Effect of Hairy Vetch Incorporated as Green Manure on Growth and N Uptake of Sorghum Crop

Bongsu Choi and Hiroyuki Daimon

(Graduate School of Life and Environmental Sciences, Osaka Prefecture University, Naka, Sakai, Osaka 599-8531, Japan)

Abstract: Hairy vetch (Vicia villosa Roth) has the potentials for preventing soil erosion and suppressing weed growth as a winter cover crop. We evaluated the additional N supplied by this crop harvested at different growing stages to the succeeding sorghum in pot experiments. Hairy vetch was grown in 1/5000a Wagner pot, and shoots (S) and roots (R) were mixed separately or together (S+R) into the soil on 30 March, 18 April and 2 May. After incorporation of the plants, seeds of sorghum were sown in the pots. Dry weight and N content of hairy vetch increased throughout the growing period. The value of nitrogenase activity in root nodules peaked on 18 April and then drastically declined. When hairy vetch was harvested on 30 March, N content of sorghum in the S pots was definitely less than that in the R and S+R pots. When hairy vetch harvested on 2 May, however, the N content in the S pots was similar to that in the S+R pots, and it was significantly higher than that in the R pots. Although N input from hairy vetch was higher in the S pots than in the R pots, N uptake by sorghum was not reflected in those values. The belowground parts of hairy vetch may have a considerable effect on N uptake of sorghum when using this plant species as green manures.

Key words: Allelopathy, Cover crop, Crop rotation, Nitrogen recycling, Root nodules.

Since N fixed by the rhizobium symbiosis in legumes would be considerable N source in crop production, the chemical N fertilizer demand could be reduced in the various cropping systems including legume production. Several winter legumes have been used for green manure crops and cover crops which attribute to improve land productivity to spring-sown crops (Hargrove, 1986; Torbert et al., 1996; Wivstad, 1999; Baggs et al., 2000; Boyd et al., 2001; Rochester et al., 2001; Komatsuzaki, 2002).

Among the winter legumes, hairy vetch (Vicia villosa Roth) has been well recognized as a plant having the potentials of increasing soil N levels. In the USA and several EU countries, many reports indicated that corn, cotton, grain sorghum, and some horticultural crops such as tomato and potato grown after hairy vetch yielded as high as in conventional cropping systems with N fertilizer (Decker et al., 1994; Abdul-Baki et al., 1997; Duiker and Hartwig, 2004; Sweeney and Moyer, 2004; Sainju et al., 2005). The beneficial effects on N uptake of those crops might depend on N₂ fixation by rhizobium-hairy vetch symbiosis.

On the other hand, the benefit of hairy vetch might also be associated with other factors such as weed control, water-holding capacity and soil conservation. For instance, hairy vetch is well known as a weed control crop acting as ground-cover and with allelopathic potential to inhibit the growth of weed plants. Ngouajio and Mennan (2005) indicated that this plant species had a high ability to suppress weeds in the cucumber cropping system, and they also reported that sod culture of hairy vetch suppressed weeds in hazelnut orchard (Mennan et al., 2006). As reported by Kamo et al. (2003), cyanamide produced by this plant would be a possible allelochemical to inhibit the growth of associated plants. Further, hairy vetch can maintain water content in the soil for the subsequent spring-sown crop, and can also prevent soil erosion, as reviewed by Hartwig and Ammon (2002).

In Japan, the values of using hairy vetch as a winter leguminous crop in upland field and in the field converted from paddy field have recently been expected especially in sustainable crop production practices, since this plant species could supply fixed N from fall to spring to the following crop. Even in Okinawa situated in the subtropical region in Japan, hairy vetch cultivation is used as N source in order to solve problems of soil fertility depletion in these regions (Zougmore et al., 2006).

Among many beneficial effects of hairy vetch described above, supplying N derived from N₂ fixation would be of particular interest in a low input cropping system. For the effective use of a hairy vetch crop as N source, timely management based on the growth stages of the plant in spring would be required. Especially in use as a green manure material under tillage management, in which they would be incorporated into the soil before killing or death with defoliation, evaluation of both promoting effect on N uptake and reducing effect on growth of the succeeding crop
by allelochemicals is needed. However, there has been little information about relationship between promoting and inhibitory effect of the incorporated materials of hairy vetch on the growth of the succeeding crops. In the present study, we examined the relationships between shoots and roots through evaluation of the additional N supplied by this crop harvested at different growing stages to the succeeding sorghum in pot experiments.

Materials and Methods

1. Cultivation of hairy vetch

Hairy vetch (cv. Mamekko) was grown in 1/5000 a Wagner pots containing 1:2 mixture of vermiculite and ‘Akadamatuchi’. ‘Akadamatuchi’ is subsoil of Andosol with a pH (H2O) of 5.2, electric conductivity (EC) of 0.06 ds m-1, total nitrogen (T-N) of 0.11%, ammonium N of 10.4 mg kg-1, nitrate N of 13.4 mg kg-1, Truog-P of 0.6 mg kg-1, cation exchange capacity (CEC) of 30.7 cmol kg-1, exchangeable Ca2+ of 0.71 cmol kg-1, exchangeable Mg2+ of 0.17 cmol kg-1, and exchangeable K+ of 0.25 cmol kg-1. Chemical fertilizer (N:P2O5:K2O = 3:10:10) was applied at the rate of 2 g per pot.

Three seeds of hairy vetch were sown in the pot on 9 November 2005. Immediately after sowing, 10 ml of rhizobial (Rhizobium leguminosarum strain U0404HV) suspensions (OD620: 0.2) was applied to the pot. The plants were grown outdoors under natural conditions of the experimental field of Osaka Prefecture University, Sakai, Osaka, Japan. Ten days after sowing, the seedlings were thinned to one plant per pot.

On 16 and 30 March, 18 April, and 2 May 2006, shoots and roots of the plants grown in 5 pots were sampled from 60, 55, 40 and 25 pots, respectively. The number of pots at each sampling date varied with the number of residual pots after harvesting the shoots and roots for incorporation as green manure.

Nitrogenase activity of the root nodules was determined by a detached system using the acetylene reduction assay (Hardy et al., 1968). After detection of acetylene reduction activity, the plants were separated into shoots and roots, and then oven-dried at 70°C for 48 h. After measurement of dry weight, the samples were ground into a fine powder for analyzing N concentration. It should be noted that there were differences in the growth period (days after sowing) of the succeeding sorghum plants among three treatments, in which hairy vetch was incorporated on 30 March, 18 April, and 2 May, respectively.

The data for growth and N uptake of the succeeding sorghum plants were analyzed by ANOVA, and Tukey’s LSD was calculated when F values were significant to determine differences among S, R, and S+R incorporation pots.

Results

1. Growth and N2 fixation of hairy vetch grown as green manure

The seedlings of hairy vetch uniformly emerged at 9–10 days after sowing. During the early growing stage, growth rate of the plants was not considerably high. However, they exhibited vigorous vegetative growth with higher leaf emergence rate after late-March. They began to flower in mid-April, and almost all the pots were at full anthesis in late-April.

Table 1 shows changes in fresh and dry weights, total N contents, C/N ratios of shoot and root, and acetylene reduction activity of root nodules in hairy vetch plants sampled 4 times from March to May. The fresh and dry weights and N content of whole plant increased throughout the growing period. A marked increase was observed from 16 to 30 March. After late-April, defoliation of lower leaves was observed and biomass productivity slightly decreased. However, the fresh and dry weights and total N content of the roots considerably increased from 18 April to 2 May. On the other hand, those of shoots did not necessarily increase during this period. The C/N ratios of shoots...
and roots ranged from 11.8 to 20.9 throughout the growing period.

When the seedlings of hairy vetch were thinned to one plant per pot at 10 days after sowing, no root nodule was observed on the main and lateral roots of the removed plants. On 16 March (4 months after sowing), lots of indeterminate root nodules with several meristematic regions were found on the roots, and they exhibited reddish in color inside of the nodules, indicating that the rhizobia in this stage had N2-fixing activity with leghemoglobin produced by the host plant. On 30 March and 18 April, the color of the nodules became more reddish and the size of the nodules became larger. On 2 May, the color inside of the nodules changed to dark green or black showing lower nitrogenase activity. In fact, the value of acetylene reduction activity of root nodules was higher on 30 March and 18 April than on 16 March, and it drastically decreased on 2 May (Table 1).

2. Growth and N uptake of sorghum after incorporation of hairy vetch

Table 2 shows the fresh weight and the amount of total N of the hairy vetch harvested on 30 March, 18 April and 2 May, and the growth and N uptake of the succeeding sorghum sampled on 7 August. Since the growth of hairy vetch increased from 30 March to 18 April as shown in Table 1, the fresh weight of the incorporated shoot (S), root (R) and both (S+R) were relatively heavier in the plants harvested on 18 April and 2 May than harvested on 30 March. Total N content of the incorporated material was calculated from the value of the plant sampled for investigation of growth and N accumulation at each growing stage. According to these values, N input through S, R, and S+R of hairy vetch harvested at different stages had different influences on the dry weight and N content of the sorghum plant sampled on 7 August. In general, relatively lower concentrations of N of sorghum plants were found in all the treatments, because lower fertility soil was used for evaluating N contribution from green manures.

Comparing S, R, and S+R treatments in incorporation of the hairy vetch harvested on 30 March, both dry weight and N content of whole plant of sorghum in S incorporation pots were significantly lower than those in R and S+R pots, that is, total N content was 5.3 mg, 27.4 mg, and 30.1 mg, in S, R, and S+R pots, respectively. In incorporation of the plants harvested on 18 April, the trends with lower values of the dry weight and N content in S pots were also found. However, the difference in N content between S incorporation and other two treatments (R and S+R) became less than that found in plants harvested on 30 March. In incorporation on 2 May, the dry weight in S pots was also lower than that in R and S+R pots. However, N content of the whole plant in S pots did show the same value as in S+R pots, and it was significantly higher than that in R pots. In other words, total N content of incorporated materials in S pots was definitely higher than that in R pots in all the growing stages of hairy vetch, but the differences in the N content of sorghum between the S and R pots were not reflected by those values, indicating that shoots incorporated on 30 March reduced the N uptake of the succeeding sorghum, and the reducing effect gradually disappeared with changes of incorporation date.

Discussion

1. Growth and N2 fixation of fall-sown hairy vetch

Several recent reports indicate that use of hairy vetch as a winter legume generally enhances soil fertility in both no-tillage and tillage systems in spring-
The growth and N\textsubscript{2} fixation of hairy vetch cv. Mamekko, which has been widely spread in the present experiment, we examined the potentials of the growing season in spring should be defined. In the spring-sown crops, N supply to the succeeding sorghum would be important for N supply to the succeeding sorghum. As reported by several researchers, N accumulated in legume roots could be transferred to the associated crops in mixed cropping and intercropping systems through decomposition of debris of legume roots including root nodules and/or exudation of nitrogenous compounds from the roots (Chestnutt et al., 1980; Chujo and Daimon, 1984; Høgh-Jensen and Schjoerring, 2001; Paynel et al., 2001; Paynel and Cliquet, 2003; Rasmussen et al., 2007). Especially after shoot removal such as defoliation and cutting, the N release from belowground parts was drastically increased (Osman and Diek, 1982; Daimon and Moyer, 2004; Sainju et al., 2005). The plants are either left as ground-cover continuously after the reproductive phase in the no-tillage system, or are incorporated as green manures at an appropriate time in tillage system. In both systems, changes in growth and N\textsubscript{2} fixation at anthesis in mid-April, and declining thereafter.

On the other hand, N status of belowground parts with root nodules showing different N\textsubscript{2}-fixing abilities, which would be different among harvesting date as shown in Table 1, should also be considered for N supply to the succeeding sorghum. As reported by several researchers, N accumulated in legume roots could be transferred to the associated crops in mixed cropping and intercropping systems through decomposition of debris of legume roots including root nodules and/or exudation of nitrogenous compounds from the roots (Chestnutt et al., 1980; Chujo and Daimon, 1984; Høgh-Jensen and Schjoerring, 2001; Paynel et al., 2001; Paynel and Cliquet, 2003; Rasmussen et al., 2007). Especially after shoot removal such as defoliation and cutting, the N release from belowground parts was drastically increased (Osman and Diek, 1982; Daimon and Chujo, 1986). In this experiment, cutting of shoots

Table 2. Dry weight, N concentration and N content of the succeeding sorghum grown after incorporation of different parts of hairy vetch as a green manure legume.

| Incorporation date | Plant parts* | Input FW (g plant\textsuperscript{-1}) | Input N** (mg plant\textsuperscript{-1}) | DW (g plant\textsuperscript{-1}) | N concentration (%) | N content (mg plant\textsuperscript{-1}) |
|-------------------|-------------|--------------------------------------|-------------------------------|--------------------------------|-------------------|-----------------------------------|
|                   |             |                                      |                               | Shoot Root Total | Shoot Root | Shoot Root Total | Shoot Root Total |
| 30 March          | S           | 14 ± 0.7                             | 74.9 ± 6.0                    | 0.2 b 0.3 b 0.5 b | 1.43   | 0.75 | 3.2 b 2.1 b 5.3 b |
|                   | R           | 14 ± 1.2                             | 20.1 ± 0.8                    | 3.2 a 1.8 a 5.0 a | 0.60   | 0.45 | 19.4 a 8.0 a 27.4 a |
|                   | S+R         | 26 ± 2.1                             | 89.4 ± 6.9                    | 2.9 a 1.4 a 4.3 a | 0.80   | 0.52 | 23.1 a 7.0 a 30.1 a |
| 18 April          | S           | 20 ± 1.9                             | 113.7 ± 13.7                  | 1.1 c 1.0 c 2.1 c | 1.16   | 0.71 | 12.6 c 7.0 c 19.6 c |
|                   | R           | 18 ± 2.6                             | 38.7 ± 3.3                    | 5.3 b 3.0 b 8.3 b | 0.42   | 0.41 | 22.0 b 12.2 b 34.2 b |
|                   | S+R         | 40 ± 4.0                             | 160.8 ± 14.1                  | 7.8 a 4.7 a 12.5 a | 0.46   | 0.50 | 35.6 a 23.2 a 58.8 a |
| 2 May             | S           | 22 ± 2.6                             | 102.1 ± 6.3                   | 4.2 a 1.6 b 5.8 b | 1.33   | 0.81 | 55.9 a 12.6 b 68.5 a |
|                   | R           | 25 ± 2.9                             | 53.7 ± 5.4                    | 5.8 a 2.7 a 8.5 a | 0.38   | 0.38 | 22.0 b 10.3 b 32.3 b |
|                   | S+R         | 45 ± 5.8                             | 152.7 ± 13.5                  | 5.5 a 3.0 a 8.6 a | 0.91   | 0.68 | 50.5 a 20.6 a 71.1 a |

Sorghum plants were sampled on 7 August, 2006.
Values are means ± standard deviation of 5 pots.
Values in a column in each harvesting date followed by the same letter are not significantly different at the 0.01 probability level.
* S: only shoots were incorporated. R: only roots were incorporated. S+R: both shoots and roots were incorporated.
** Values were calculated from N content of the plant sampled for measurement of growth and N uptake shown in Table 1.

sown crop production (Czapar et al., 2002; Ruffo and Bollero, 2003; Duiker and Hartwig, 2004; Sweeney and Moyer, 2004; Sainju et al., 2005). The plants are either left as ground-cover continuously after the reproductive phase in the no-tillage system, or are incorporated as green manures at an appropriate time in tillage system. In both systems, changes in growth and N\textsubscript{2} fixation of the plants during the growing season in spring should be defined. In the present experiment, we examined the potentials of the hairy vetch cv. Mamekko, which has been widely spread as a “fallow crop” in Japan, for supplying N to high-N-requiring crop by using sorghum as a testing crop in a pot experiment.

Hairy vetch showed greater N\textsubscript{2} fixation activity from 16 to 30 March, and it continued until 18 April, and then drastically reduced on 2 May (Table 1). Mean temperature and irradiation from March to May were not different from the year average (data not shown). The growth and N\textsubscript{2} fixation of hairy vetch cultivar, ‘Mamekko’, grown in pots normally responded to natural conditions, showing maximum N\textsubscript{2}-fixing activity at anthesis in mid-April, and declining thereafter.

The seasonal changes in growth and N\textsubscript{2} fixation shown in this experiment were in agreement with the results of the previous reports on the growth characteristics of fall-sown hairy vetch. For instance, Hanano et al. (1998) showed that rapid growth of hairy vetch after March was effective for covering soil surface of upland and abandoned paddy fields in Sikoku island, Japan. Power and Zachariassen (1993) also indicated that this plant species during spring in temperate regions had great potential for use as a winter legume in various cropping systems. Considering the changes in growth and N\textsubscript{2} fixation of this cultivar, N supply to the succeeding sorghum especially through belowground parts is discussed in the following section.

### 2. N supply from incorporated materials to the succeeding sorghum

In practical tillage systems including winter leguminous cover crop, the cover crop is incorporated into the soil before defoliation of shoots. Since about two-thirds of the total N in winter legumes is contained in shoots (Mitchell and Teel, 1977; Hargrove, 1986), shoot biomass would be important for N supply to the spring-sown crops. In the present experiment, the amount of shoot (S) N was greater than that of root (R) N at each harvesting time (Table 1). Hence, total amounts of N supplied to the succeeding sorghum after decomposition of all the incorporated materials could be greater in S+R pots than in S or R pots.

On the other hand, N status of belowground parts with root nodules showing different N\textsubscript{2}-fixing abilities, which would be different among harvesting date as shown in Table 1, should also be considered for N supply to the succeeding sorghum. As reported by several researchers, N accumulated in legume roots could be transferred to the associated crops in mixed cropping and intercropping systems through decomposition of debris of legume roots including root nodules and/or exudation of nitrogenous compounds from the roots (Chestnutt et al., 1980; Chujo and Daimon, 1984; Høgh-Jensen and Schjoerring, 2001; Paynel et al., 2001; Paynel and Cliquet, 2003; Rasmussen et al., 2007). Especially after shoot removal such as defoliation and cutting, the N release from belowground parts was drastically increased (Osman and Diek, 1982; Daimon and Chujo, 1986). In this experiment, cutting of shoots
for incorporation might induce the release of N from belowground parts through deprivation of photoassimilates to the root nodules in the plants incorporated on 30 March and 18 April. N flow through this pathway in hairy vetch incorporation should also be considered.

As we described in the previous reports on N supply by green manures (Yano et al., 1994; Ohdan and Daimon, 1998a,b; Daimon and Kotoura, 2000; Uratani et al., 2004; Daimon, 2006), mineralization of N in green manures such as *Crotalaria* and *Sesbania* immediately after incorporation would be expected when C/N ratios of the manures are lower than 25. In the present experiment, C/N ratios of shoot and root were not markedly different among three harvesting times, in which they ranged from 12.6 to 20.9 (Table 1). According to these data, it might not be difficult for shoots and roots harvested at each time to be decomposed immediately after incorporation, suggesting that the pathway through N release from belowground parts as described above would be important for N supply to sorghum.

In addition to the contribution of belowground parts as described above, the suppressive effect of shoot on the growth of the succeeding sorghum should also be considered. As shown in Table 2, although higher N recovery rate in S pots was expected from the total N input, N supply from shoots was substantially less when incorporated on 30 March and 18 April. This reduction in S pots considerably became less in the incorporation on 2 May, indicating that inhibitory substances such as cyanamide exuded especially from shoots through decomposition (Kamo et al., 2003) severely reduced N uptake of sorghum. On the other hand, as the reproductive phase of hairy vetch plant advances, the suppression effect would be reduced (Table 2).

Since the shoots alone would not be incorporated in the practical cropping system, traits of the belowground parts of hairy vetch, which could be altered due to harvesting date, should be considered in effective use of this plant species as green manure. For understanding the relationships between contribution of belowground parts and suppression by shoots, changes in N compounds in the soil after incorporating belowground parts should be defined in comparison with the changes in inhibitory substances produced mainly by shoots.

Acknowledgement

We thank Dr. Araki, Hokkaido University, and Drs. Ohe, Harada and Nakayama, Osaka Prefecture University, for their valuable comments.

References

Abdul-Baki, A.A., Teasdale, J.R. and Korcak, R.F. 1997. Nitrogen requirements of fresh-market tomatoes on hairy vetch and black polyethylene mulch. HortScience 32 : 217-221.

Baggs, E.M., Watson, C.A. and Rees, R.M. 2000. The fate of nitrogen from incorporated cover crop and green manure residues. Nutr. Cycl. Agroecosys. 56 : 153-163.

Boyd, N.S., Gordon, R., Asiedu, S.K. and Martin, R.C. 2001. The effects of living mulches on tuber yield of potato (*Solanum tuberosum* L.). Biol. Agric. Hortic. 18 : 203-220.

Chestnutt, D.M.B., Bartholomew, P.W. and Binnie, R.C. 1980. The interaction of perennial ryegrass and timothy in mixtures and their reaction to clover and nitrogen in cut swards. Grass Forage Sci. 35 : 281-286.

Chujo, H. and Daimon, H. 1984. Plant growth and fate of nitrogen in mixed cropping, intercropping and crop rotation. 1. Growth acceleration of some temperate grasses in early stage of mixed cropping with red clover. Jpn. J. Crop Sci. 55 : 213-221*.

Czapor, G.F., William, S.F. and Bullock, D.G. 2002. Delayed control of a hairy vetch (*Vicia villosa* Roth) cover crop in irrigated corn production. Crop Prot. 21 : 507-510.

Daimon, H. and Chujo, H. 1986. Plant growth and fate of nitrogen in mixed cropping, intercropping and crop rotation. 2. Nitrogen content of wheat in association with pea or broad bean. Jpn. J. Crop Sci. 55 : 162-170*.

Daimon, H. and Kotoura, S. 2000. Incorporation of *Crotalaria spectabilis* grown at a high seeding rate inhibits the growth of the succeeding wheat crop. J. Agron. Crop Sci. 185 : 137-144.

Daimon, H. 2006. Traits of the genus *Crotalaria* used as a green manure legume on sustainable cropping systems. JARQ. 40 : 299-305.

Decker, A.M., Clark, A.J., Meisinger, J.J., Mulford, F.R. and McIntosh, M.S. 1994. Legume cover crop contributions to no-tillage corn production. Agron. J. 86 : 126-135.

Duiker, S.W. and Hartwig, N.L. 2004. Living mulches of legumes in imidazolinone-resistant corn. Agron. J. 96 : 1021-1028.

Hanano, Y., Fujii, Y., Sato, K., Osozawa, S. and Fujihara, S. 1998. Weed control by hairy vetch (*Vicia villosa* Roth) in Shikoku area. -Vegetation test and field survey in 1993 to 1997-. Bull. Shikoku Natl. Agric. Exp. Stn. 62 : 45-70*.

Hardy, R.W.F., Holsten, R.D., Jackson, E.K. and Burns, R.C. 1968. The acetylene-ethylene assay for N₂ fixation : Laboratory and field evaluation. Plant Physiol. 43 : 1185-1207.

Hargrove, W.L. 1986. Winter legumes as a N source for no till grain sorghum. Agron. J. 78 : 70-74.

Hartwig, N.L. and Ammon, H.U. 2002. Cover crops and living mulches. Weed Sci. 50 : 688-699.

Høgh-Jensen, H. and Schjoerring, J.K. 2001. Rhizodeposition of nitrogen by red clover, white clover and ryegrass leys. Soil Biol. Biochem. 33 : 439-448.

Kamo, T., Hiradate, S. and Fujii, Y. 2003. First isolation of natural cyanamide as a possible allelochemical from hairy vetch *Vicia villosa*. J. Chem. Ecol. 29 : 275-283.

Komatsuzaki, M. 2002. New cropping strategy to reduce weed populations in hazelnut (*Corylus avellana* L.). Jpn. J. Crop Sci. 53 : 213-221*.

Kamo, T., Hiradate, S. and Fujii, Y. 213-221*.

Kamo, T., Hiradate, S. and Fujii, Y. 2003. First isolation of natural cyanamide as a possible allelochemical from hairy vetch *Vicia villosa*. J. Chem. Ecol. 29 : 275-283.

Komatsuzaki, M. 2002. New cropping strategy to reduce weed populations in hazelnut (*Corylus avellana* L.). Jpn. J. Crop Sci. 53 : 213-221*.

Kamo, T., Hiradate, S. and Fujii, Y. 2003. First isolation of natural cyanamide as a possible allelochemical from hairy vetch *Vicia villosa*. J. Chem. Ecol. 29 : 275-283.
Ngouajio, M. and Mennan, H. 2005. Weed populations and pickling cucumber (*Cucumis sativus*) yield under summer and winter cover crop systems. Crop Prot. 24 : 521-526.

Ohdan, H. and Daimon, H. 1998a. Evaluation of amount of nitrogen fixed in *Crotalaria* spp. and nitrogen turnover to the succeeding wheat. Jpn. J. Crop Sci. 67 : 193-199**.

Ohdan, H. and Daimon, H. 1998b. Growth of *Crotalaria juncea* and *Sesbania cannabina* under different underground water levels and their nitrogen contribution to the succeeding spinach plant. Jpn. J. Crop Sci. 67 : 467-472**.

Osman, A.E. and Diek, A.A.A. 1982. Effect of defoliation on yield and forage quality of some tropical grasses, legumes and their mixtures. Exp. Agric. 18 : 157-166.

Paynel, F., Murray, P.J. and Cliquet, J.B. 2001. Root exudates : a pathway for short-term N transfer from clover to ryegrass. Plant Soil 229 : 235-243.

Paynel, F. and Cliquet, J.B. 2003. N transfer from white clover to perennial ryegrass, via exudation of nitrogenous compounds. Agronomie 23 : 503-510.

Power, J.F. and Zachariassen, J.A. 1993. Relative nitrogen utilization by legume cover crop species at three soil temperatures. Agron. J. 85 : 134-140.

Rasmussen, J., Eriksen, J., Jensen, E.S., Esbensen, K.H. and Høgh-Jensen, H. 2007. In situ carbon and nitrogen dynamics in ryegrass–clover mixtures : Transfers, deposition and leaching. Soil Biol. Biochem. 39 : 804-815.

Rochester, I.J., Peoples, M.B., Hulugalle, N.R., Gault, R.R. and Constable, G.A. 2001. Using legumes to enhance nitrogen fertility and improve soil condition in cotton cropping systems. Field Crops Res. 70 : 27-41.

Ruffo, M.L. and Bollero, G.A. 2003. Modeling rye and hairy vetch residue decomposition as a function of degree-days and decomposition-days. Agron. J. 95 : 900-907.

Sainju, U.M., Whitehead, W.F. and Singh, B.P 2005. Biculture legume-cereal cover crops for enhanced biomass yield and carbon and nitrogen. Agron. J. 97 : 1403-1412.

Sweeney, D.W. and Moyer, J.L. 2004. In-season nitrogen uptake by grain sorghum following legume green manures in conservation tillage systems. Agron. J. 96 : 510-515.

Torbert, H.A., Reeves, D.W. and Mulvaney, R.L. 1996. Winter legume cover crop benefits to corn : Rotation vs. fixed-nitrogen effects. Agron. J. 88 : 527-535.

Uratani, A., Daimon, H., Ohe, M., Harada, J., Nakayama, Y. and Ohdan, H. 2004. Ecophysiological traits of field-grown *Crotalaria incana* and *C. pallida* as green manure. Plant Prod. Sci. 7 : 449-455.

Wivstad, M. 1999. Nitrogen mineralization and crop uptake of N from decomposing 15N labelled red clover and yellow sweetclover plant fractions of different age. Plant Soil 208 : 21-31.

Yano, K., Daimon, H. and Mimoto, H. 1994. Effect of sunn hemp and peanut incorporated as green manures on growth and nitrogen uptake of the succeeding wheat. Jpn. J. Crop Sci. 63 : 137-143.

Zougmore, R., Nagumo, F. and Hosikawa, A. 2006. Nutrient uptakes and maize productivity as affected by tillage system and cover crops in a subtropical climate at Ishigaki, Okinawa, Japan. Soil Sci. Plant Nutr. 52 : 509-518.

* In Japanese with English summary.

** In Japanese with English abstract.