Soil properties and vegetable production with organic mulch and no-tillage system

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Summary

Organic mulch was formed by mowing wheat straw and hairy vetch in a no-tillage field. Soil temperature under the organic mulch was constant, and the organic mulch decreased soil temperature in summer and early autumn and increased it in middle and late autumn compared with a bare and tilled field. The pF was maintained at 1.5-1.8 even in the dry weather of August. Though much more release of inorganic nitrogen in the soil covered with organic mulch was recognized than in the bare and tilled field, there was no definite difference in the quantity of inorganic nitrogen released between the wheat straw and the hairy vetch mulch. Nitrogen concentration in lettuce produced in the hairy vetch mulch field was a little higher than that of lettuce in the bare and tilled field in autumn, 1995. Weed growth was suppressed effectively in the field covered with hairy vetch, and weed control was 53% in the wheat straw mulch field compared with that in the bare and tilled field. The yield of leaf lettuce (butter head), tomato and pod soybean in the hairy vetch mulch field was higher than in the wheat straw mulch field or the bare and tilled field.

Introduction

Some trials are under way for the establishment of a sustainable agriculture system. Some conservational tillage systems have been developed for reducing soil erosion and saving on

farm energy use. The crop rotation and utilization of winter legume crop are very important in the LISA program^{1,2)}. When autumn sowing cover crops such as legume and gramineous plants were mowed, killed by herbicide or died out naturally, organic mulch (not plowed, no-tilled soil covered with crop residue) will be formed in the field the following spring. Some crops have been produced in that condition, especially in the U.S.A.

Legume cover crops and gramineous plants have been used as a desiccated plant residue mulch (organic mulch) in a no-tillage system. It was reported that such organic mulch had some effects to improve soil environment, such as reducing soil erosion^{3,4)}, improving soil organic content⁵⁾, nitrogen availability⁶⁾, increasing soil water-holding capacity^{7, 8)}, decreasing soil temperature⁹⁾, and reducing weed growth^{10,11)}. Increased crop yield was also reported in the cultivation with a cover crop or organic mulch^{12,13,14)}.

There are only a few reports on crop production with cover crop and organic mulch in Japan^{15,16)}. When introducing an organic mulch system to crop production, it is necessary to consider environmental conditions such as climate and soil texture. Japan has much rain, yet sometimes water shortages are a concern outside of the rainy season (June and July).

In the present paper, we examined soil conditions formed by an organic mulch field with a no-tillage system, and investigated the possibility of vegetable production in that field.

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Materials and Methods

1. Cultivation of cover crops and lettuce in organic mulch field in late autumn (1995)

Hairy vetch (*Vicia villosa*) and wheat (*Triticum aestivum* cv. mulchmugi) were sown in tilled field with no chemical fertilizer in the University Farm, Niigata University on 17 July, 1995, and grown for two months. The sowing rate of these plants was 5 kg/10 a. On 17 September, 1995, organic mulch was produced by mowing these plants, and the plant growth (dry weight of foliage) and weed control (dry weight of weed) under these plants were measured. Next, lettuce seedlings (*Lactuca sativa* cv. Ontario, crisp head type) were planted by hand in the field covered with organic mulch, with a 35 cm interval between plants and 50 cm row spacing, on 17 September. Growth of lettuce under the organic mulch was compared with that of lettuce planted in the bare and tilled soil. Leafy head weight of lettuce grown in the bare and tilled soil and the organic mulch field (no-tillage) was measured on 5 December, 1995. The nitrogen concentration in the outer leaves of lettuce and the soil (10 cm depth) grown lettuce were examined with C/N corder (Yanaco Co. Ltd., MT-700). Five plants in each plot were used for analysis of total nitrogen in leaves. Soil samples were collected from 4 points (10 cm depth) in each plot and mixed them. Plants and soil samples were dried at 70°C for 48 hours and filtrated through 0.2 mm stainless mesh for analysis by C/N corder.

2. Soil environment when covered with organic mulch

On the following spring (1996), hairy vetch emerged and spread vines and leaves, and wheat elongated the culms. On 20 June, the foliage of hairy vetch and wheat were mowed with a bush cutter to form organic mulch (hairy vetch mulch and wheat straw mulch). The soil environment (soil temperature, soil moisture and nitrogen mineralization) was investigated mentioned below. Soil temperature was measured by an elec-

tric precision long-term remote thermograph (CAT-P 147, Isuzu Seisakusho Co., Ltd.) from 29 July to 30 October. The temperature sensor of the thermograph was positioned underground (15 cm depth) in each field. Soil moisture (pF) was investigated in the bare and tilled field and hairy vetch mulch field. A ceramic pF sensor (SPAD: PF 33, Fujiwara Co., Ltd.) was set underground (20 cm depth) in each field, and the pF was measured daily from 20 July to 31 August. On 5 October, 1996, the 10 cm depth soil samples were collected from 4 points in each field and dried in the greenhouse. Dried soil samples from 4 points in each field were mixed, and the mixed soil was used for nitrogen analysis. Then, the soil samples were incubated with the 60% of maximum water requirement at 30°C. Incubated soil sample (10 g) was extracted with 100 ml of 2 M-KCl. The inorganic nitrogen was measured by the Indo-phenol method ($\text{NH}_4\text{-N}$) and the Cadmi-column method ($\text{NO}_3\text{-N}$).

3. Vegetable production in organic mulch field (1996)

The seedlings of three vegetables, tomato (*Lycopersicon esculentum* cv. Zuiko 102 grafted with root stock tomato cv. Joint), pod soybean (*Glycine max* cv. shinkohirakata) and lettuce (*Lactuca sativa* cv. Okayama-saradana, butter head type), were planted in the organic mulch field (hairy vetch mulch and wheat straw mulch), and their yields were measured in comparison to those in the bare and tilled field, respectively. The cultivating period was 3 July to 20 September in Tomato, 29 July to 7 October in pod soybean and 29 July to 20 August in butter head lettuce. Tomatoes formed in the 2nd to 4th fruit cluster were harvested. Fungi were controlled with Bis-dithane [dizinc bis (dimethyldithio carbamate) ethylenebis (dithiocarbamate), Tokyo Yuki Co., Ltd.] in tomato and Sumitop-M [dimethyl 4,4'-0-phenylenebis (3-thioallo-phanate), Nihon Soda Co., Ltd.] in pod soybean. Pests were controlled with Sumithion [MEP (dimethyl 4-nitro-m-tolyl phosphorothioate), Nissan

Chemical Co., Ltd] in tomato and Diadinon [diethyl 2-isopropyl-4-methyl-6-pyrimidinyl phosphorothioate, Nissan Chemical Co., Ltd] in pod soybean.

The plot area was 40 m² (2 m × 20 m) and no chemical fertilizer was added to the soil in 1995 and 1996. In each plot, 6-10 plants were measured for growth and yield, and this experiment was designed with 2 replications. The experiments were conducted at the University Farm, Niigata University, Muramatsu, Niigata Prefecture, volcanic soil (soil texture ; SiC).

Results

1. Growth of cover crops and lettuce cultivation in autumn (1995)

Hairy vetch developed vigorously after the middle of August, 1995. Though weed emergence was observed in early and mid-August, 1995, almost all weeds were covered with foliage of hairy vetch when mowing. Wheat showed only vegetative growth from July to September because cv. mulchmugi is an autumn sowing variety. But the leaf emerging speed was slow.

When mowing on 17 September, 1995, a large amount of weeds (820 g DW/m²) was measured in the field without cover crops (Table 1). Weed growth was suppressed in the hairy vetch field (278 g DW/m²). Weed control in the wheat field was smaller than in the hairy vetch field. New weeds did not emerge after weeds and 2 cover crops (hairy vetch and wheat) were mowed by bush cutter on 17 September because the air

temperature decreased. The field was covered with dense foliage of hairy vetch after mowing (Fig. 1).

Leafy head weight of lettuce grown in wheat and hairy vetch mulch field was greater than in the bare and tilled field ; leafy head weight reached 277 g in the hairy vetch mulch field (Table 2).

The nitrogen concentration in a leaf of lettuce grown in the bare and tilled field was 3.44% (Table 3). A slightly higher nitrogen concentration (3.76%) was observed in a leaf of lettuce

Table 1 Growth of cover crops and weeds (1995)^z

Cover crop	Dry weight (g/m ²)	
	Cover crop	Weed
Bare soil	—	820 a
Wheat	28.8	504 b
Hairy vetch	19.4	278 c

^z Values within columns followed by the same letter are not significantly different according to Duncan's multiple range test, p=0.05.

Table 2 Lettuce growth in bare and tilled soil and organic mulch field^z

Mulch	Leaf length (cm)	Head weight (g)
Bare soil	14.1 a	160 a
Wheat	14.9 a	209 b
Hairy vetch	16.2 b	277 c

^z Values within columns followed by the same letter are not significantly different according to Duncan's multiple range test, p=0.05.

Fig. 1 Lettuce planted in the bare and tilled field (left) and hairy vetch mulch field (right) in 1995.

Table 3 Nitrogen concentration of soil and lettuce in the bare and tilled field and the hairy vetch mulch field²

Mulch	Soil (% of DW)	Leaf (% of DW)
Bare and tillage	0.70 a	3.44 a
Hairy vetch	0.69 a	3.76 b

² Values within columns followed by the same letter are not significantly different according to Duncan's multiple range test, $p=0.05$.

grown in the hairy vetch mulch field. The nitrogen concentration in the soil covered with the hairy vetch mulch was the same as that of the bare and tilled field.

2. Soil environment when covered with organic mulch (1996)

(1) Soil temperature

The diurnal range of soil temperature became small in the soil covered with hairy vetch mulch, compared with that of the bare and tilled field, in mid-summer (3 August), autumn (16 September) and late autumn (22 October), respectively (Fig. 2). On 3 August, although the maximum soil temperature in the bare and tilled field was 32°C, it was only 27°C in the hairy vetch mulch field. Soil temperature was about 20°C throughout both day and night on 16 September in the hairy vetch mulch field. On the other hand, the minimum soil temperature in the bare and tilled field showed 11°C, and increased to 14°C in the hairy vetch mulch soil on 22 October.

In the wheat straw mulch field, the diurnal change of soil temperature was small, the same as in the hairy vetch mulch field. Moreover, the

maximum soil temperature decreased to 24°C on 20 August, against 31°C in the bare and tilled field (Fig. 3).

(2) Soil moisture

From the end of the rainy season (23 July), there was good weather throughout July and August, except for 23 July, 15 August, 23 August and 24 August. The pF was 1.4 on 23 July (Fig. 4). The soil drying was rapid, and the pF increased after 24 July in the bare and tilled soil, eventually reaching 2.9, which is not suitable for root growth of tomato plants. Soil drying did not progress in the hairy vetch mulch field in good weather throughout the experiment, and the pF was 1.8 on 6 August, in spite of no rainfall for 2 weeks.

(3) Mineralization of inorganic nitrogen in soil

The NH_4 -nitrogen concentration increased until 3 days after incubation, and the NO_3 -nitrogen concentration increased gradually in any soil (Fig. 5). According to the change of nitrogen concentration, the inorganic nitrogen was supplied from the organic nitrogen in the soil examined. The concentration of NO_3 -N in the wheat and hairy vetch mulch soil was higher than in the bare and tilled soil; the difference in nitrogen concentration between the two mulch soils was not significant.

3. Weed control and crop yield in no-tillage field covered with organic mulch (1996)

(1) Weed control

In July and August, 343 g/m² of weed (Dry weight) emerged on the bare and tilled field (Fig. 6). The weed quantity decreased in the field covered with the wheat and hairy vetch compared

Fig. 2 Change of soil temperature when covered with hairy vetch mulch

Fig. 3 Change of soil temperature when covered with hairy vetch mulch and wheat mulch

Fig. 4 Change of pF value in the soil covered with or without hairy vetch mulch. (Rainfall: 52 ml at 23 July, 28 ml at 15 August, 27 ml at 23 August, 33 ml at August)

Fig. 5 Change of nitrogen mineralization in soil with or without organic mulch.

with the bare and tilled field, reaching 17 g/m² (Dry weight) in the hairy vetch mulch field, approximately 1 cm of plant residue thickness. Weed control was 53% in the wheat straw mulch field compared with the bare and tilled field. Lateral shoots developed from the wheat stubble.

(2) Crop yield

Vegetable seedlings could be transplanted to

the no-tillage soil covered with hairy vetch mulch because the mulch was soft and no stubble was left. Three vegetable seedlings planted in the hairy vetch mulch field grew vigorously compared with the bare and tilled field and the wheat straw mulch field. The yield of each of the 3 vegetables in the hairy vetch mulch field was significantly higher than in those of the

other fields (Fig. 7). The pod weight/10 plants and fruit weight/plant showed 485 g in pod soybean and 490 g in tomato cultivated in the hairy vetch mulch field. These yields were approximately more than 1.5 times or twice that of plants cultivated in the bare and tilled field and the wheat straw mulch field. The yield of the vegetables grown in the wheat straw mulch field was the same as those grown in the bare and tilled field in pod soybean and tomato.

The yield (fresh leaf weight) of butter head lettuce showed 42 g in the hairy vetch mulch field, 6 times that of the plants cultivated in the

bare and tilled field, and its yield in the wheat straw mulch was higher as well.

Discussion

Some data obtained in the present examination support the previous reports describing the soil environment when covered with organic mulch (plant residue).

Organic mulches generally decrease maximum but increase minimum soil temperature^{8,17)}.

Bare soil temperature rises 30°C in mid-summer and decreases to about 10°C in late autumn in Muramatsu, Niigata Prefecture. The optimum soil temperature for plant growth is known to change owing to the growth stage of vegetables, and tends to decrease as plants grow older. In general, high soil temperature near 30°C inhibited plant growth in most vegetables, except for melon, watermelon and cucumber. For plant growth, 25°C in tomato¹⁸⁾, 18-23°C in soybean and 13-18°C in lettuce are suitable temperatures¹⁹⁾. The hairy vetch mulch cooled in mid-summer and warmed in late autumn, so the soil temperature was close to optimum for plant growth. Besides, the soil temperature becomes stable under hairy vetch mulch conditions.

Hairy vetch desiccated mulch showed the effect of soil water retention. Soil water condition (pF; 1.4-1.8) formed in the hairy vetch mulch field was good for tomato growth, because pF 1.5-2.0 is recognized to be suitable for tomato growth after transplanting in open field²⁰⁾. How-

Fig. 6 Dry weight of weed emerged in July and August, 1996.

Fig. 7 Yield of 3 vegetables grown in bare soil and organic mulch field. Vertical bar indicates standard error.

ever, soil moisture is concerned with fruit quality, and soil water maintained under the organic mulch has to be estimated by the fruit quality of vegetables.

Increase of yield was recognized in any vegetable used in the examination. The increase of lettuce yield in late autumn of 1995 showed that more suitable growing conditions for lettuce are provided by the no-tillage and hairy vetch mulch, compared with the bare and tilled soil, because serious weed damage did not occur in any fields used and nitrogen absorption was increased in the lettuce grown in the hairy vetch mulch field in late autumn. It was reported that winter legume crops such as hairy vetch and crimson clover provided more N equivalent, approximately $100 \text{ kg} \cdot \text{ha}^{-1}$ in the conserved tillage^{13,21}. The mineralization of organic nitrogen in the soil covered with the hairy vetch mulch was also expected in this experiment. Further investigation is needed to determine the nitrogen supplying effect in the soil when covered with organic mulch.

It was supposed that weed emergence strongly affected the yield of the 3 vegetables in 1996. In tomato and pod soybean, which take a long time until harvest of mature fruit and edible bean, the yield decreased remarkably in the bare and tilled field and the wheat mulch field because of the greater weed quantity than in the hairy vetch mulch field. Besides, new lateral shoots developed from the stubbles of wheat mowed, and the possible nutritional competition between wheat with new lateral shoots and vegetables planted in the wheat straw mulch field was also a factor. On the other hand, butter head lettuce rapidly grows to harvest size in a relatively short period, and weed damage was small during growth. The difference in weed quantity between the wheat straw mulch and the hairy vetch mulch was supposed to be caused by ground cover ability, shading of ground—surface and decomposing speed of plant residue. Such characteristics will be investigated in order to determine useful cover crops. Nowadays, to pre-

vent environmental disruption, the development of chemical mulch film with easy decomposing ability in the field is much anticipated. Organic mulch is very useful because of its natural decomposing ability.

In some crop production with organic mulch in Japan, yields of sweet corn and watermelon produced in the no-tillage field with hairy vetch mulch were the same as those of the tilled and bare soil and the wheat straw mulch field¹⁵. Japanese apricot showed greater fruit weight and yield in mulch and no-tillage field¹⁶.

It is well known that the no-tillage system leads to saving energy²². However, when sowing the seeds of some crops in the no-tillage field, seed germination was not often observed to be uniform in some practices²³. In the present investigation, transplanting of vegetables were used to estimate the plant growth in the organic mulch and no-tillage field to prevent lack of uniformity in seedling growth. Recently, pod soybeans are transplanted into the field at the juvenile stage (with 2 leaves) in Niigata Prefecture. Field crops which are usually sown in the soil directly, such as corn and sorghum, were produced in the examination under legume organic mulch and no-tillage condition^{13, 24}. It is now necessary to establish a seeding technology for field crop production in the organic mulch and no-tillage field.

Conventionally, mulching effect and no-tillage effect on soil environment and crop development have been investigated separately. The cropping system combined with organic mulch and no-tillage in the present examination introduced new cultivating conditions for crop growth and human work. Besides, utilization of plant residue mulch, not chemical film mulch, is one of the field management utilizing plant function and mineralization of organic nitrogen by decomposing of legume plant residues in present examination. The present cropping system with organic mulch and no-tillage will be evaluated as one form of sustainable agriculture. Further investigation of cropping techniques and crop

growth are needed for the establishment of this system.

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Keywords :

organic mulch, no-tillage, soil temperature, soil moisture, weed prevention, nitrogen mineralization, hairy vetch, wheat

オーガニックマルチ・不耕起システムにおける土壌特性と野菜の試作

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摘 要

1995年7月に緑肥用コムギと1年性マメ科牧草のヘアリーベッチを栽培し、9月に刈り倒して「オーガニックマルチ・不耕起」状態で結球型レタスが無肥料で試作すると、無マルチ耕耘圃場・コムギマルチ圃場（出穂せず茎葉の残渣）・ヘアリーベッチマルチ圃場の順に収量が増加した。

1996年春季にコムギは出穂し、ヘアリーベッチは茎葉を繁茂させたので、6月に再度刈り倒して「オーガニックマルチ・不耕起」状態を作り、土壌環境を調査して、3種野菜を無肥料で試作した。オーガニックマルチ圃場の地温は無マルチ耕耘圃場より安定し、夏季や初秋では地温を低下させ、晩秋には地温を上昇させた。土壌水分に関して、地中15cmのpF値は無マルチ耕耘圃場では梅雨終了後急速に上昇したが、ヘアリーベッチマルチ圃場ではpF1.5～

1.8に維持され、保水性が示された。オーガニックマルチ下の土壌を10月に採集して培養すると、無機化窒素量は無マルチ耕耘圃場に比べて多かった。7～8月に発生した雑草量は無マルチ耕耘圃場に比べて、コムギマルチ圃場では53%に減少し、ヘアリーベッチマルチ圃場では約5%に減少した。ヘアリーベッチマルチ圃場で無肥料栽培したトマト・エダマメ・サラダナの収量は他より有意に高かった。

キーワード :

オーガニックマルチ, 不耕起, 地温, 土壌水分, 窒素無機化, 雑草抑制, ヘアリーベッチ, コムギ