Interseeding a Cover Crop as a Weed Management Tool is More Compatible with Soybean than with Maize in Organic Farming Systems

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Abstract: Weeds are the most serious threat to crop production in organic farming systems. Information on the spatial distribution of weeds is important for effective weed management. The objective of this study was to evaluate the effect of the ground cover of the main crops (soybean and maize) and cover crop on the spatial distribution of weeds for two row sections, ‘within the row (IR)’ and ‘between the rows (BR)’. The cover crop was interseeded in BR 3 – 4 weeks after sowing the main crops in two years, and weed density and vegetation cover ratio (VCR, an index of ground cover) of the main crops and cover crop were measured. There was a significant difference in the spatial distribution of weeds between the two main crops. In IR, weed density was higher in maize than in soybean, while in BR, it was higher in soybean. This means that weed suppression in IR was more important for maize, while the suppression in BR was more important for soybean. The negative relationship between VCR of the main crop plus cover crop and weed density in each row section suggests that the difference in ground cover was one of the reasons for the difference in weed density between the two main crops. The cover crop markedly increased the VCR in BR, but only slightly increased VCR in IR in both main crops. These results suggest that the cover crop was more compatible with soybean than with maize, because the high weed density in IR of maize could not be decreased sufficiently by the slight increase of VCR in BR by the cover crop.

Key words: Canopy structure, Ground cover pattern, Maize (Zea mays L.), Soybean (Glycine max Merr.), Vegetation cover ratio, Weed spatial distribution.

Weeds cause significant crop yield loss (Swanton et al., 1993) and are one of the most serious threats to crop production particularly in organic farming systems (Clark et al. 1998). Weed control without using herbicides is necessary for crop production in organic farming systems.

One of the alternatives to herbicides is interseeding a cover crop. Abdin et al. (2000) reported that weeds could be suppressed significantly with little effect on maize (Zea mays L.) yield by interseeding the cover crop 10 and 20 days after maize emergence. Uchino et al. (2009) examined the effects of interseeding date of the cover crop on the growth of the main crop and weeds in organic farming systems, and revealed that weed growth was suppressed sufficiently without significant yield reduction of the main crop when the cover crop was sown 3 weeks after sowing the main crop. In that study, the effects of the cover crop on weed growth varied with the main crop species, i.e., the cover crop decreased the weed density by 59% in soybean (Glycine max Merr.), while by 29% in maize. For more effective and reliable weed suppression, it is necessary to understand the growth dynamics of the main crops, cover crop and weeds in more details.

Information on spatial distribution of weeds is important for effective weed suppression (Bhowmik, 1997; Cardina et al., 1997; Gerhards and Christensen, 2003). A greater precision in the monitoring of the spatial distribution of weeds is needed for the estimation of crop yield loss (Auld and Tisdell, 1987) and decision-making in weed control (Auld and Tisdell, 1988). The spatial distribution of weeds is affected by many factors, for example, cultural practices...
We consider that plant canopy structure is another factor affecting the spatial distribution of weeds through changes in environment beneath the canopy. Significant relationships of the canopy structure with environment beneath the canopy have been reported. For example, Drouet and Kiniry (2008) simulated the relationship between maize canopy structure and light transmission by using three-dimensional models. They found that the amount and distribution of transmitted light was strongly affected by the canopy structure: the amount of transmitted light was higher between the maize rows than on the maize rows especially at the early growth stage. Sharratt and McWilliams (2005) also revealed a significant effect of maize leaf distribution on soil temperature: the soil temperature was lower when leaves were distributed more uniformly.

On the other hand, environmental factors also have a significant effect on weed growth. For example, soil temperature, light intensity and light quality are known to affect weed germination and growth (Liebman and Davis, 2000; Zimdahl, 2004). Guo and Al-Khatib (2003) reported that growth of redroot pigweed (Amaranthus retroflexus L.), which is one of the most troublesome weeds in many cropping systems, was enhanced at 25/20°C (day/night temperature) compared to other temperature regimes.

Although the relationship between environmental factors and canopy structure or weed growth have been reported separately, the relationship between ground cover of crop vegetation and the spatial distribution of weeds within a field has not been studied directly or quantitatively. The objective of the present study was to provide a better understanding of the quantitative relationship of the ground cover of the main crops (soybean and maize) and cover crop with the spatial distribution of weeds. To address this issue, we employed the vegetation cover ratio (VCR; also called mulch cover percentage (Steinmaus et al., 2008)), which is the percentage of area covered by vegetation to unit soil surface area and was proved to be a good index of maize or soybean performance in our previous study (Uchino et al., 2009). The VCR and density of weeds that were taller than 40 cm were calculated on two row sections, ‘within the row (IR)’ and ‘between the rows (BR). The difference in weed density between soybean and maize, effect of the cover crop on weed density and relationship of VCR of main crops and/or cover crop with weed density were analyzed in each row section.

**Materials and Methods**

The field experiments were carried out at the Field Science Center for the Northern Biosphere, Hokkaido University (Sapporo, Hokkaido, Japan, 43°04’N, 141°20’E) in 2005 and 2006. The soil was brown lowland (Fluvisol in FAO classification (IUSS Working Group WRB, 2006)) with a pH 6.0 – 6.2 and approximately 4.5% organic matter. Soybean ‘Toyomusume’ (a medium maturing and determinate type variety) and maize ‘39H32’, an early maturing (relative maturity: 85 days) dent flint variety, were planted as the main crops in organic farming systems on two adjacent fields with the same soil type and chemical properties. One of the fields was allocated to soybean in 2005 and maize in 2006, and the other to maize in 2005 and soybean in 2006. Main crops were grown under the conditions with or without a cover crop of winter rye (Secale cereale L.) ‘Fuyumidori’ and hairy vetch (Vicia villosa Roth) ‘Mameya’ as gramineous and...
leguminous cover crop, respectively. These cover crops are widely used as green manure crops in this region.

Two to four weeks before sowing the maize seed, fully ripened compost (N: 0.73%, P$_2$O$_5$: 0.59%, K$_2$O: 0.87% w/w in fresh weight) was broadcasted and incorporated into the soil (at a depth of ca. 10 cm) at 40 and 30 t ha$^{-1}$ in 2005 and 2006, respectively. In addition, one t ha$^{-1}$ of fermented organic fertilizer made mainly from fish meal, fish bone, palm ash and rapeseed oil cake (N: 5%, P$_2$O$_5$: 6%, K$_2$O: 4%; manufactured by Katakura Chikkarin Co., Ltd., Tokyo, Japan) was applied ca. 5 cm below the seeding furrow of the main crop before seed sowing of maize. Application rate of compost and fermented organic fertilizer in soybean was reduced to half relative to maize because of the nitrogen fixation by soybean.

The experiment was arranged in a randomized complete block design with four replications with a plot size of 3 m × 4 m, which consisted of five soybean rows planted 60 cm apart with 20 cm distance between plants, or four maize rows planted 75 cm apart with 18 cm distance between plants. Soybean seed was sown on 26 May 2005 and 18 May 2006, whereas maize was sown on 21 May 2005 and 18 May 2006 (Fig. 1). There were two treatments: (a) no cover crop (NoC) – cover crop was not sown.; (b) with a cover crop (WithC) – in 2005, main crops were grown with winter rye or hairy vetch, and these two cover crop treatments were averaged because there was no significant interaction with cover crop treatment in any of the measured variables (Uchino et al., 2012). In 2006, soybean and maize were grown with winter rye and hairy vetch, respectively. Cover crop seeds were interseeded manually in the interrow space of main crops at a rate of 333 and 320 seeds m$^{-2}$ in soybean and maize, respectively, 21 – 28 days after sowing the main crops (DAS) (Fig. 1). In both treatments, weeds were completely removed by inter-row tillage and hand weeding prior to sowing the cover crop.

Water was applied at 28 and 33 DAS in maize (total: 42 mm) and at 29 DAS in soybean (23mm) in 2005 and at 1 DAS in maize (19 mm) and 2 DAS (19 mm) in soybean in 2006, because soil had dried due to less rainfall.

The VCR of main crops (VCR$_m$) and cover crop (VCR$_c$) were recorded at weekly intervals until canopy closure. Farred images of the center rows were taken from 1 to 3.5 m above ground by using a cover ratio camera (Kimura Oyokogei, Saitama, Japan). The measurement areas of the VCR were 80 × 120 cm (i.e., 4 plants × 2 rows) and 90 × 75 cm (i.e., 5 plants × 1 row) in soybean and maize, respectively. For analysis of VCR$_{m+c}$ cover crops and weeds were cut off manually using an image processing program (Adobe Photoshop Elements version 1.0J, Adobe Systems, CA, USA), and then VCR$_{m+c}$ was calculated by using software (Kimura Oyokogei, Saitama, Japan) after image binarization. The VCR$_c$ was also analyzed by the similar procedure.

At harvest of the main crops (half milk-line stage of maize and physiological maturity stage of soybean), the number of weeds that were taller than 40 cm and the distance of each weed from the main crop row were recorded. In addition, the dry weight of aboveground weed biomass was measured only in 2006. The effect of ground cover of crop vegetation on the weed growth was examined by calculating the VCR of the main crops plus cover crop (VCR$_{m+c}$) and weed density on two row sections, IR and BR (Fig. 2). Then, the relationship between the VCR$_{m+c}$ at 150ºC·day after weeding and interseeding and the weed density at the harvest stage of main crops were analyzed in each row section. The VCR at this accumulated effective temperature (150ºC·day) could be used as a reliable index to evaluate weed suppression ability in a cool summer region, Hokkaido (Uchino et al., 2009, 2012). The accumulated effective temperature for dominant weed was calculated as the sum of daily mean air temperature minus lower threshold temperature of the dominant weed for germination. In the present study, lower threshold temperature of redroot pigweed, which was a dominant annual weed in the present field, was assumed to be 10ºC (Wiese and Binning, 1987). Meteorological data were obtained from the Sapporo District Meteorological Observatory (43º04’N, 141º20’E).

Statistical analysis was conducted using the SPSS software (version 14.0J, SPSS Japan). The row section factor was considered as a sub-plot nested within the main plot, cover crop treatment. To analyze the effect of year and main crop species, we performed analysis of variance (ANOVA) with a combined model (McIntosh, 1983). The year, main crop species, cover crop treatment and row section (IR or BR) were treated as fixed factors, and replication was treated as a random factor.
Results

1. Climatic conditions

Figure 1 shows the daily mean air temperature and precipitation during the growing period in 2005 and 2006. The temperature from seed sowing of main crops to the end of June was lower in 2006 than in 2005 and the ten-year average. The average temperature in June was 15.7ºC in 2006 while it was 18.3 and 16.8ºC in 2005 and the ten-year average, respectively. Total precipitation during the growing period was about 100 mm less in 2006 than in 2005 for both main crops.

2. Weed spatial distribution

Figure 3 shows the weed density in relation to the distance from the main crops, soybean (a-d) and maize (e-h) in 2005 (a, b, c, f) and (c, d, g, h) 2006. Abbreviations of treatments: NoC: no cover crop; WithC: with cover crop.
pronounced in IR for both soybean (Fig. 3b, d) and maize (Fig. 3f, h).

For a quantitative analysis of the difference in the spatial distribution of weeds, the weed density was calculated on IR and BR. The ANOVA table is shown in Table 1 (interaction effects of year, main crop species and cover crop treatment) and Table 2 (interaction effects of row section with the other factors). There was a significant interaction between year and main crop species: in soybean, weed density was higher in 2006 than in 2005, while in maize, the difference between years was not significant (Table 1). The main effect of cover crop was significant and the interaction between cover crop treatment and year was not significant: weed density was lower in WithC than in NoC in both two years.

The interaction between row section and year was significant: in BR, weed density was much higher in 2006 than in 2005, while the difference was less pronounced in IR (Table 2). The significant interaction between row section and main crop species indicates that weed density was higher in maize than in soybean in IR, while it was higher in soybean than in maize in BR. The interaction between row section and cover crop treatment was also significant: weed density was decreased markedly by the cover crop in BR, but only slightly in IR. In addition, the non-significant interaction between row section and cover crop treatment or main crop species indicates that this decrement of weed density by the cover crop did not differ significantly between soybean and maize, i.e., cover crops did not decrease markedly either low weed density in IR of soybean or high weed density in IR of maize (Fig. 4). The weed density was also affected significantly by a three-way interaction between row section, cover crop treatment and year (Table 2): the decrease in weed density by the cover crop was much larger in BR in 2006 than in the other row section or year (detailed data not shown).

The weed dry weight, which was measured only in 2006, showed a trend similar to the weed density. There was a

### Table 1. Interaction effects of year with main crop species and cover crop treatment on the density of weeds (plant m⁻²) that were taller than 40 cm at the harvest stage of main crops.

| Source                  | Year (Y)          |          |          |
|-------------------------|-------------------|----------|----------|
|                         | 2005              | 2006     |          |
| Main crop species (MC)  |                   |          |          |
| Soybean                 | 1.4 ± 0.2         | 10.4 ± 1.0 |          |
| Maize                   | 7.0 ± 1.7         | 6.8 ± 1.3 |          |
| Cover crop treatment (CC)|                   |          |          |
| NoC                     | 5.6 ± 1.4         | 12.1 ± 1.0 |          |
| WithC                   | 2.8 ± 0.4         | 5.1 ± 1.3 |          |
| ANOVA (Mean squares with significance) | |          |          |
| Y                       | 309.3 **          |          |          |
| MC                      | 16.1 NS           |          |          |
| Y × MC                  | 339.5 **          |          |          |
| Pooled error A          | 22.8              |          |          |
| CC                      | 383.0 **          |          |          |
| CC × Y                  | 74.0 NS           |          |          |
| CC × MC                 | 13.4 NS           |          |          |
| CC × Y × MC             | 0.2 NS            |          |          |
| Pooled error B          | 25.8              |          |          |

Values are mean ± standard error (n = 4).
Abbreviations: NoC: no cover crop; WithC: with cover crop; NS, not significant.
** Significant at 1% level of probability.

### Table 2. Interaction effects of row section with year, main crop species and cover crop treatment on the density of weeds (plant m⁻²) that were taller than 40 cm at the harvest stage of main crops.

| Source                  | Row section (R) |          |          |
|-------------------------|-----------------|----------|----------|
|                         | IR              | BR       |          |
| Year (Y)                |                 |          |          |
| 2005                    | 5.7 ± 1.5       | 2.7 ± 0.3 |          |
| 2006                    | 6.6 ± 1.1       | 10.6 ± 1.2 |          |
| Main crop species (MC)  |                 |          |          |
| Soybean                 | 3.1 ± 0.5       | 8.7 ± 1.4 |          |
| Maize                   | 9.2 ± 2.1       | 4.6 ± 1.0 |          |
| Cover crop treatment (CC)|                 |          |          |
| NoC                     | 7.4 ± 1.8       | 10.3 ± 0.8 |          |
| WithC                   | 4.9 ± 1.0       | 3.1 ± 0.9 |          |
| ANOVA (Mean squares with significance) | |          |          |
| R                       | 4.1 NS          |          |          |
| R × Y                   | 191.5 **        |          |          |
| R × MC                  | 417.0 ***       |          |          |
| R × CC                  | 87.3 *          |          |          |
| R × Y × MC              | 19.8 NS         |          |          |
| R × CC × Y              | 121.6 *         |          |          |
| R × CC × MC             | 43.1 NS         |          |          |
| R × CC × Y × MC         | 7.3 NS          |          |          |
| Pooled error            | 16.9            |          |          |

Values are mean ± standard error (n = 4).
Abbreviations: NoC: no cover crop; WithC: with cover crop; IR: within the row; BR: between the rows; NS, not significant.
* Significant at 5% level of probability.
** Significant at 1% level of probability.
*** Significant at 0.1% level of probability.
significant positive correlation between the weed density and the weed dry weight in 2006 ($r = 0.88$, $p = 0.003$, $n = 8$), suggesting that the density of weed that was taller than 40 cm, was a useful indicator of weed biomass.

3. **Ground cover pattern of main crops and cover crop**

Figure 5 shows the time course of VCR$_{m+c}$ in both soybean and maize crops in each row section. The VCR in NoC was higher in 2005 than in 2006, while the VCR$_{m+c}$ in BR was increased markedly by sowing a cover crop in both soybean and maize crops.

For a statistical analysis, ANOVA and mean values of the VCR at the accumulated effective temperature of 150°C·day after weeding and interseeding are shown in Table 3 and Table 4, respectively. The accumulated effective temperature of 150°C·day corresponded to 45 (soybean) and 40 (maize) DAS in 2005 and to 47 (soybean) and 44 (maize) DAS in 2006.

The main effect of cover crop treatment and its interaction with the other variables was not significant in the VCR$_m$ (Table 3), indicating that the growth of the main crops was not suppressed by the cover crop at 150°C·day. The interaction between row section and year occurred because the VCR$_m$ was lower in 2006 than in 2005 in both IR and BR, and this difference was much larger in BR (difference between years: 23.9%) than in IR (16.3%) due to the markedly-low VCR$_m$ in BR in 2006 (Table 4). The interaction between row section and main crop species was also significant: in IR, the VCR$_m$ was much higher in soybean than in maize (difference between main crops: 26.4%), while in BR, the difference of the VCR$_m$ was very
small between the two main crops (1.2%).

Regarding the VCR\textsubscript{m+c}, all main effects and interactions were significant (Table 3). A significant three-factor interaction between row section, cover crop treatment and main crop species indicates that the effect of cover crop on the VCR\textsubscript{m+c} differed with the main crop species and row section. In IR, the cover crop increased the VCR\textsubscript{m+c} by 5.8% (average of two years) in maize but only by 1.1% in soybean (Table 4), VCR\textsubscript{m+c} in WithC being significantly higher than in NoC in maize but not in soybean. In BR, a cover crop increased the VCR\textsubscript{m+c} by 35.2% and 16.1% in maize and soybean, respectively, causing a significantly higher VCR\textsubscript{m+c} in WithC than in NoC in both main crops. In addition, a significant four-factor interaction between row section, cover crop treatment, year and main crop species indicates that this increment of the VCR\textsubscript{m+c} in BR by the cover crop was larger in 2006 than in 2005, but the difference between years was small in IR. In particular, the VCR\textsubscript{m+c} in BR of maize was increased markedly by the cover crop in 2006, indicating vigorous growth of winter rye.

### Table 4. The vegetation cover ratio (%) of main crop (VCR\textsubscript{m}), cover crop (VCR\textsubscript{c}) and main crop plus cover crop (VCR\textsubscript{m+c}) at 150°C·day after weeding and interseeding cover crops in each row section.

|          | IR   | BR   |
|----------|------|------|
|          | Soybean | Maize | Soybean | Maize |
| 2005     |       |      |       |      |
| NoC      |       |      |       |      |
| VCR\textsubscript{m} | 93.5 ± 0.7 | 65.3 ± 2.7 | 37.3 ± 5.0 | 32.1 ± 5.1 |
| VCR\textsubscript{c} | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| VCR\textsubscript{m+c} | 93.5 ± 0.7 | 65.3 ± 2.7 | 37.3 ± 5.0 | 32.1 ± 5.1 |
| WithC    |       |      |       |      |
| VCR\textsubscript{m} | 93.5 ± 0.4 | 66.4 ± 2.3 | 32.1 ± 4.6 | 31.3 ± 4.4 |
| VCR\textsubscript{c} | 0.3 ± 0.1 | 4.0 ± 0.6 | 12.1 ± 4.5 | 6.4 ± 0.3 |
| VCR\textsubscript{m+c} | 93.8 ± 1.0 | 70.3 ± 1.9 | 44.2 ± 1.2 | 37.7 ± 4.0 |
| 2006     |       |      |       |      |
| NoC      |       |      |       |      |
| VCR\textsubscript{m} | 76.3 ± 4.7 | 49.2 ± 3.4 | 9.7 ± 3.2 | 9.3 ± 1.7 |
| VCR\textsubscript{c} | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 ± 0.0 |
| VCR\textsubscript{m+c} | 76.3 ± 4.7 | 49.2 ± 3.4 | 9.7 ± 3.2 | 9.3 ± 1.7 |
| WithC    |       |      |       |      |
| VCR\textsubscript{m} | 75.5 ± 1.7 | 52.5 ± 2.5 | 8.4 ± 1.6 | 9.9 ± 1.1 |
| VCR\textsubscript{c} | 1.9 ± 0.7 | 7.6 ± 1.4 | 20.0 ± 2.4 | 63.9 ± 2.8 |
| VCR\textsubscript{m+c} | 77.4 ± 1.2 | 60.1 ± 3.3 | 28.4 ± 1.8 | 73.8 ± 2.4 |

Values are mean ± standard error (n = 4).
Analysis of variance is shown in Table 3.
Abbreviations: IR: within the row; BR: between the rows; NoC: no cover crop; WithC: with cover crop.

4. Relationship between the VCR\textsubscript{m+c} and weed density

Figure 6 shows the relationship between the VCR\textsubscript{m+c} at 150°C·day after weeding and interseeding cover crop and the weed density that were taller than 40 cm at the harvest stage of main crops in each row section. When analyzing the relationship in each row section, there were significant negative regressions between the two parameters in both IR and BR: the weed density was lower when the VCR\textsubscript{m+c} was higher.

The regression equation for IR was different from that for BR (Fig. 6). The weed density was higher in IR than in BR, at the same VCR\textsubscript{m+c}.

### Discussion

1. Relationship between VCR and weed growth in each row section

VCR is an index that correlates closely with LAI (Mullan and Reynolds, 2010; Ramirez-Garcia et al., 2012). Although the VCR provides only two-dimensional information, it could be measured easily and non-destructively and was a useful index to evaluate competition for light between plants (Rasmussen et al., 2007). For example, Peachy et al., (1999) and Steinmaus et al., (2008) reported significant and negative correlations between the VCR of the crop and weed growth. Uchino et al. (2009, 2012) also investigated the effects of VCR\textsubscript{m} and/or VCR\textsubscript{c} on weed growth in organic farming systems of soybean, maize and potato (Solanum tuberosum L.) in Hokkaido. They revealed...
that the VCR at 150°C-day correlated strongly with weed biomass, and concluded that the VCR at this accumulated
effective temperature was a reliable index to analyze the
competition between crops and weeds in Hokkaido. In the
present study, analysis of the relationship between the VCR
and weed density in each row section revealed a significant
relationship between the VCRm, at 150°C-day and weed
density at harvest stage of main crops (Fig. 6). This result
indicates that, in each row section, weed growth could be
suppressed by increasing the VCR.

Kobayashi et al. (2004a, b) revealed the significant
suppression of weed emergence by winter barley (Hordeum
vulgare L.) and suggested that this suppression was mainly
caused by the reduction of transmitted light and diurnal
soil temperature range beneath the barley canopy. Teasdale
and Daughtry (1993) also reported that weed dry
weight was sufficiently suppressed by hairy vetch due to the
reduction of transmitted light and diurnal soil temperature
range. Although emergence of weed was not measured in
the present study, increase in VCR was expected to
suppress the weed emergence and growth through the
changes in environmental factors (e.g. soil temperature,
light intensity) beneath the crop canopy.

2. Difference in VCRm and weed growth between
soybean and maize

The weed density was markedly higher in maize than in
soybean in IR, while it was higher in soybean than in maize
in BR (Table 2). The significant relationship between the
VCR and weed density in each row section (Fig. 6)
depicted that this difference in weed density was attributed
to the difference in the VCR between the two main crops,
i.e., higher weed density in IR of maize (Table 2) was
caused by markedly lower VCRm in IR of maize relative to
that of soybean (Table 4).

We consider that the differences of the VCRm between
soybean and maize in each row section were attributed to the
differences of canopy structure between the two main
crops. Kumudini (2010) described in his review that the
development rate of main stem and branching could
influence canopy size and structure of plant. In general,
soybean has many branches and expands its leaves radially
with 2/5 spiral phyllotaxy (Nakaseko, 1984; Kokubun,
2010). Blad and Baker (1972) also measured the azimuth
direction of soybean leaf and revealed that soybean
allocated the leaves evenly to all azimuth directions. We
consider that these traits in soybean canopy structure caused the lower VCRm in IR of maize (Fig. 5,
Table 4).

3. Effects of cover crops on VCR and weed growth

The weed density between NoC and WithC in each row
section was decreased markedly by the cover crop in BR,
and only slightly in IR (Table 2). In addition, this decrease
in weed density by the cover crop did not differ
significantly between soybean and maize (Fig. 4). This
significant weed suppression by the cover crop in BR was
caused by a large increase of the VCR by the cover crop in
BR (Table 4). We consider that this large increase of the
VCR in BR was attributed to the spatial arrangement of the
cover crop. The cover crop, which was interseeded in BR,
started to cover the soil surface from BR, resulting in the
high VCR, in BR.

These significant effects of the cover crop on the
increase of VCR and the decrease of weed density were
more pronounced in 2006 than in 2005, i.e., VCRm in BR
of maize was very low, but in 2006, this low VCR was
increased markedly by the considerably high VCRc in BR
(Table 4). This was probably because the low temperature
from sowing to the end of June in 2006 (Fig. 1) was
unfavorable for the growth of summer main crop (maize),
but favorable for the growth of the winter cover crop
(winter rye). Uchino et al. (2012) also suggested the
importance of a combination of summer main crop with
winter cover crop for stable weed suppression, especially in
a region where main crops are often exposed to a cool
summer.

Contrary to the cover crop, main crops, which were
sown along the row, started to cover the soil surface from
IR, resulting in higher VCRm than VCRc in IR (Table 4).
These differences in the VCR increment between main
crop and cover crop imply that the cover crop is more
compatible with soybean than with maize. In soybean,
the soil surface in IR could be covered sufficiently by a
markedly high VCRm, and the low VCRm in BR was
compensated considerably by a high VCRc (Table 4, Fig. 5).
In maize, on the other hand, although a low VCRm in BR
was compensated by a high VCRc, it was not easy to
compensate the low VCRm in IR by the cover crop. As a
result, cover crops could not decrease sufficiently the high
weed density in IR of maize (Fig. 4). Since it is technically
difficult to interseed a cover crop in IR of the established
main crops at 21-28 DAS, a combination of cover crops
with other cultural techniques is needed to suppress weed
growth in IR of maize in organic farming systems.
Narrowing hill spacing between maize plants may be one
of the techniques. Although under conventional farming
systems (using herbicide), Tollenaar et al. (1994) reported
a significant enhancement in weed suppression by
increasing maize plant density by narrowing hill spacing
under same row distance. Further investigation is needed
to clarify the effects of the main crop hill distance on weed growth in IR in organic farming systems.

4. Comparison of the relationship of VCR with weed growth between IR and BR

As described above, there was a significant relationship between the VCR and weed density in each row section (Fig. 6). However, the regression equations in the two row sections were different. In addition, as shown in Fig. 5, the VCR in IR increased more rapidly in IR than in BR for both years. This means that the light environment was more favorable for weed growth in BR than in IR. Nevertheless, weed density in IR tended to be higher than that in BR of maize (Fig. 4). These results imply that weed growth was affected not only by VCR but also by other factors.

Relative position of weeds to applied fertilizer might be one of the factors affecting weed growth. Di Tomaso (1995) mentioned that plant growth was strongly affected by fertilizer placement. Petersen (2001) and Petersen and Mortensen (2002) reported that nitrogen uptake and dry matter production increased, when the distance from crop row to fertilizer band decreased. Furthermore, the shorter the distance from the plant to fertilizer, the more vigorous is the plant growth (Cochran et al., 1990; Rasmussen, 2002). In the present study, the weeds grew more vigorously in IR than in BR by uptake of nutrients from the fermented organic fertilizer applied in IR.

Conclusions

In BR, weed density was higher in soybean than in maize, while in IR, it was higher in maize than in soybean. The cover crop decreased weed density markedly in BR but only slightly in IR in both soybean and maize. These results suggest that the cover crop was more compatible with soybean than with maize, because the high weed density in IR of maize could not be decreased sufficiently by interseeding a cover crop. A significant relationship of weed density with the VCR in each row section indicates that these differences in weed density were well explained by the difference in VCR. However, the regression equation for IR was different from that for BR. This implies that weed growth was affected not only by VCR but also by other factors such as relative position of plants to applied fertilizer. Further experiments with different levels of fertilizer input and fertilizer application position are necessary to examine and quantify the interaction effects of soil nutrients and ground cover on the spatial distribution of weeds.

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