Effect of Incorporation of Hairy Vetch and Rye Grown as Cover Crops on Weed Suppression Related with Phenolics and Nitrogen Contents of Soil

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Abstract: Characterization of the release of degradable components of cover crops is important for determining the quality of soil nutrients for the following crop and weed occurrence. We have examined the temporal changes in soil phenolic carbon (C) and nitrogen (N) after incorporation of cover crops (hairy vetch and rye) with different C to N ratio and their effects on subsequent weed occurrence. Cover crops, hairy vetch (Vicia villosa Roth. cv. Hungvillosa) and rye (Secale cereale L. cv. Winter-green), grown in a glass house for 60 days, were harvested and incorporated into soil at the rate of 35 and 25 ton ha$^{-1}$, respectively. The contents of total phenolics (TP) in hairy vetch- and rye-incorporated soil increased from 45.5 to 21.3 μg g$^{-1}$ DW and decreased from 17.7 to 37.0 μg g$^{-1}$ DW, respectively, from 10 to 50 d after incorporation (DAI). Inorganic nitrogen (InN) was substantially released from hairy vetch residues, and it remained over four-fold greater than those in the control or rye-incorporated soil at 30 DAI. In the correlation analysis, the TP content of soil correlated negatively (r = −0.55, P < 0.01) with total carbon (TC), but TP content of soil did not correlate with total nitrogen (TN) or inorganic nitrogen (InN) contents of soil. Occurrence of weed species was not significantly different among the treatments, whereas weed density was decreased by the incorporation of hairy vetch- or rye-residues. Weed dry weights observed at 50 DAI revealed that the growth of weeds on hairy vetch-incorporated soil was about ten- and four-fold greater than that on rye-incorporated and control soil, respectively. It is concluded that incorporation of hairy vetch did not suppress weed growth, but incorporation of rye significantly suppressed the emergence and growth of weed.

Key words: Cover crop, Phenolics, Soil carbon, Soil nitrogen, Weed occurrence.

Many legume plants have positive effects on the yield and nutrient use efficiency of subsequent crops (Karlen et al., 1994; Ranells and Wagger, 1997; Sainju et al., 2001) and also contribute to weed management (Liebman and Dyck, 1993; Weston, 1996; Liebman and Ohno, 1997). Hairy vetch (Vicia villosa Roth) is a legume cover crop that suppresses weed emergence and supplies nitrogen for sustainable cropping systems (Ngouajio and Mennan, 2005; Choi and Daimon, 2008), but its residues in soil rapidly degrade rather than persist. Cereal rye (Secale cereale L.), is another commonly used as a cover crop, reduces density and biomass of several weed species (Liebl et al., 1992; Mohler and Teasdale, 1993).

Carbon (C) and nitrogen (N) concentrations have been extensively used to show residue quality. In addition, the C/N ratio is often used to explain different decomposition rates for early residue decomposition. Water soluble C and N compounds present in crop residues before initiation of decomposition have been considered readily available for decomposition.

Allelopathy is defined as a beneficial or detrimental effect supplied from a donor plant to the neighboring or following plants through the release of chemical compounds (Rice, 1984). The allelochemicals can be broadly classified into plant phenolics and terpenoids, which show great chemical diversity and are involved in a number...
of metabolic and ecological processes. The allelochemicals may occur through leaching and volatilization of plants or root exudation during the degradation (Anaya et al., 1990).

There are few studies on the interaction between soil phenolic carbon and nitrogen and it is also controversial whether cover crop incorporation has an effect on the suppression of weed occurrence. The aim of the present study was to explore the temporal changes in phenolic carbon and nitrogen in soil, and weed occurrence after incorporation of cover crops (hairy vetch and rye) with different C to N ratio in laboratory condition.

Materials and Methods

1. General procedures

This study was performed in a glass house at the National Academy of Agricultural and Science (NAAS), RDA, Korea in 2006. The soil was a sandy clay loam (Gopyeong series) with a pH of 7.4 (1:5, soil:water), containing 14.9 and 1.39 g kg⁻¹ soil of total C and N, respectively, which was collected from the experimental field, in which hot pepper was cultivated, in 2005. Green manure crops, hairy vetch (Vicia villosa cv. Hungvillo) and rye (Secale cereale cv. Wintergreen) were sown in cylindrical pots (40 cm×30 cm, height×i.d.) with 4 replicates on 28 Feb., 2006. They were grown in glass-houses and harvested 60 d after sowing and divided into two fractions for analyzing nitrogen contents of shoot and root. The above-ground parts of hairy vetch and rye after harvest were incorporated into soil to determine whether the input of cover crop has a substantial effect on weed control. The incorporation rate of the cover crop was expected on the application rate; in general, fresh hairy vetch and rye were incorporated into soil at the rate of 35 and 51 Mg ha⁻¹, respectively. The incorporation rate of fresh hairy vetch and rye was 17.7 g and 25.5 g per kg of soil, respectively, in plastic pots (20 cm×20 cm×15 cm). The experimental soil was the same as that used for growing the cover crops. The water content of the above-ground parts of hairy vetch and rye were 83% and 81%, respectively, and total carbon and nitrogen of dried hairy vetch were 37.8, and 2.57%, respectively; and those of rye were 41.5, and 1.48%, respectively. The soil without cover crop used as the control. Sixty-three pots (3 treatments×3 sampling time×7 replications) were arranged in a completely randomized block design (CRBD). The temperature in the glass-house was automatically controlled within the range of 30±2°C and soil water was adjusted to about 60% of the saturated water capacity. Soil samples (c.a. 100 g pot⁻¹) were collected at 10, 30 and 50 d after incorporation, and then shade-dried and sieved (<2 mm) for further studies.

2. Determination of the concentrations of total phenolic carbon (TP), total carbon (TC), total nitrogen (TN), and inorganic nitrogen (InN) in soil

The modified Folin-Ciocalteu method was used to determine the TP (free and bound) content of the soil (Chandler and Dodds, 1983). Briefly, 5 g of soil sample were shaken with 25 ml of 95% ethanol for 3 d at 4°C, centrifuged (6000 rpm, 10 min), incubated with Folin-Ciocalteu reagent and assayed. Absorbance was measured at 750 nm and ferulic acid was used to generate the standard curve and the concentrations were expressed in ferulic acid equivalent units.

The concentration of InN, NH₄⁺ (Kopp and McKee, 1978) and NO₃⁻ (Keeney and Nelson, 1982), in the fresh soil were colorimetrically determined by flow injection analyzer after extracting with 2 M KCl. Total carbon and nitrogen contents of soil were determined using a CN elemental analyzer (VARIOMAX CN, ELEMENTAR, Germany).

3. Data collection and statistical analyses

Seven pots with hairy vetch, rye, and without cover crops (control), 21 pots in total, were placed randomly. The population density and composition of weeds were assessed by counting the number of weeds occurring in each of the pots (7 pots). Weed samples were collected at 30 and 50 DAI, respectively. Dry weights of weeds were measured after drying for 2 d at 70°C. All data were subjected to ANOVA, and means were separated using Fisher’s Protected LSD test using SAS program (ver. 9.0).

Results and Discussion

1. Carbon and nitrogen in cover crops-incorporated soils

Table 1 shows the concentrations in TP, TC, TN and InN in the soil at different sampling dates. The TP concentration in hairy vetch-incorporated soil, 45.5 μg g⁻¹ DW, was 2.6-fold higher than that in the control. The TC and TN concentrations were also increased in hairy vetch-incorporated soil, 27.8 μg g⁻¹ DW and 1.48%, respectively. The InN concentration was also increased in hairy vetch-incorporated soil, 35.8 μg g⁻¹ DW, compared to the control.

| Treatment       | 10 DAI | 30 DAI | 50 DAI |
|-----------------|--------|--------|--------|
|                 | TP (μg g⁻¹) | TC (g kg⁻¹) | TN (g kg⁻¹) | InN (μg g⁻¹) | TP (μg g⁻¹) | TC (g kg⁻¹) | TN (g kg⁻¹) | InN (μg g⁻¹) |
| Control         | 17.4 b | 12.6 b | 1.41 b | 189.3 b | 28.1 | 12.6 | 1.59 | 131.7 b | 25.7 | 12.5 b | 1.37 | 101.4 b |
| Hairy vetch     | 45.5 a | 12.0 a | 1.61 a | 779.2 a | 18.5 | 13.2 | 1.61 | 707.5 a | 21.3 | 13.5 a | 1.51 | 97.0 b  |
| Rye             | 17.7 b | 14.1 a | 1.33 b | 168.8 b | 30.9 | 13.0 | 1.43 | 109.3 b | 37.0 | 12.1 b | 1.32 | 137.1 a |

Table 1. Total phenolics, total carbon and total nitrogen content of soil incorporated with cover crop residues.

*TP: total phenolics; TC: total carbon; TN: total nitrogen; InN, inorganic nitrogen (nitrate + ammonium).

Means within column followed by the same letter are not significantly different at the 5% level as determined by Fisher’s protected LSD test.

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higher than that in the control or rye-incorporated soil at 10 DAI, but decreased to 21.3 μg g⁻¹ DW at 50 DAI. On the other hand, rye-derived TP tended to increase steadily (17.7 to 37.0 μg g⁻¹ DW) until the end of the experiment. The result that hairy vetch with a lower C/N ratio (37.8% C; 2.57% N), decomposed earlier than rye with a higher C/N ratio (41.3% C; 1.48% N; 28 : 1). Martens (2000) reported that the TP from some crop residues decreased constantly with time, with decomposition ranging from 16 to 69%. The TC concentrations were varied from 12.0 to 14.1 g kg⁻¹ for all treatments throughout the study. On the contrary, Yenish et al (1995) presented a different result that the release of allelochemicals from rye residues continued for a long period, which was similar to that of TP from rye residue in our study.

The fluctuations in the TC content of soil showed an opposite trend with the TP. The TC in hairy vetch-incorporated soil was slightly increased in 50 DAI whereas decreased gradually in rye-incorporated soil. Soil organic carbon in the incubation experiment decreased slightly with time (Martens, 2000), and the rye alone showed higher organic carbon contents compared with the rye/ vetch system (Ding et al., 2006). According to the previous report, the relationship between TP and TC shows positive pattern (Gallet and Keller, 1999). In our study the negative correlation was caused by the different behavior between TP and TC during the experiment. Therefore, further study is required to understand contradictory behavior of TP and TC resulted from the present study.

The TN content of soil showed a significant difference among treatments at 10 d, but not at 30 and 50 DAI. The TN content of the hairy vetch-incorporated soil was higher than that of the control and rye-incorporated soils. The release of InN from hairy vetch residues was marked and rapid, and the InN content of soil was more than four-fold that of the control and rye-incorporated soils at 30 DAI. Christensen (1986) found that high-N straw lost 40% of its own N within the first month after incorporation into soil, which was 3- and 6-fold higher rates than that from medium-N and low-N straws, respectively. The InN content of in hairy vetch-incorporated soil (97 μg g⁻¹) rapidly decreased at 50 DAI, and the high N supplied from hairy vetch residues seemed to stimulate weed growth (Fig. 2). In the correlation analysis, the TP content of soil showed a negative relationship (r = −0.55, P < 0.01) with the TC content (Fig. 1), but there was no obvious correlation between TP and TN or InN contents of soil.

2. Effect of cover crops on weed occurrence

Table 2 shows the weed species occurring at 50 DAI in
each treatment, and Table 3 shows the dominant species of broad-leaved species and grasses observed at 50 DAI, and the percentage of the number of each weed including all treatments. The broad-leaved and grasses accounted for 42% and 58% of the total population, respectively.

The major weed species were *Cyperus difformis* L. (small flatsedge), *Oxalis corniculata* L. (Bealsane), *Erigeron annuus* (L.) Pers. (oxalis), *Setaria viridis* (L.) P. Beauv. (foxtail), and *Digitaria sanguinalis* Scop. (wire grass). These five species occupied over 80% of the observed weeds. The predominant weed species found in Koreea upland (Park et al., 2003) were broad-leaved weeds (Erigeron annuus (L.) Pers., Persicaria hydropiper L. and Calystegia japonica Choisy,) and grass weeds (Digitaria ciliaris (Retz.) Koeler., Setaria viridis L. Beauv, and Cyperus amuricus Maxim.), which collectively occupied as much as 70% of the total population.

Difference in weed species richness was not significant among the treatments and the sampling dates. Weed density at 30 and 50 DAI was significantly higher in the control than either rye or hairy-vetch (Table 4). A total of 13.0 and 13.3 weed plants pot$^{-1}$ emerged in the control at 30 and 50 DAI, respectively. At the same time, less than 9.1 weed plants pot$^{-1}$ emerged under the cover crop treatments. Rye incorporation showed the greatest weed suppression, and resulting that weed density was 4.6 and 3.4 plants pot$^{-1}$ at 30 and 50 DAI, respectively, about 75 and 65% reduction compared with the control, during the experiment. Incorporation of hairy vetch also suppressed weed density however, it seems to function as an N supplier rather than a weed suppressor (Fig. 2). Weed dry weights in the control increased merely 2 fold from 30 to 50 DAI, but more than 16 fold in hairy vetch treatment. Legume residues have been shown to have allelopathic potential on weeds (Weston, 1996). Incorporation of cover crops such as sudangrass, rye and hairy vetch reduced substantially weed density and dry biomass (Ngouajio and Mennan, 2005), but also supplied nitrogen in sustainable cropping systems (Teasdale and Daughtry, 1993; Choi and Daimon, 2008). Red clover treatment significantly decreased radical growth by 20% only at the early stage of incorporation and this was closely related to soil phenolic compounds (Ohno et al., 2000). Inderjit and Asakawa (2001) found that root length of radish mixed-cropped with hairy vetch was significantly reduced from 33 to 55% by the release of phenolics from hairy vetch.

Table 2. Weed species occurring in each treatment at 50 DAI.

| Weed species by treatment | Control | Hairy vetch | Rye |
|---------------------------|---------|-------------|-----|
| *Cyperus difformis*       | Cyperus difformis | Cyperus difformis | |
| *Digitaria sanguinalis*   | Digitaria sanguinalis | Digitaria sanguinalis | |
| *Oxalis corniculata*      | Oxalis corniculata | Oxalis corniculata | |
| *Portulaca oleracea*      | Portulaca oleracea | Setaria viridis | |
| *Setaria viridis*         | Echinochloa crus-galli | Erigeron annuus | |
| *Stellaria media*         | Stellaria media | Mullugo pentaphylla | |
| *Erigeron annuus*         | Chenopodium ficifolium | | |
| *Chenopodium ficifolium*  | Veronica persica | | |
| *Mullugo pentaphylla*     | Galinsoga parviflora | | |
| *Acathylua australis*     | Erigeron canadensis | | |
| *Chenopodium album var. centrorubrum* | | | |

Table 3. Major broad-leaved and grass weeds observed at 50 DAI$^\text{1}$ and their proportion.

| Broadleaves                          | Relative proportion (%)$^\text{2}$ | Grasses                          | Relative proportion (%) |
|--------------------------------------|-----------------------------------|----------------------------------|-------------------------|
| *Oxalis corniculata*                 | 13                                | *Cyperus difformis*              | 35                      |
| *Erigeron annuus*                    | 12                                | *Setaria viridis*                | 11                      |
| *Mullugo pentaphylla*                | 4                                 | *Digitaria sanguinalis*          | 10                      |
| *Stellaria media*                    | 4                                 | *Echinochloa crus-galli*         | 2                       |
| *Portulaca oleracea*                 | 2                                 |                                   |                         |
| *Chenopodium album var. centrorubrum*| 2                                 |                                   |                         |
| Others                               | 5                                 |                                   |                         |

$^1$DAI is days after cover crop incorporation.

$^2$The relative proportion (%) means the percentage of each species to total species estimated from all treatments (Control + Hairy vetch + Rye) at 50 DAI.
We observed that incorporation of hairy vetch residues affected weed density, but it released unexpected amounts of InN into soil, thus resulting in considerable weeds growth at the end of the experiment. On the contrary, incorporation of rye residues reduced weeds growth markedly, and this suppression was thought to be the combined effect of N deficiency by unchanged InN and gradual increase in TP. In conclusion, the present did not demonstrate the suppression of weed growth by the incorporation of hairy vetch, although the incorporation of rye residue was shown to reduce weed growth.

References

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Table 4. Number of weed species occurring and weed density after incorporation of different cover crop residues.

| Treatment   | Weed species | Weed density (plant pot) |
|-------------|--------------|--------------------------|
|             | 30 DAI†      | 50 DAI                   |
| Control     | 50 DAI       | 30 DAI                   |
|             | 30 DAI       | 50 DAI                   |
| Hairy vetch | 9*           | 12                       |
| Rye         | 3.4 ± 0.9 c  | 4.6 ± 1.1 b              |

†DAI is days after cover crop incorporation.
*Value means total weed species occurred in seven pots of each treatment at each sampling day.
**Means within column followed by the same letter are not significantly different at the 5% level as determined by Fisher’s protected LSD test.
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