of 1.2 $\text{l}\cdot\text{min}^{-1}$, then the CO_2 concentration of the air expelled from the chamber was analyzed. Apparent photosynthetic rate was calculated from the difference in CO_2 concentration between the air drawn into and the air expelled from the chamber.

Exp. 2: Effect of RFM on CO_2 assimilation

Carnation cv. Improved White Sim was used. Seedlings were planted on April 5, 1990. They were brought into a greenhouse, then transplanted in pots (15 cm in diameter) and pinched at the 4th node on August 26, 1990. They were grown in the greenhouse until the photosynthesis measurements were performed. At the time of measurement, average values of plant height, length of primary branches and unfolded leaf number were 76.3 cm, 50 cm and 15.4, respectively. The test plants were placed in a cabinet (30(W) × 60(D) × 70 cm(H)) made of transient acryl panels placed in a phytotron. The cabinet was equipped with a propeller (Orix, 11.9 mm, air flow 3 $\text{m}^3\cdot\text{min}^{-1}$) for maintaining the air circulation, and 2 pipes, one for drawing air and the other for expelling air. Two pots of the plants were placed in the cabinet, then they were illuminated for 12 h per day using metal halide lamps at irradiances of 395 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (400–700 nm) at the plant top level and 16.5 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ at the soil surface. The room temperature was set at 20°C. $^{14}\text{CO}_2$ was generated according to the following method. We prepared a flask containing a sufficient amount of $\text{Na}_2^{14}\text{CO}_3$ to generate the required amount of carbon dioxide. An excess of lactic acid was added

to the carbonate and the gas in the flask was then sucked into an 800 l bag. The carbon dioxide concentration was 350 ppm and the radioactivity of the carbon dioxide was $10 \mu\text{Ci}\cdot\text{ml}^{-1}$. The plants were exposed to $^{14}\text{CO}_2$ for 1 h in the cabinet: 1) with mulching with a reflective film or 2) without mulching. After 1 h exposure, light was immediately turned off and the $^{14}\text{CO}_2$ in the cabinet was replaced with ambient air (8 l min^{-1} , 20 min). Then one pot was removed from the cabinet and the other one was left there for 24 h under the light and temperature conditions previously described for the translocation of the ^{14}C -assimilates. Plots 3) and 4) corresponded to the translocation treatment for plots 1) and 2), respectively. We conducted at least 3 replications per plot. The test plants of the 4 plots were then divided into the following 9 parts; flowers (including flower buds), folded leaves, leaves on main stem, leaves on primary branch, leaves on secondary branch, main stem, primary branch stem, secondary branch stem, and roots. Each of the parts was weighed (FW, DW), then ground into a powder and used for ^{14}C counting. Ten to 15 mg of the dried powdered tissues were burnt in oxygen with ASC113, Aloka, then counts were made with a liquid scintillation counter (LS3500, Aloka). Quenching correction was conducted according to the external standard channel ratio method. Measurement time was 1 min each.

Results

Exp. 1: Effect of RFM on the photosynthetic rate of carnation

(Exp. 1-1) Influence of RFM on the photosynthetic rate on a seedling basis

Photosynthetic rate of carnation plant remained steadily high from 11 to 20°C , then gradually declined above 20°C (Fig. 1). Under a higher temperature

regime above 30°C , it was only about 50% of the maximum value. Photosynthetic rate rose as the PPFD increased. Photosynthetic rate increased with the increase of the reflected light intensity (Table 1). The photosynthetic rate increased almost in parallel to the increase of the reflective intensity. (Exp. 1-2) Difference between the photosynthetic activity of leaves illuminated on their adaxial surface and those on their abaxial surface

Varietal difference in the photosynthetic rate was not appreciable at $135 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, but evident at $410 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. The highest photosynthetic rate was obtained in cv. Coral, and it was 1.5 times as high as the lowest value recorded in cv. Wiko (Table 2). There was no difference between the photosynthetic activity of the leaves measured when they were illuminated on their abaxial or on their adaxial surface. Photosynthetic rates of leaves

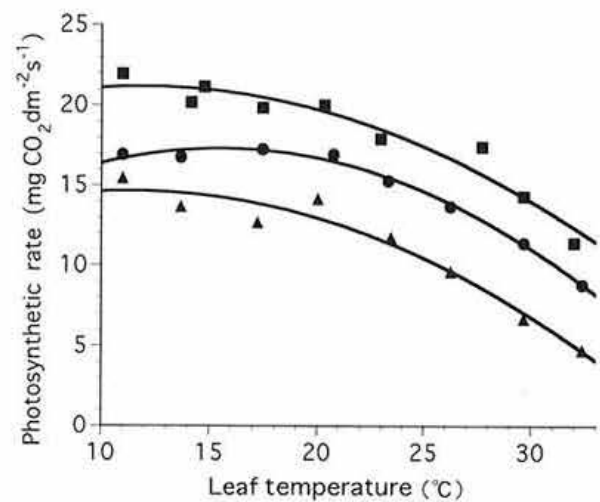


Fig. 1. Effect of leaf temperature on photosynthetic rate in carnation cv. Pearl Lake

Light was supplied at intensities of 1,640 (■), 859 (●), and 587 (▲) $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, respectively.

Table 1. Effect of reflective film mulching (RFM) on the photosynthetic rate of carnation cv. Pearl Lake and reflected light intensity

Treatment	Photosynthetic rate ($\text{mg CO}_2 \text{ dm}^{-2}\cdot\text{h}^{-1}$) ^{a)}	Reflected light intensity ($\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) ^{b)}	Rate of light reflectance (%) ^{c)}
Black mulch	16.1	14	3
PolyShine Cloth	21.2	158	32
Silver Polyto	19.0	94	19

a): Measured at light intensity of $495 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ (plant top level) and leaf temperature of 21.5°C on carnation cv. Pearl Lake.

b): Measured at 10 cm above the mulch surface.

c): Percentage of reflected light intensity (at 10 cm above the mulch) to direct downward light intensity.

Table 2. Varietal difference in photosynthetic rate (illumination on abaxial and adaxial leaf surfaces), leaf thickness, SPAD value and number of stomata

Cultivar	Photosynthetic rate (mg CO ₂ dm ⁻² h ⁻¹)				Leaf thickness (mg FW cm ⁻²)	SPAD value ^{a)}	No. of stomata (mm ⁻²)
	PPFD 410 ^{b)}		PPFD 135 ^{b)}				
	Adaxial ^{c)}	Abaxial ^{c)}	Adaxial	Abaxial			
Coral	17.9	16.2	9.7	9.7	52.7	76.8	59
Pink Barbie	16.2	15.3	11.1	10.4	57.8	71.8	73
Wiko	13.1	12.3	10.4	9.7	30.2	49.0	92
Scania	12.1	11.3	9.0	8.7	55.7	71.6	64
Scarlet Bell	12.3	12.3	9.0	8.6	48.3	71.0	62

a): Measured with a SPAD-501 (Minolta).

b): Photosynthetic rate measured at light intensities of 410 and 135 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, respectively.

c): Measured when illuminated on the adaxial or abaxial leaf surface, respectively.

illuminated on the adaxial surface were approximately 90% of those of leaves illuminated on the abaxial surface regardless of the cultivar or light intensity. Photosynthesis did not display any interaction between the leaf thickness or number of stomata per cm². SPAD values seemed to display an interaction with the photosynthetic rate but only at the light intensity of 410 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$; photosynthesis increased with the increase of the SPAD value (Fig. 2).

(Exp. 1-3) Effect of supplemental illumination on the abaxial leaf surface on photosynthetic rate

Supplemental illumination on the abaxial leaf surface increased the photosynthesis on a single leaf basis for every light intensity in this experiment. The photosynthetic rate increased under a higher light

intensity regime (Fig. 3). The response of the photosynthetic rate to supplemental illumination varied depending on the cultivars. Supplemental illumination enhanced the photosynthetic rates of both

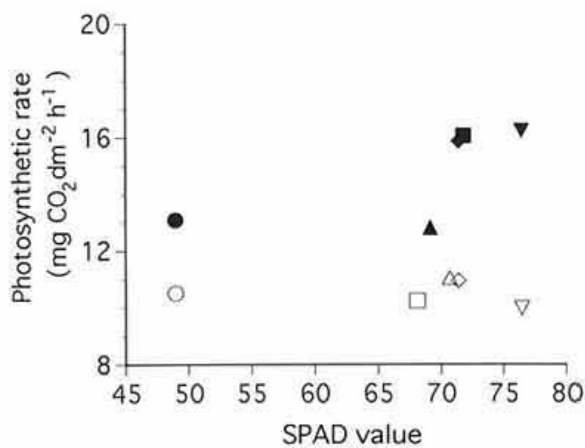


Fig. 2. Varietal difference of photosynthetic rate in carnation with (solid symbols) or without (open symbols) supplemental illumination on leaf abaxial surfaces

Cultivars used were Coral (∇), Scania (\diamond), Pink Barbie (\square), Wiko (\circ), and Scarlet Bell (\triangle).

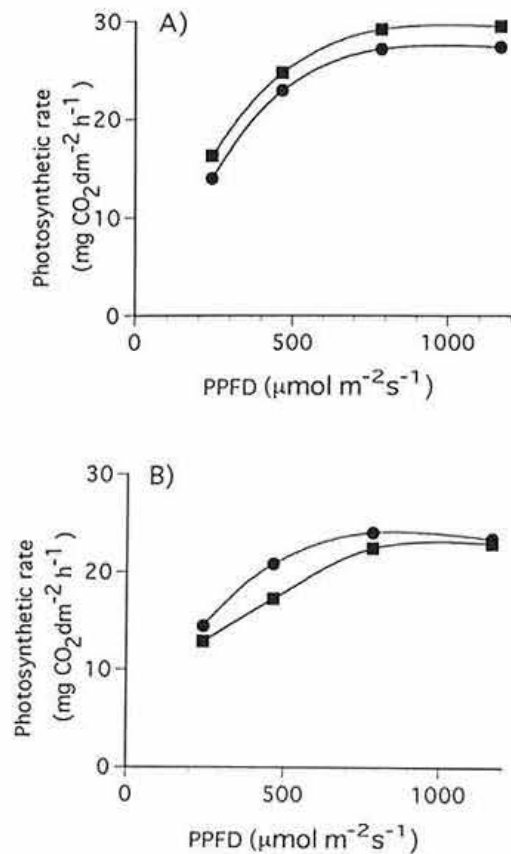


Fig. 3. Light-photosynthetic rate curves in carnation cvs. Coral (A) and Scarlet Bell (B) with (\blacksquare) or without (\bullet) supplemental illumination on leaf abaxial surfaces

Supplemental illumination was applied on the abaxial surface of each leaf at 1/3 intensity of that on the adaxial surface.

cultivars but the response was greater at a higher intensity in cv. Coral, while larger at a lower intensity in cv. Scarlet Bell. The SPAD values in the former cultivar were higher than those in the latter one (Exp. 1-2). In both cultivars the photosynthetic rate reached the light saturation point under $1,170 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, and supplemental illumination could not obviously increase the photosynthetic rate at the saturation point.

(Exp. 1-4) Photosynthetic activity on a single leaf basis depending on age

Specific photosynthetic rate (photosynthetic rate on a leaf area basis) was lower at a lower leaf position (Fig. 4). A remarkable decrease was observed in cv. Scania, in which the magnitude of the photosynthetic rate of leaf at the 4th or lower node was around 20% of that at the 1st node. On the other hand, since in cv. Seto no Megumi, the photo-

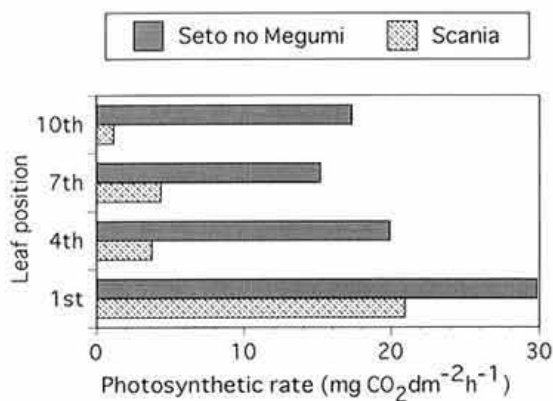


Fig. 4 Photosynthetic rate of first, 4th, 7th and 10th leaves from the neck node in carnation cvs. Scania and Seto no Megumi

synthetic rate declined more gradually when the leaf position was lower, the magnitude of photosynthesis of a leaf at the 4th or lower node was more than 50% of that at the 1st node.

Exp. 2: Effect of RFM on CO₂ assimilation

In the experiment, average values of plant height and dry weight of seedlings were 76 cm and 16.2 g, respectively. The reflected light intensities at the plant top were $115 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in the RFM plot and $16.5 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in bare soil. After 1 h exposure to labeled gas, accumulated radioactivity (Bq/mg F.W.) was higher in the leaves on the primary and secondary branches than in other parts (Table 3). The highest radioactivity was recorded in leaves on primary branches in the RFM plot whereas in leaves on secondary branches in bare soil. After 24 h of exposure to darkness for transpiration, total radioactivity (Bq/plant) was higher in the RFM plot than in bare soil (Table 3). The amount of ¹⁴C-assimilation products in leaves decreased due to respiration and translocation, whereas those in stems, folded leaves, roots and flowers increased mainly due to translocation from the leaves. Mulching treatment exerted some influence on the distribution of the ¹⁴C-assimilation products. The amount of distributed ¹⁴C-assimilation products in stems was higher in bare soil than in the RFM plot, and radioactivity in the stems of primary and secondary branches in the RFM plot was 81% of that in bare soil. On the contrary, the ¹⁴C-amount of folded leaves, roots and (unfolded) leaves was larger in the RFM plot than in bare soil, and the ratio of ¹⁴C-radioactivity of the RFM plot to that of bare soil ranged from

Table 3. Amounts of ¹⁴C-assimilated products in each organ (or part) of carnation (cv. Improved White Sim) exposed to labeled gas for 1 h

Organ/Part	Immediately after exposure				24 h after exposure				
	RFM				RFM				
	No		Yes		No		Yes		
	Bq (× 10 ³)	%	Bq (× 10 ³)	%	Bq (× 10 ³)	%	Bq (× 10 ³)	%	
Leaf	Primary branch	52.98	49.4	54.66	52.4	12.85	14.8	17.34	18.3
	Secondary branch	46.47	43.3	38.43	36.8	13.78	15.9	15.71	16.6
	Main stem	1.10	1.0	2.13	2.0	0.60	0.7	3.82	4.0
Stem	Unfolded	1.60	1.5	2.03	1.9	5.97	6.9	9.85	10.4
	Primary branch	1.34	1.2	1.61	1.5	8.07	9.3	6.70	7.1
	Secondary branch	3.21	3.0	5.05	4.8	32.06	37.0	26.10	27.6
Flower (including bud)	0.07	0.1	0.17	0.2	2.97	3.4	3.24	3.4	
Root	0.42	0.4	0.31	0.3	6.81	7.9	7.06	7.5	
	0.06	0.1	0.06	0.1	3.56	4.1	4.87	5.1	
Total	107.27	100.0	104.45	100.0	86.67	100.0	94.69	100.0	

1.15 (leaf on secondary branch) to 6.41 (leaf on main stem). No differences could be observed in the amount of distributed ^{14}C -assimilation products in flowers and main stems between the RFM plot and bare soil.

Discussion

Reflective film mulching (RFM) was reported to alter environmental factors through the increase of the light intensity by the reflection of downward light^{5,9}, reduction of soil temperature^{1,8} and increase of air temperature above the reflective surface¹⁴. Yamaguchi¹² reported that reflective film mulching increased the light intensity of the middle to lower parts of the plant community. In this report, we confirmed that RFM increased the reflected light intensity at 10 cm above the mulching surface by 19 to 32% compared with black film mulching (Exp. 1-1). We also demonstrated that there was no difference in the photosynthetic activity of the leaves between the abaxial surface and adaxial surface when they were illuminated (Exp. 1-2). Supplemental illumination on the abaxial surface at 1/3 intensity of that on the adaxial surface increased the photosynthetic rate, and the response of the photosynthetic rate was greater at a low intensity, but supplemental illumination could not increase the photosynthetic rate at the saturation point. Moreover in the lower leaves CO_2 fixation was adequate, as their photosynthetic rate on a leaf area basis was 20 to 50% of that of the leaves at a higher position.

Photosynthetic activity on a single leaf basis was higher in lower leaves than in the higher ones because the size of the lower leaves was larger than that of the higher leaves. Saeki⁶ observed that herbaceous plants readily lost their photosynthetic activity compared with woody plants probably because of their short leaf age. However, Tanaka & Tanaka¹⁰ reported that the photosynthetic rate of carnation could remain at about approximately half of its maximum value even at an age of 230 to 270 days although the photosynthetic activity of carnation declined with age as in other herbaceous plants. The data shown here and presented by Tanaka & Tanaka¹⁰ suggested that the photosynthetic activity of carnation plant could last for a long period of time among herbaceous plants. Usually in cultural practices, CO_2 fixation of lower leaves may be relatively low due to the shortage of sunlight caused by self-shading. Increase of reflected light supplied to the lower leaves by RFM could

be as effective as supplemental downward light and may result in the increase of total CO_2 fixation of the plant community.

Although it was reported that RFM improved the cut flower yield by 30% compared with the plot without mulch, the reflection was unexpectedly low and less than 1/3 of downward direct solar radiation¹². Similar results were obtained in Exp. 1-1, when the use of PolyShine Cloth mulch, with a reflection percentage of 32%, increased the photosynthetic rate by 32% compared with the black film whose reflection was 3%. On the other hand, as shown in Exp. 1-3, the photosynthetic rate on a single leaf basis increased by only 16% at most by supplemental illumination and the percentage was not high enough to induce the increase of photosynthesis observed on a seedling basis. We therefore assume that the higher yield associated with RFM may be caused by the activation of CO_2 fixation of lower leaves rather than by the increase of CO_2 fixation of each leaf in an individual plant. Stanhill et al.⁹ reported that by covering the paths of a rose greenhouse in mid-winter with a highly reflective layer of aluminized polyester the downward solar radiation increased by an average of 3% compared with an untreated glasshouse. They estimated that the additional upward solar flux was 6 times as large as the measured increase in the downward flux because a large proportion of the upward flux of solar radiation was absorbed by the canopy. Their report also suggested that the photosynthetic rate of leaves that lack light, without a reflective surface, may increase.

Exp. 2 could not substantiate the presence of a higher CO_2 fixation in RFM that was suggested in Exp. 1, although the qualitative contribution of RFM was confirmed. Eventually, RFM activated photosynthesis especially in lower leaves. RFM increased the photosynthetic activity of leaves on the main stem or primary branch located in the middle to lower parts of the plant community. Though the total amount of $^{14}\text{CO}_2$ fixed was not influenced by the treatments (the value in the RFM plot was 97.4% of that of bare soil), the decrease of the amount during the 24 h dark period after exposure to labeled gas was less pronounced in the case of RFM, and resulted in higher contents (109.2%) than in bare soil. Tanaka & Tanaka¹⁰ reported that in carnation the ^{14}C -assimilation products fixed by higher leaves were translocated mainly to the axillary branches at higher nodes while those fixed by lower leaves were distributed mainly to the roots and stem. Miura

et al.⁴⁾ reported in an experiment of ¹⁴C-feeding to carnation that the main source organ should be the leaves on the primary branches, while the shoot apex and axillary bud displayed a strong sink activity. Exp. 2 indicated that RFM promoted the formation of such a large amount of assimilation products in higher leaves that the assimilation products remained in leaves even after most of them were translocated to the folded leaves as main sink organ. Similarly, lower leaves in the RFM plot fixed a sufficient amount of carbohydrates for distribution to roots, and the amount of ¹⁴C-assimilation products detected in roots became larger than that in the plot without mulch. Tanaka & Tanaka¹⁰⁾ also reported that the assimilates fixed by the leaves on lateral shoots at the same node mainly translocated to those shoots. These observations suggest that since the assimilates fixed in lower leaves may be mainly translocated to the branches developed at the lower nodes, RFM accelerated the flowering and increased the yield of carnation when lateral shoots at the lower nodes were used as cuttings for the cultivation of carnation.

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(Received for publication, November 2, 1995)