Possibility of Introducing Winter Legumes, Hairy Vetch and Faba Bean, as Green Manures to Turmeric Cropping in Temperate Region

Kenji Yamawaki¹, Atsushi Matsumura¹, Rintaro Hattori¹, Arata Tarui¹, Mohammad Amzad Hossain², Yoshiyuki Ohashi¹ and Hiroyuki Daimon¹

¹Graduate School of Life and Environmental Sciences, Osaka Prefecture University, Sakai 599-8531, Japan; ²Faculty of Agriculture, University of the Ryukyus, Nishihara 903-0213, Japan

Abstract: A field experiment was conducted to examine the possibility of introducing winter legumes, hairy vetch and faba bean, as green manures to turmeric cropping in a temperate region. Hairy vetch shoots were incorporated to determine the effect of N and P added as green manure. Higher values in plant height and number of leaves of turmeric were observed in the treatment with incorporation of hairy vetch than in that without incorporation (no-incorporation) throughout the growth periods. The differences in total amounts of N and P of turmeric between incorporation and no-incorporation treatments were the highest on 15 October, when the amount was increased by 8.0 g N and 1.1 g P m⁻² compared with the no-incorporation treatment. From September to October, curcumin content rapidly increased with rhizome thickening, and gradually increased. We also quantified the N and P contribution from faba bean residues to the succeeding turmeric. The total amounts of N and P in turmeric cultivated after incorporating shoot and root residues into previously cultivated faba bean field were 2.5 g N and 1.0 g P m⁻², respectively, larger than incorporating only roots. In previously fallow field, the incorporation of the shoot increased the total amount of N and P in turmeric by 4.5 g and 1.9 g m⁻², respectively, compared with that without incorporation. In the second year after incorporation, growth and nutrient uptake of the turmeric crop did not significantly differ from those without incorporation. In the temperate region, these winter legumes would be used as basal organic matters for turmeric production.

Keywords: C/N ratio, C/P ratio, Cropping system, Curcumin, Rhizome.

Turmeric (Curcuma longa L.; family Zingiberaceae) is an herbaceous plant that is used as a condiment, dye, drug and cosmetic. Curcumin, a major ingredient in the plant's rhizome, has antioxidant (Han and Yang, 2005), anticancer (Holy, 2002), antiviral (Mazumder et al., 1995), and anti-amyloidogenic properties (Frautschy et al., 2001). In Japan, turmeric is produced mainly on the Okinawa Islands and other subtropical and temperate regions such as the southwestern districts, but the amount of domestic production is only about 100 t per year in contrast to the 4000 t of dried turmeric imported annually from India, China, and other Asian countries.

The international price of turmeric has doubled over the past decade and consumers have recently begun to grow the plant in home gardens. In addition, organic farming has been gaining importance especially for food and recreational crops. Therefore, an increase in the domestic cultivation area of turmeric crop is required in Japan, and efficient cultivation practices should be established to sustain a low-input crop production system.

In turmeric production, inorganic fertilizers such as N and P are not necessary as basal application, because the rhizomes store nutrients for seedling growth. An important manuring practice is basal application of organic matter to improve the physical properties of the soil such as soil porosity, water holding capacity, and aggregate stability for better growth of the turmeric root (Hossain and Ishimine, 2007; Dinesh et al., 2010). In addition, inorganic fertilizer application as a top dressing when 2 – 3 leaves emerge promotes culm elongation (Ishimine et al., 2004; Hossain, 2010). On the contrary, several spring weeds grow vigorously when inorganic fertilizer is applied before
turmeric seedling emergence, because of the slower growth of turmeric compared with the weeds (Ishimine et al., 2004). The yield of rhizome of turmeric was 4.7 – 5.6 kg fresh weight m\(^{-2}\), under basal application of matured farmyard manure at the rate of 5 kg with 100 g of inorganic fertilizer (N : P\(_2\)O\(_5\) : K\(_2\)O = 12.5 : 12.5 : 12.5) m\(^{-2}\) in Okinawa (Kinjo et al., 2001), and 2.5 kg fresh weight m\(^{-2}\) under application of farmyard manure at 4 kg m\(^{-2}\) in Yakushima and Tanegashima islands, subtropical regions in Japan (Aoi et al., 1988; Aoi, 1992a, 1992b). Under basal application of farmyard manure and inorganic fertilizers in Kochi and Ibaraki prefectures in the temperate region, the yield was 2.5 kg and 1.2 kg fresh weight m\(^{-2}\), respectively (Morishita et al., 2009; Kobayashi et al., 2010). These reports indicated that basal application of farmyard manure is fundamental to turmeric cropping.

On the other hand, applying farmyard manure has some drawbacks, such as increased labor and cost to convey the manure from the farmyard to the field. In small-scale agriculture, in particular, where a stable supply of farmyard manure is often difficult, an alternative method of application of organic matters should be introduced into turmeric cropping systems. An alternative supply of farmyard manure might be by green manuring, in which the plant waste from the plants that were grown as the preceding winter crops are also used. In temperate regions such as the southwestern districts in Japan, seed rhizome is planted in late-May to early-June, 1 – 2 months later than in the subtropical region, Okinawa. In this planting practice, several preceding winter legumes may be used as a source of organic matter. Hence, we tried to evaluate two winter legumes described below as organic matter applied basally.

Hairy vetch (\textit{Vicia villosa} Roth) is a winter cover crop that is used to suppress weeds and supply N for the subsequent crops. This crop is an efficient N fixer, accumulating a large amount of N during the growing period (Hartwig and Ammon, 2002; Choi and Daimon, 2008; Anugroho et al., 2009a). For example, hairy vetch yearly produced 7.6 – 16.7 g N m\(^{-2}\) (Sainju et al., 2006), 10 – 15 g N m\(^{-2}\) (Anugroho et al., 2009b), 14.9 g N m\(^{-2}\) (Campiglia et al., 2010a), and 23.8 g N m\(^{-2}\) (Campiglia et al., 2010b) during their growth season, and its cultivation as a cover crop and an organic fertilizer increased the yields of several crops such as corn, cotton, sorghum, potato, and tomato compared with the other cover crops such as ryegrass and subclover, or conventional weedy fallow (Czapor et al., 2002; Sainju et al., 2006; Campiglia et al., 2009; Campiglia et al., 2010a, 2010b). However, no data is available on the effect of incorporating hairy vetch on the growth and yield of turmeric.

Although several researchers have recently shown that hairy vetch is an effective constituent for low-input crop production, the growers have not necessarily introduced it into their cropping system because it is not a cash crop, especially in small-scale agriculture, where there is a high utilization of the arable land. In temperate regions, winter grain legumes such as faba bean (\textit{Vicia faba} L.) and pea (\textit{Pisum sativum} L.) are grown as a food crop. The crop residues of such winter grain legumes should also be used as an organic matter. Several studies have shown the N\(_2\) fixation of faba bean (López-Bellido et al., 2010; López-Bellido et al., 2011) and its potential contribution to the sustainability of cropping systems, including wheat (Tosti and Guiducci, 2010; Melero et al., 2011; Muñoz-Romero et al., 2011) and melon (Stagnari and Pisante, 2010). According to Köpke and Nemecek (2010) and Jensen et al. (2010), this crop species has an important role in sustainable farming practice, particularly, in nutrient supply. Accordingly, we examined the effect of crop residues of faba bean on the growth and nutrient uptake of turmeric crop. There are many varieties of faba bean, such as large- and small-seed types, that display vigorous growth with green leaves and stems even at the ripening stage, thereby providing sufficient nutrients as an organic matter in the crop residues for the succeeding turmeric crop.

Through the present study using winter legumes, hairy vetch and faba bean, we preliminarily examined the effect of basal application of these green manures as organic matters on growth and nutrient uptake of turmeric crop. Prior to the practical field experiment to compare the effect of different organic matters applied to the field, we evaluated amounts of N and P supplied by these green manures comparing with no incorporation of these legumes, and we discussed the possibility of using these green manures for turmeric cropping newly introduced to temperate regions such as the southwestern districts in Japan.

**Materials and Methods**

1. **Incorporation of hairy vetch shoots**

The experiment was conducted from 2008 to 2010 at the experimental farm for upland field crops (Gray lowland soil) in Osaka Prefecture University in Sakai, Osaka, Japan. As organic matter to be incorporated into the turmeric field, hairy vetch (\textit{Vicia villosa} Roth cv. ‘Mamekko’; Kaneko Seeds, Japan) seeds were sown at 5 g m\(^{-2}\) on 12 November, 2008. Shoots of hairy vetch were harvested at the flowering stage on 20 May, 2009, and then transferred to the other experimental plots, where corn (\textit{Zea mays} cv. ‘Gold dent KD850’; Kaneko Seeds, Japan) had been grown as the preceding summer crop to recover nutrients in the experimental field. In the present experiment, shoots of hairy vetch were incorporated into the field fallowed after corn production to determine the effect of N and P added after eliminating the influence of the preceding crop cultivation.
The experimental field (12 m²) was plowed and divided into 4 plots of 3 m² (3 × 1 m) each. The soil collected before incorporation of hairy vetch was air-dried and passed through a 2-mm sieve. The chemical properties of the soil were as follows; pH (H₂O) 4.8, electrical conductivity (EC) 0.07 dS m⁻¹, 9.58 g C kg⁻¹, 1.33 g N kg⁻¹, 12.8 mg inorganic N kg⁻¹, 0.76 g P kg⁻¹, and 71.4 mg Truog P kg⁻¹. Two plots were used for the incorporation treatment (with hairy vetch), and shoots of hairy vetch cut to 5 – 10 cm length were incorporated at 5 kg fresh weight m⁻² on 26 May, 2009. No green manure was incorporated into the other 2 plots (without hairy vetch). Thus, the experiment was conducted with 2 treatments and 2 replications.

Approximately 30 g of fresh seed rhizome of the Okinawa local cultivar (Curcuma longa L.), which is called "autumn turmeric", was planted in a paper pot containing vermiculite on 25 May, 2009, and then grown in a greenhouse. After 23 days, the young plants with 1 leaf were transplanted to a depth of 10 cm in a 30-cm triangular pattern in 2 rows on each plot with a planting density of 6.7 plants m⁻². Compound synthetic fertilizer (N : P₂O₅ : K₂O = 8 : 8 : 8) at 83 g m⁻² was applied twice to all the plots; once on 30 July and once on 29 August. The plants were watered using overhead irrigation immediately after transplanting and applying fertilizer.

Plant height, number of leaves, and number of stems of 5 plants in each plot were measured at 30-day intervals. Three plants showing average growth in each plot were sampled on 16 August, 2009 (60 days after transplanting [DAT]), on 15 September (90 DAT), 15 October (120 DAT), and 4 January, 2010 (201 DAT). The plants were dried and ground to determine the total N and P concentrations in the shoots and rhizomes. Total N concentration was measured using the vario MAX CN (Elementar, Germany). For determining the total P concentration, the samples were first ashed in a muffle furnace at 550°C and then subjected to vanadomolybdate colorimetry. The curcumin concentration in the rhizome was measured using HPLC (LC-20ADXR, Shimadzu, Japan) with a C18 column and an ethanol solvent, and then detected at 425 nm. The mean values of the 6 plants sampled in each treatment at each growth stage described above were compared using a t-test.

2. Incorporation of faba bean residues

The experiment was conducted from 2009 through 2011 at the experimental farm for vegetable crops in Osaka Prefecture University. Squash (Cucurbita maxima Duch) plants had been grown as the preceding crop. The chemical properties of the soil were as follows; pH (H₂O) 7.0, EC 0.13 dS m⁻¹, 26.1 g C kg⁻¹, 3.25 g N kg⁻¹, 58.5 mg inorganic N kg⁻¹, 2.65 g P kg⁻¹, and 1.45 g Truog P kg⁻¹.

We tried to quantify the contribution of N and P from faba bean residues by conducting the following 2 experiments. The experimental main plot size was 90 m² (4 × 22.5 m). Faba bean (Vicia faba L. cv. ‘Nintoku Issun’; Takii Seeds, Japan) seedlings with 2 – 3 leaves were transplanted in a 40-cm triangular pattern in 2 rows on each ridge spaced 1 m apart on one-half (45 m²) of the main plot with a planting density of 5 plants m⁻² on 8 December, 2009. Faba bean seeds were previously sown in a plastic pot containing vermiculite on 27 October, 2009. The other half (45 m²) of the main plot was laid fallow. Through the experiment using these two fields (faba bean cropping and the fallow), we tried to evaluate the N and P supplied using the faba bean shoots as yield residues and also to evaluate those of roots residues. No fertilizer was applied to the plots.

Faba bean pods were harvested on 18, 21, and 26 May, 2010 and total pod yields were measured. After harvest, pods were separated into seeds and shells and then weighed. Total N and P concentrations of seeds, shells and leaves and stems (crop residues) were analyzed as described above. Shoots (leaves and stems) and/or roots as crop residues were incorporated into each plot on 3 June, 2010, as described below. In faba bean cropping plots, two treatments were applied as follows: (1) both shoots and roots (S + R) were incorporated, and (2) only roots (R) were incorporated. In the previous fallow plots, (1) shoots (S) were incorporated, and (2) no matter was incorporated (C). The experiment was laid out in a randomized complete block design with 2 treatments under the same preceding cropping with 5 replications. Each plot size was 4.5 m².

Approximately 30 g in fresh weight seed rhizomes of turmeric were planted at a depth of 10 cm in a 30-cm triangular pattern in 2 rows on each plot at a planting density of 6.7 plants m⁻² on 14 June, 2010. No chemical fertilizer was applied to the plots. The percentage of plantlet emergence, plant height, number of leaves, and number of stems of 2 plants in each plot were measured at 30-day intervals. Five plants showing average growth for each treatment were sampled on 13 August (60 days after planting [DAP]), 12 October (120 DAP), and 11 December (180 DAP). They were dried, weighed, and ground to determine the N and P concentrations in the shoots and rhizome and curcumin concentration of the rhizome. To investigate the successive effect of faba bean on turmeric plants grown in the second year after incorporation of the residues, we planted turmeric seed rhizomes in each plot on 25 May, 2011. Each growth parameter of the turmeric plants was measured every 30 days and then shoots and rhizomes were sampled on 26 September and 5 December. Total N and P concentrations in the shoots and rhizomes and curcumin concentration in the rhizomes were analyzed. The data on a turmeric crop grown in the preceding cropping were analyzed using a
Results and Discussion

1. Effect of hairy vetch shoots incorporated as a green manure on the growth of turmeric crop

Table 1 shows the fresh and dry weights and the amounts of total N and P in hairy vetch shoots incorporated as a green manure for the turmeric cropping. At the flowering stage in late May, hairy vetch grown at the experimental site in Osaka, Japan were 3.6 kg in fresh weight and 690 g in dry weight m⁻², with 20.4 g N and 2.3 g P m⁻², that were then incorporated into the turmeric field at 5 kg m⁻² as fresh-weight hairy vetch shoots. As mentioned above, previous studies showed that 8 – 26 g N m⁻² were produced by hairy vetch under various conditions (Sainju et al., 2006; Anugroho et al., 2009b; Campiglia et al., 2010a, 2010b). In this experiment, shoots of 5 kg m⁻² in fresh weight were actually incorporated to determine whether hairy vetch green manure was effective as organic matter applied basally for turmeric crop. Therefore, we evaluated the effects of comparatively large amounts of N added to the turmeric field. The incorporated materials had a C/N ratio of 14.3 and a C/P ratio of 126, which are not critical for rapid decomposition after incorporation as green manures (Kuo and Sainju, 1998; Rosecrance et al., 2000; Chaves et al., 2004).

Plant height, number of leaves and number of stems of turmeric plants increased after incorporation compared with that without incorporation (no-incorporation) (Fig. 1). The differences in plant height and number of leaves between incorporation and no-incorporation became markedly large on 16 August. The dry weights of shoots and rhizomes were significantly increased by the incorporation even on 16 August and 15 September, respectively (Figs. 2A and B). Changes in the amount of total N and P in the shoots showed a similar pattern throughout the growth periods (Figs. 2C and E), and those in the rhizome also showed a similar pattern (Fig. 2D and F). The differences in the amounts of total N and P (total amounts of N and P) between incorporation and no-incorporation were the largest on 15 October, when the amount of N and P was increased by 8.0 g N m⁻² [(9.7 g in shoot + 4.3 g in rhizome) – (3.9 g in shoot + 2.1 g in rhizome)] and 1.1 g P m⁻² [(1.6 g in shoot + 1.5 g in rhizome) – (0.9 g in shoot + 1.1 g in rhizome)], respectively, by the incorporation. Root biomass could not be measured in this experiment because there was no reproducibility in the experimental field consisting of Gray lowland soil.

The leaves and stems of turmeric plants that turned

| Fresh weight (g m⁻²) | Dry weight (g m⁻²) | N content (g m⁻²) | P content (g m⁻²) | C/N ratio | C/P ratio |
|----------------------|-------------------|------------------|------------------|-----------|-----------|
| 3614                 | 690               | 20.4             | 2.3              | 14.3      | 126       |
| (5000)               | (955)             | (28.7)           | (3.2)            |           |           |

Shoots of hairy vetch were harvested at 20 May, 2009 and then incorporated. Values in parentheses are amounts of shoots incorporated as a green manure to turmeric cropping.
Many researchers have considered that hairy vetch is beneficial as both a cover crop and green manure to increase nutrient uptake by the succeeding crop (Czapar et al., 2002; Hartwig and Ammon, 2002; Sainju et al., 2006; Choi and Daimon, 2008; Anugroho et al., 2009a, 2009b).

Yellow were found in early December 2009, and the rhizomes were harvested in early January 2010. There was no difference in the curcumin concentration in the rhizomes on 15 September, 15 October, and 4 January (Fig. 3A). On 15 October, the rhizomes had thickened (Fig. 2B), and the amount of curcumin in the rhizomes in the incorporation treatment was larger than that in no incorporation (Fig. 3B). From September to October, the amount of curcumin content rapidly increased with rhizome thickening, and then gradually increased until 4 January, 2010.

Many researchers have considered that hairy vetch is beneficial as both a cover crop and green manure to increase nutrient uptake by the succeeding crop (Czapar et al., 2002; Hartwig and Ammon, 2002; Sainju et al., 2006; Choi and Daimon, 2008; Anugroho et al., 2009a, 2009b;
Campiglia et al., 2010a, 2010b; Zablotowicz et al., 2011). In general, 10 – 20% of N incorporated as organic matter could be utilized by the succeeding crop cultivated immediately after incorporation, while the utilization rate of N might depend on the decomposition properties of the organic matter such as the C/N ratio and concentrations of lignin and polyphenolics (Kuo and Sainju, 1998; Rosecrance et al., 2000; Chaves et al., 2004; Uratani et al., 2004). Our previous studies on the effect of hairy vetch incorporation into sorghum crop, indicated that hairy vetch shoots harvested at the flowering stage had no difficulty in decomposition of the organic matter, and that their potential for N contribution to the succeeding sorghum crop was high (Choi and Daimon, 2008). In this experiment, 8 g N m$^{-2}$ of shoot plus rhizome was supplied to the succeeding turmeric plants by incorporating hairy vetch shoots with a C/N ratio of 14.3 (Figs. 2C and D, and Table 1), indicating that hairy vetch could be considerably effective as a green manure for turmeric cropping. Moreover, a comparatively low C/P ratio (126) in hairy vetch shoots might be effective for rapid decomposition of the incorporated materials (Sharpley and Smith, 1989; Lupwayi et al., 2007). This green manure material might also be a source of P supply.

2. Effect of incorporation of faba bean residues on the growth of the succeeding turmeric crop

The harvest index (HI) for dry weight and the amount of N and P in the preceding crop must be considered for effective use of the crop residues as green manures. Jensen et al. (2010) reported that faba bean crop, which was grown on a sandy loam soil in Denmark, accumulated 1.24 kg dry matter m$^{-2}$ by maturity and assimilated 32.4 g N and 3.6 g P m$^{-2}$. The HI values were 43% for dry matter, 73% for the amount of N, and 83% for the amount of P. López-Bellido et al. (2006) also described that HI of faba bean crop grown on a rainfed Vertisol field in Spain averaged 39% through a 4-year experiment and that the HI value for the amount of N was 67%. Table 2 shows the pod yield and the amount of total N and P in faba bean residues after harvesting the pods. The residual aboveground parts after harvesting pods had dry weights of 446 g m$^{-2}$, 8.5 g N m$^{-2}$, 1.4 g P m$^{-2}$, a C/N ratio of 21.9, and a C/P ratio of 123. Thus, 55% dry weight, 69% N, and 67% P in aboveground parts were removed from the field. These results were consistent with those obtained in previous studies, especially regarding the amount of total N and P, when considering the amount of N and P supplied through green manuring by using the faba bean shoot residues.

Table 2. Growth and N and P contents in different parts of faba bean grown as the preceding crop to turmeric.

| Plant parts          | Fresh weight (g m$^{-2}$) | Dry weight (g m$^{-2}$) | N content (g m$^{-2}$) | P content (g m$^{-2}$) | C/N ratio | C/P ratio |
|----------------------|---------------------------|-------------------------|------------------------|------------------------|-----------|-----------|
| Seeds                | 3335a                     | 239                     | 11.7                   | 1.8                    | 8.4       | 54        |
| Pod shells           | 312                       | 6.9                     | 1.1                    | 18.2                   | 112       |
| Residual shoots      | 2310                      | 446                     | 1.4                    | 21.9                   | 123       |

Pods (seeds and pod shells) were collected at 18, 21 and 26 May, 2010 and crop residues were incorporated at 3 June.

a : Seeds + pod shells

Fig. 3. Effect of incorporation of hairy vetch shoots on curcumin concentration in the rhizome (A) and the amount of curcumin in the rhizome per m$^{-2}$ (B) in the succeeding turmeric crop. Data are means of six replications. ** represents significant difference at 1% probability level. NS means no significant difference.
We investigated the influence of shoot residues of faba bean on turmeric yield through the experiments using the 2 fields, faba bean cropping and the fallow. On the basis of the data obtained from these experiments, we evaluated the N and P supplied from faba bean residues in these cropping system.

The values of plant height, number of leaves, and number of stems of turmeric crop grown in the previous faba bean plot were higher in the S + R plot than in the R plot (Figs. 4A, C, and E). Further, the growth parameters of turmeric that was grown in the previous fallow plot were higher in the S plot than in the C plot (Figs. 4B, D, and F). Shoot dry weight of turmeric grown in the S + R plot was significantly heavier than that in the R plot on 13 August, 12 October, and 11 December (Fig. 5A). Moreover, the rhizomes formed by 12 October and were harvested on 11 December. The dry weight of the rhizomes in the S + R plot was heavier than that in the R plot at both sampling times (Fig. 5A). Thus, the total dry weight of turmeric (sum of shoot and rhizome) was significantly heavier in the S + R plot than in the R plot, and the difference between the 2 treatments was approximately 190 g m$^{-2}$ (1240 g in S + R plot – 1050 g in R plot) at the final harvest. On the other hand, the dry weight of shoots and rhizomes of turmeric grown in the S plot, where yield residues collected outside the boundary of the preceding faba bean field were incorporated, were significantly higher than those in the C plot, where no residues were incorporated. On 11 December, the difference between the 2 treatments was approximately 350 g m$^{-2}$ (1210 g in S plot – 860 g in C plot) (Fig. 5B).

Changes in the amount of total N and P in shoots and rhizomes m$^{-2}$ showed patterns similar to the changes in the dry weight (Figs. 5C, D, E, and F). The amount of total N and P in turmeric grown in the S + R plot were significantly larger than those in the R plot at each sampling date. On the basis of the amount of total N and P in the R plot subtracted from those in the S + R plot, the amounts of N
and P increased by incorporation of shoots were estimated as 2.5 g m⁻² (14.9 g in S + R plot – 12.4 g in R plot) and 1.0 g m⁻² (6.5 g in S + R plot – 5.5 g in R plot), respectively. Similarly, experimental results in the previous fallow field showed that the amount of N and P increased by incorporation of shoots from a neighboring field were approximately 4.5 g m⁻² (14.8 g in S plot – 10.3 g in C plot) and 1.9 g m⁻² (6.4 g in S plot – 4.5 g in C plot), respectively. No difference among the plots in curcumin concentration in the rhizome was observed on 12 October and 11 December (Figs. 6A and B). However, the amounts of curcumin in the rhizome in the S + R and S plots were significantly larger than those in the R and C plots, respectively, because of the increase in the dry matter (Figs. 6C and D).

Thus, we quantified the N and P input from faba bean residues, and particularly focused on the contribution of faba bean shoot residues to turmeric growth by using 2 plots; the preceding faba bean plots and fallow plots. Conversely, the succeeding crop growth might also be affected by root residues, especially by rhizodeposited nutrients (Choi et al., 2008; Kätterer et al., 2011; López-Bellido et al., 2011). Faba beans are often introduced into crop rotation as a grain and green-manure legume, and several researchers have referred to the beneficial role of their belowground parts in nutrient cycling in several cropping systems, including cereals (Lopez-Bellido et al., 2006; Jensen et al., 2010; Muñoz-Romero et al., 2011). N and P flow from root residues and rhizodeposited matter to the succeeding turmeric crop could not be estimated in
this experiment. Further study on influences of belowground residues is needed.

In this study, field experiments in successive 2 years were conducted to determine the effect of incorporating the faba bean residues on turmeric growth. In the second year after incorporation of the residues, plant height, number of leaves, and number of stems of the succeeding turmeric crop in the plots did not significantly vary. No differences in dry weight, N content and P content of shoot and rhizome, and in curcumin content of rhizome were also observed among the plots on 26 September and 5 December, 2011 (data not shown). Thus, we assume that contribution of faba bean residues as green manure to N and P fertility of soil may not continue for 2 years in turmeric cropping in the temperate region.

3. Potential benefit of winter legumes as an organic matter for basal application in turmeric cropping

Before using a legume as green manure, including crop residue, the ability of the legume to supply its own N by N$_2$ fixation associated with rhizobia should be estimated, because N input by a legume to the cropping system has considerable importance in the management of soil fertility. As described above, we quantified the amount of N in hairy vetch shoots and faba bean shoot residues, which ranged from 2.5 to 8.0 g m$^{-2}$, under different field conditions (Figs. 2C, D and 5C, D). However, symbiotically fixed N in hairy vetch and faba bean grown in the present experiments was not determined. As described above, both legume species accumulate a large amount of N. For example, the amount of N$_2$ fixed by faba bean was estimated to be larger than that by other grain legumes, and the proportion of N fixed to the total N accumulated in the faba bean crop would be high, although this depends on many environmental factors (Patriquin, 1986; Rochester et al., 1998; Fan et al., 2006). Actually, the amount of N$_2$ fixed by faba bean has been reported to range from 5 to 20 g N m$^{-2}$ as the potential contribution to soil N (Unkovich and Pate, 2000; López-Bellido et al., 2006). Considerable amounts of fixed N$_2$ might be added by residue input in this experiment, and these residues could be used as the N source by the succeeding turmeric crop. On the other hand, N uptake by the succeeding crop is dependent not only addition of N to the soil by the preceding legume, but also removal of N from the soil. We could not evaluate N balance in relation to N fixation and N removal by the preceding legumes, hairy vetch and faba bean, in these experiments. In further studies, the role of green manures in turmeric production should be defined through quantitative evaluation of both N$_2$ fixation and nutrient removal by these winter legumes.

In general, a turmeric crop is grown using farmyard

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Fig. 6. Effect of incorporation of faba bean residues on curcumin concentration in the rhizome (A, B) and the amount of curcumin in the rhizome per m$^{-2}$ (C, D) in the succeeding turmeric crop. Data are means of five replications. ** represents significant difference at 1% probability level. NS means no significant difference.

A and C: experiment in the preceding faba bean plot.
B and D: experiment in the preceding fallow plot.
manure in combination with inorganic fertilizers, and its uptake of N and P at harvest averages 15 – 30 g m⁻² and 3 – 4 g m⁻², respectively (Sivaraman, 2007). In the present study, 8.0 g N m⁻² and 1.1 g P m⁻² was increased by incorporation of both shoot and rhizome of hairy vetch compared with no incorporation (calculated from data shown in Figs. 2C, D, E, and F). Faba bean residues, on the other hand, supplied 2.5 – 4.5 g N m⁻² and 1.0 – 1.9 g P m⁻² to the turmeric in the same cropping system. These amounts of N and P added to the soil as green manures might contribute to turmeric yield as a nutrient source. The present study indicated that basal organic matter application by using 2 winter legumes, hairy vetch and faba bean residue, would be effective for turmeric crop grown in the temperate region, where seed rhizomes are planted in June.

In addition to N and P supply through green manure, potassium (K) supply should also be considered in basal application of green manure as an organic matter in turmeric cropping (Yamaguchi et al., 2001; Jagadeeswaran et al., 2005). Kinjo et al. (2001) reported that slow-release inorganic fertilizer such as CDU555 and LPBB555, which contain N, P, and K, were effective for rhizome yield. In the present study, input of K through green manure application could not be determined. As a rate of leaching loss of K is often higher, application of K as an organic matter should also be evaluated in turmeric cropping.

Soil physical properties such as soil porosity, water holding capacity, and aggregate stability, are generally improved by organic matter application. In turmeric cropping in Okinawa, these properties of soil should be adequately maintained for higher yield. Therefore, completely matured farmyard manures such as chicken, cow and goat manures, which can improve the soil physical properties, are often applied as basal fertilizer (Kinjo et al., 2001; Hossain and Ishimine, 2007). Incorporation of green manure also has these functions, indicating that the growth improvement of the turmeric crop found in the present experiment might also be due to these functions.

On the other hand, application of green manure as an organic matter instead of completely matured farmyard manure may induce inhibition of turmeric plantlet emergence. This is because both excreting growth inhibiting substances and N starvation during decomposition of green manures often have a suppressive effect on early growth of the succeeding crop (Daimon and Koutoura, 2000; Uratani et al., 2004; Daimon, 2006). In general, a month after incorporation is needed for maturation of green manures (Ngouajio and Mennan, 2005; Liebman and Sundberg, 2006; Choi and Daimon, 2008; Blaise, 2011; Espinoza et al., 2012). Although seed rhizomes of turmeric were planted 11 days after incorporation of faba bean residues in the present experiment, no inhibition of turmeric emergence was observed in any plot, and plantlet emergence rate was 100% at 30 DAP (41 days after incorporation of the faba bean residues). In case of hairy vetch incorporation, growth inhibition of turmeric plantlets was also not observed. Accordingly, 3 – 4 weeks (from 23 May to 17 June) after incorporation of hairy vetch shoots were sufficient to eliminate both N starvation and exudation of toxic substances that remain after incorporation.

4. Conclusion

In Okinawa, subtropical region in Japan, turmeric is planted in early April under application of farmyard manure as an organic matter beside inorganic fertilizers. When this plant species would be produced in the southwestern districts in Japan, temperate region, winter green manure legume and crop residue such as hairy vetch and faba bean might be utilized as an organic matter, because these legumes have sufficient growth periods prior to the turmeric growing season in this region. Turmeric growers involved in small-scale agriculture that requires high utilization rate of arable land should consider maintaining the N and P balance, especially when incorporating faba bean residue, because faba bean is more marketable than several winter legumes, including green manure crops such as hairy vetch.

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