Research Paper

Effect of No-Tillage and Hairy Vetch Mulch on Soil Properties and Tomato Yield in Plastic Greenhouse

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1. Introduction

To establish a production system that saves both energy and labor, alternative agricultural methods have been examined, mainly in the United States and Europe. A crop production system using a mulch of cover crop residue is thought to be one of the more promising alternative methods because of its low input of agricultural chemicals and improvement of soil properties (Sainju and Singh 1997; Araki and Ito, 1999). The soil is not tilled if plant residue mulch remains on the soil surface.

Legume winter cover crops provide substantial amounts of nitrogen to succeeding crops (Peoples et al., 1995; Sainju and Singh 1997; Kuo et al., 1996; Vigil and Kissel 1991). Sainju and Singh (1997) estimated that the yield increases of the summer crops following legumes were equivalent to those produced by nitrogen fertilizer applied 15 to 200 kg/ha. Hairy vetch (HV: Vicia villosa Roth.) is one of the more promising cover crops because its creeping vines cover the ground surface effectively. A plant residue mulch of hairy vetch is effective for weed control (Teasdale 1993) and produces positive changes in soil properties, such as holding soil moisture and stabilizing soil temperature (Hoyt and Hargrove 1986; Teasdale and Abdul-Baki 1995). Therefore, it is expected to be an alternative to polyethylene mulch. In addition, high levels of nitrogen are rapidly released into the soil when hairy vetch decomposes because of its high nitrogen concentration (approximately 4% of dry matter) (Abdul-Baki et al., 1997; Holderbaum et al., 1990; Mitchell and Teel 1977), and its low C : N ratio (Wagger 1989; Creamer et al., 1996). Released nitrogen supports the growth of summer crops subsequently planted even if hairy vetch residue remains on the ground surface (Abdul-Baki et al., 1996; Kuo et al., 1996).

When cover crops are remained as organic mulch on the field surface, the field is not able to be tilled. The no-till production system with plant residue mulch of cover crop has mainly been used in vegetable and upland crop cultivation in open plots in the USA (Sainju and Singh 1997). However, a large amount of fresh-market tomatoes
are grown mostly in plastic greenhouses in Japan because they produce good-quality fruits due to protection from damage by insects and rainfall in areas where it rains intermittently. It is important to investigate the possibility of no-till and plant residue mulch system in vegetable production in plastic greenhouse because cover cropping is one of saving system of agricultural inputs.

In the present study, fresh marketable tomatoes were grown in the tilled or no-tilled soil with hairy vetch residue mulch in the plastic greenhouse, and the effects of no-till and hairy vetch mulch on soil properties and tomato yields were examined for establishment of cover cropping in future.

2. Materials and Methods

All experiments were conducted in 1999 at Muramatsu Station of the Field Center for Sustainable Agriculture and Forestry, Niigata University, Muramatsu, Japan. The soil at Muramatsu Station belongs to the Andosol and soil type is SiC.

1) Field preparation

Four plots in field treatment were prepared in a plastic greenhouse (5.4 m in width × 16.2 m in length) by tillage and HV residue mulch; 1) a conventionally tilled plot without HV (Till), 2) a no-till plot without HV (NT), 3) a tilled plot with HV mulch (Till-HV), and 4) a no-till plot with HV mulch (NT-HV). The details of the four plots were as follows.

HV seeds were sown at the seeding density of 5 kg/10a in one half of an area of the plastic greenhouse on October 5, 1998, but were not cultivated in the other half of the tunnel (no HV plot). Using a bush cutter, HV was mowed on May 13, 1999, at the flowering stage. The soil in the half of the HV plot was not tilled and the HV residue was left on the ground surface of the NT-HV plot. In the Till-HV plot, the residue of HV was transferred outside of the plot after mowing and the soil was conventionally rotary-tilled (15-cm depth), and then the tilled soil was recovered with the HV residue again (Till-HV). Half of the no HV plot was rotary-tilled (Till) and the other half was not tilled, but only weeded (NT) before planting the tomatoes. Each plot was 7 m × 2 m, including 40 tomato plants. There was no replication due to the small area of the plastic greenhouses.

2) Tomato cultivation

Tomato (Lycopersicon esculentum M.) ‘Momotaro T93’ (Takii Co., Ltd.), grafted with ‘Kagemusha’ (Takii Co., Ltd.) for root stock, was used as the plant material. Both cultivars were sown on February 12 and 17, 1999, respectively, in a greenhouse in which the minimum temperature was kept above 15℃. ‘Momotaro T93’ was grafted with ‘Kagemusha’ using ‘Superwith’ (Nasnic Co., Ltd.) on April 2, 1999. The grafted tomatoes were transferred to plastic pots (10.5 cm in diameter) and grown with ‘Napra-power’, liquid fertilizer diluted 5 thousand fold (Yammer, Co., Ltd.). This liquid fertilizer contains some water soluble components such as N 15%, P2O5 20%, K2O 15%, Mg 1%, Mn 0.1% and B 0.1%. Forty seedlings were planted on May 14 when flowerlets in the 1st cluster began to bloom in each plot of the plastic greenhouse. In every plot, there were two lines on a flat row, 1 m distance between the lines and 40 cm distance between the plants in each line; planting density was 1,372 plants/10a (Fig. 1). In each plot, there were 3 sites including 6 tomato plants to measure growth and yield. Lateral buds were removed so as to elongate only one major stem in

Fig. 1 Tomato production in the field with (right) and without (left) hairy vetch (HV) mulch in plastic greenhouse.
each tomato plant. Pollination was carried out with a vibrator and 4 fruits were set in every cluster. Tomatoes were grown until September 30.

3) Fertilizer

Prior to tomato planting in all plots, high analysis compound fertilizer (12 kg N, 25 kg P₂O₅ and 15 kg K₂O) was applied per 10a as a basal dressing on the soil surface. Three kg/10a of each nitrogen and potassium were applied for topdressing by N-K high analysis compound fertilizer (NPK : 18-0-18) at flowering of the 3rd (June 23), 5th (July 7), 7th (July 21), 9th (August 4), 11th (August 18) and 13th (September 1) clusters. Liquid Calcium fertilizer including 10.5% CaO was sprayed every 2 weeks to prevent blossom end rot.

4) Soil Properties

(1) Irrigation

Three tension meters (DIK-8330, Daiki Rika Co., Ltd.) were set at a 10 cm depth in each plot tested for watering, and pF values were measured at 4:30 PM every day. When the pF value was higher than 2.5, watering (360 L/h) was done through an irrigation tube for 40 minutes from 9:30 AM of the following day. Irrigation was finished at September 25 because of late period of tomato cultivation.

(2) Soil hardness

Soil hardness was measured with a corn penetrometer (DIK-5520, Daiki Rika Co., Ltd.) at the start (May 20) and completion (September 30) of tomato production. Data on 10 points were obtained in every plot tested.

(3) Three-phase of soil

Distribution of the three-phase (liquid, solid and air) of examined soil was measured at a 10–20 cm depth with a soil three-phase meter (DIK-1120, Daiki Rika Co., Ltd.). Measurements were done at 10 sites in each plot tested. The difference of 3 phase between May and September was analyzed by t-test in all distribution.

(4) Soil and air temperature

Soil temperature at 20 cm depth was measured with a thermal data logger (Model SK-L200T, Sato Keiki Co., Ltd.) every hour during tomato production. Two sensors were set at 20 cm depth of soil in each plot. Besides, two sensors set at 2 m high from the ground for the measurement of air temperature around tomato fruit.

5) Nitrate concentration in leaf petiole

Leaf petioles just beneath fruits, 2–3 cm in diameter, were collected from 6 tomato plants in each plot. One gram of petiole was macerated with 19 ml distilled water, and the NO₃⁻ concentration was measured with an RQ flex (Merck Co., Ltd).

6) Tomato growth and yield

Plant length and stem diameter at 1–2 cm above the grafted portion were measured in 3 sites, using 6 plants/site, from May 28 to August 20. Tomatoes up to the 7th fruit cluster were harvested from July 7 to September 30, and their fresh weights were measured using 6 plants/site same as growth investigation. The fruit that weighed more than 115 g and showed no damage was considered as marketable.

7) Statistic analysis

Multiple range tests were performed by Tukey-Kramer method in the data on soil hardness, nitrate concentration in petiole, tomato growth and tomato yield. The difference in the distribution of three-phase of soil between May and September was analyzed by t-test.

3. Results

1) Soil Hardness

On May 20, soil hardness at a 10 cm depth measured 18.8 kgf/cm² and 11.0 kgf/cm² in NT and NT-HV plots, respectively, which were higher than those in tilled plots, Till and Till-HV (Fig. 2). The difference in soil hardness between Till and NT plots diminished as the soil depth increased. There was little difference in soil hardness between NT-HV and Till plots at 20 cm depth. The hardness of the plots with HV mulch was low compared with that of plots without HV mulch in
both Till and NT soil to a depth of 30 cm.

Soil hardness measured 17.8 kgf/cm² in NT and 15.0 kgf/cm² in NT-HV at a 10 cm depth on September 30, the end of the tomato harvest, which was higher than the hardness of Till (12.1 kgf/cm²) and Till-HV (11.8 kgf/cm²). However, significant differences were rarely observed among the 4 plots at soil depths below 20 cm. Soil hardness in tilled soil increased during tomato production so that the difference between tilled and no-till soil decreased.

2) Three-phase of soil

On May 20, air distribution in Till (39.2%) and Till-HV (37.6%) was higher than that in NT (31.8%) and NT-HV (31.3%) (Table 1). A high level of liquid-distribution was recognized in NT (34.2%) and NT-HV (35.0%) compared with that in tilled soil. Air distribution greatly decreased in Till, NT and Till-HV at September 30, but no major decrease was observed in NT-HV. Though liquid distribution changed in all plots during tomato production, those in NT and NT-HV were high compared to tilled soil. The solid distribution increased in all plots, 2.6–4.7%. The porosity of NT-HV plot measured 63.7% in September, a value close to those in tilled plot. As a rule, the change of the distribution of three-phase between May and September was small in NT-HV compared other plots.

3) Soil temperature

High air temperature continued from mid-July to early-September, 1999. Average soil temperature in NT-HV was 1–2°C higher from early June to early July than that in other plots (Fig. 3). On the other hand, that of tilled plots was 1°C higher in early August. After mid-August, there was not significant difference in soil temperature among the 4 plots.

4) Nitrate Concentration in Petiole

High concentrations of nitrate in the petioles, close to or more than 3,000 ppm, were observed in all plots in June, especially in Till-HV and NT-HV (Fig. 4). After June, the nitrate concentrations decreased as tomatoes were set in higher clus-
ters in all plots. Nitrate concentrations in the petioles of tomatoes grown in tilled plots, Till and Till-HV, were higher than those in no-tilled soil on July 1 and 8. They measured more than 1,500 ppm until July 8 in Till and until July 15 in Till-HV.

5) Tomato growth

Plant lengths in till, Till-HV and NT-HV were higher than that in NT (Fig. 5). Stem diameter in Till-HV was higher from late in May to late in August and that in NT was small. However, significant difference was not recognized among plots after August. Though vigorous growth such as strong elongation of lateral shoots was observed in Till and Till-HV plots, tomato growth in NT-HV was moderate compared to tilled plots during the examination.

6) Tomato Yield

Tomatoes were harvested mostly from July 9 to August 14, with the yield declining after August 18 (Data not shown). In the 1st and 2nd clusters, yields of 500-700 g/cluster were obtained, and the yields in Till-HV and NT-HV were higher than those in Till and NT in 1st cluster (Fig. 6). After 3rd cluster, tomato yield in Till-HV was tended to higher but significant difference was not recognized except for 3rd clusters.

The total tomato yield in Till-HV (3.23 kg/plant, 4.4 t/10a) was higher than that in Till (2.66 kg/plant, 3.65 t/10a) and NT (2.51 kg/plant, 3.4 t/10a), and followed by NT-HV (2.85 kg/plant, 3.9 t/10a) (Table 2). A wide range was recognized in the total and marketable yields from plants.
grown in Till, Till-HV and NT plots, especially in Till (0.77–4.02 kg/plant in total yield), whereas the range was small in NT-HV (2.37–3.44 kg/plant). Average fruit weight in Till-HV was the highest (155.1 g), followed by NT-HV (144.6 g). Marketable yields showed the same trends as total yields, being highest in Till-HV (2.72 kg/plant, 3.7 t/10a), followed by NT-HV (2.34 kg/plant, 3.2 t/10a). The ratio of marketable fruit weight to total fruit weight was more than 80% in Till-HV and NT-HV.

4. Discussion

(1) Soil properties and temperature

Crop production in no-tilled soil with HV mulch was conducted mainly in an open plot, and soil properties were changed by 2 factors, i.e., no-till and HV mulch, compared with conventionally tilled and bare soil. Some recognized effects of no-till and hairy vetch mulch on soil properties in a plastic greenhouse are mentioned below.

Soil hardness in NT-HV was greater than in tilled soil, but less than that of NT at tomato transplanting. Reduction of soil hardness was

![Fig. 6 Fruit weight in each cluster of tomatoes grown in tilled and no-till soil with or without hairy vetch. Values followed by the same letter are not significantly different in each fruit cluster according to Tukey-Kramer test (p = 0.05).](image)

Table 2 Comparison of total and marketable yield of tomatoes grown in tilled and no-tilled soil with or without hairy vetch mulch

| Treatment | Total Average yield (kg/plant) | Total Range (Max.–Min.) | Total Average fruit weight (g) | Marketable Average yield (kg/plant) | Marketable Range (Max.–Min.) | Marketable Average fruit weight (g) | Frequency (Frequency) |
|-----------|---------------------------------|------------------------|-------------------------------|-------------------------------------|-------------------------------|-----------------------------------|----------------------|
| Till      | 2.66b                           | 4.02–0.77              | 134.7bc                       | 1.97b                               | 3.49–0.39                     | 174.7ab                          | 74.1                 |
| NT        | 2.51b                           | 4.18–1.47              | 129.8c                        | 1.82b                               | 3.68–0.41                     | 169.6b                           | 72.5                 |
| Till-HV  | 3.23a                           | 4.20–1.49              | 155.1a                        | 2.72a                               | 3.92–1.12                     | 183.1a                           | 84.2                 |
| NT-HV    | 2.85ab                          | 3.44–2.37              | 144.6ab                       | 2.34ab                              | 3.25–1.54                     | 173.0ab                          | 82.1                 |

xRange: Maximum and Mininum yield/plant in 18 plants, pooling all plants in 3 areas.
yFrequency: ratio of marketable yield to total yield
xValues followed by the same small letter are not significantly different according to Tukey-Kramer test (p = 0.05)
recognized by HV mulch compared with bare and NT soil at the beginning of tomato production. This reduction was caused by promoting soil aggregates near the ground surface as reported by McVey et al. (1989) and by an increase of porosity from the growth of HV roots.

In general, no difference in soil hardness has been found between tilled soil and no-till soil at deep layers (Chaplin et al., 1986; Whitely and Dexter 1982; Sakai 1988), and the same trend was observed in the present study. The difference in soil hardness near the ground surface among the tested plots with tillage and HV mulch declined in September. It is thought that tomato root growth was not inhibited even in no-tilled soil (NT) if it was covered with HV residue.

Water holding capacity was reported as one of the important characteristics of no-tilled soil (Kanazawa 1995). The air-distribution was increased by tillage and liquid-distribution was increased by no-till in our present study. This phenomenon coincides with the results obtained in open-plot studies (Mielke et al., 1986; Roth et al., 1988). The change in the three phases of soil by HV mulch during our study was minor, especially in NT-HV, i.e., no-till soil with HV mulch had the characteristics to maintain the three phases of soil.

A decrease of soil temperature by HV mulch in mid-summer was recognized in some experiments (Teasdale and Mohler 1993; Araki and Ito 1999). In fields with a cover crop mulch, it was reported that holding of soil moisture increased because of improved water infiltration (McVey et al., 1989) and a decline in water evaporation from the soil surface (Sainju and Singh 1997). Therefore, it is thought that the holding of soil moisture played a role in the reduction of soil temperature in mid-summer.

However, the reduction effect of soil temperature by HV mulch was not observed in the greenhouse examination. Recently, irrigation management under low soil moisture has been performed for the production of high-quality tomatoes, and watering was carried out when the pH reached 2.5 in this study. Such management is thought to be one reason for the reduction in the temperature-decreasing effect of HV mulch, besides the experiment was carried out in mid summer.

(2) Growth and yield of tomato

Nitrate in the petiole can be used as one indicator of vegetable growth (Roppongi 1991, Yamada et al., 1995). Roppongi (1991) reported that it is necessary to maintain 1,000–2,000 ppm nitrate in the petiole sap to obtain an average yield in semi-forcing tomato production in a greenhouse. In the present study, high nitrate concentrations in the petiole were observed in June, especially in HV mulch, when tomatoes of the 1st and 2nd clusters were thickening. HV is thought to contribute to tomato growth and fruit enlargement in the early stage. Though nitrate concentration in the soil was increased by continuous top dressing during tomato production, nitrate in petioles decreased in tomatoes grown in all soils after July. This phenomenon indicated that N-supplementation with topdressing did not contribute to nitrate in the petiole. Further study is needed on how to maintain a high concentration of nitrate in petioles until the late stage of tomato production so as to obtain a high yield.

Top growth was inhibited when root growth was poor in the compacted no-tilled soil (Tsuji, 1998). Plant length in NT-HV developed same as that of tilled plots because HV mulch reduced soil hardness. Thus, HV mulch improves top growth which is inhibited in NT soil.

The highest tomato yield occurred in Till-HV, followed by NT-HV, confirming that the yield of tomatoes grown in the soils with HV mulch was higher than in those without HV. Yield increase by cropping with HV mulch has been reported in tomato production (Abdul-Baki and Teasdale 1993; Kelly et al., 1995; Abdul-Baki et al., 1996). Total yield was closely associated with the nitrate in the petiole rather than in the soil. It is thought that HV promoted the early growth of tomatoes, and our results confirmed that. The range of yield/plant was small in NT-HV, and such characteristics are important since medium-sized fruit is the most marketable kind.
Based on our observations, HV contributed to both growth promotion and yield-increase in tomato production. No-till treatment led to problems with soil hardness and the three phase of soil. However, in the NT-HV mulch, such problems did not occur, and similar or greater yields were obtained compared with Till plots.

Because the examined plot was converted to grassland, a year-round trial was not possible. The present data were obtained from examination for a year, and fundamental results were obtained. HV residue-supplemented tomatoes exhibited high vigor, higher marketable yield and delayed senescence compared to those grown in bare soil in a pot examination under greenhouse conditions in the USA (Kumar et al., 2005). More years of observation of tomato yield will be needed.

Acknowledgements

The authors wish to thank Messrs. M. Ito, Y. Yamashita, Y. Matsuo, T. Yamazaki, Y. Watanabe, M. Ishimoto and T. Sato, Faculty of Agriculture, Niigata University, for their technical support and useful discussion during tomato production in the plastic greenhouse.

Summary

Effectiveness of the no-till and plant residue mulch of hairy vetch (HV) on soil properties and tomato (Lycopersicon esculentum Mill.) yield was examined in plastic greenhouse, andosol soil, in Muramatsu Station, Niigata University. HV was sown at the seeding density of 5 kg/10a on October 5, 1998 and mowed on May 13, 1999. Tomato plants ‘Momotaro T93’, grafted with ‘Kagemusha’, were planted in 4 types of field, conventionally tilled soil (Till), no-tilled soil (NT), tilled soil with HV mulch (NT-HV) and no-tilled soil with HV mulch (NT-HV) in a plastic greenhouse on May 14 and grown to September 30. Soil hardness in no-tilled soil was higher than that in tilled soils, however HV mulch decreased high soil hardness shown in NT and lightened the ratio-change in three-phases of soil during tomato production in the soil environment. Tomato yield in Till-HV was highest, following NT-HV, and that in NT was smallest. HV contributed high nitrate concentration in tomato plants in early growth period, and led to vigorous growth and fruit enlargement in tomato productivity.

Key Words

hairy vetch (Vicia villosa R.), nitrate, no-till, plastic greenhouse, residue mulch, soil hardness, soil temperature, three phase of soil, tomato yield

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摘 要

新潟大学農学部村松ステーション（黒ボク土）で、プラスチックハウスでの土壌特性の変化とトマト収量に及ぼす耕起とヘアリーベッチ（以下 HV）マルチの影響を調査した。1998年10月5日にHVを5kg/10aの密度で播種し、1999年4月にHV生育場所にハウスを設置し、5月13日に刈り倒して残渣マルチとした。ハウス内の4試験区に、台木‘影武者’に接ぎ木した‘桃太郎 T93’を5月14日に定植し、9月30日まで栽培した。

試験区は①耕起、②不耕起、③耕起後にHVを敷く（耕起-HV）、および④不耕起にHVを敷く（不耕起-HV）の4種とした。プラスチックハウスへの不耕起とHVの導入について、土壌環境からみると、不耕起では高い土壌硬度を示すのが、不耕起-HVでは土壌硬度を低下させ、土壌3相の構成比率の変化を緩和することが明らかになった。トマト収量は耕起-HVで最大となり、ついて耕起と不耕起-HVで、不耕起では減少した。HVマルチはトマト生育初期にトマト植物体中の硝酸含有量を高め、それが生育促進と収量増加に結びつくと考えられた。

キーワード

硝酸態窒素、植物残渣マルチ、地温、土壌硬度、土壌3相、トマト収量、不耕起、プラスチックハウス、ヘアリーベッチ