



Improvement of the value of green manure via mixed hairy vetch and barley cultivation in temperate paddy soil



Hyun Young Hwang^a, Gil Won Kim^a, Yong Bok Lee^{a,b}, Pil Joo Kim^{a,b,*}, Sang Yoon Kim^{c,**}

^a Division of Applied Life Science (BK 21 Program), Gyeongsang National University, Jinju 660-701, South Korea

^b Institute of Agriculture and Life Science, Gyeongsang National University, Jinju 660-701, South Korea

^c Netherlands Institute of Ecology (NIOO-KNAW), Department of Microbial Ecology, Wageningen, the Netherlands

ARTICLE INFO

Article history:

Received 26 April 2015

Received in revised form 30 July 2015

Accepted 1 August 2015

Available online 13 August 2015

Keywords:

Cover crop

Rice

Biomass productivity

Nitrogen production

ABSTRACT

Legume hairy vetch and non-legume barley mixtures are broadly cultivated to improve the value of cover crops in mono-rice paddies. Nevertheless, the effects of mixing conditions of the two cover crops on biomass and nutrient productivities and on the yield characteristics of subsequent rice crops have not been well studied. To evaluate the effects of mix-seeding legume and non-legume cover crops on the value of green manure in paddy soil, barley and hairy vetch were sown at the rice harvesting stage as pure crops at the recommended rates (180 kg ha⁻¹ of barley, B100; 90 kg ha⁻¹ of hairy vetch, V100), and as mixtures, in which the two cover crops were mix-seeded with varying seed ratios according to the replacement principle. The mixed seeding of the two crops significantly increased the cover crop biomass and nutrient productivities compared with the single barley and hairy vetch cultivation. Biomass productivity linearly increased with increasing barley seeding level, but it was not affected by the hairy vetch seeding rate. The total N content of the barley biomass clearly increased as the proportion of the total biomass accounted for by hairy vetch was increased, and this significantly improved the value of the green manure of cover crop biomass. In contrast, the total N content of the hairy vetch biomass was not affected by changes in the barley proportion. Biomass produced in the pure barley seeding could not produce the nutrients required by the recommended chemical fertilization level (N–P₂O₅–K₂O = 90–45–57 kg ha⁻¹) for rice, but the biomass increase caused by mixed seeding of the two cover crops resulted in enough nutrients to satisfy the recommended fertilization level. The highest biomass and nutrient yields were observed for the mixed seeding of barley and hairy vetch at 25 and 75% (B75V25) of their respective recommended seeding rates. This increased nutrient input stimulated the rice plant growth and significantly improved the rice yields. The highest yields were achieved with the B75V25 treatment. In conclusion, mixed seeding of legume hairy vetch and non-legume barley could be a very useful agronomic practice for increasing the cover crop biomass and its nutrient productivity and to improve the productivity of subsequent rice crops in temperate rice paddies.

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1. Introduction

In mono-rice cultivation systems in temperate-zone countries such as Korea, where the climatic during winter is characterized by dry and cold weather, the choice of winter cover crops is limited to cold-resistant crops. Winter cover crops include non-leguminous rye, barley and wheat, which generally exhibit high biomass yields,

and N-fixing plant species such as Chinese milk vetch and hairy vetch (Cho et al., 2003; Kim et al., 2013). These crops are seeded during rice harvesting in the late fall and then mechanically incorporated in situ as green manure by tillage before the subsequent rice transplanting.

The selection of a cover crop to be used as a green manure mainly depends on the primary aims to be achieved. Legumes are mainly used for their ability to fix, accumulate and supply large amounts of N (Peoples et al., 1995; Caporali, 2004; Ghaley et al., 2005; Campiglia et al., 2010), whereas non-legumes are mainly used to prevent soil erosion, trap nutrients, reduce nutrient leaching losses, and increase the soil organic carbon stock (Vos and van der Putten, 2001; Poeplau et al., 2015). Leguminous cover crops such as hairy vetch are the most popular green manure in South Korea's rice fields

* Corresponding author at: Division of Applied Life Science (BK 21 Program), Gyeongsang National University, Jinju, 660-701, South Korea. Fax: +82 55 772 1969.

** Co-corresponding author. Sang Yoon Kim, he is co-corresponding author. Please check it.

E-mail addresses: pjkim@gnu.ac.kr (P.J. Kim), soilmethane@gmail.com (S.Y. Kim).

because of their high nitrogen (N)-fixing potential (Kim et al., 2007; Na et al., 2007). However, their added biomass when used as green manure causes problems for rice cultivation because it increases the vegetative growth period of rice and leads to deterioration in the rice grain quality. In comparison, incorporation of non-leguminous rye or barley cover crops does not effectively increase the rice productivity (Jeon et al., 2013; Lee et al., 2010) because of the resulting high C/N ratio and the slow mineralization.

Adopting mixtures of non-legumes and legumes can be a practical tool to merge the advantages of individual species for cover crop utilization (Ranells and Waggoner, 1997), thereby achieving both agronomic and environmental benefits (Crews and Peoples, 2005). Use of mixtures can lead to radical modification of the biochemical composition of the aboveground biomass that is incorporated into the soil (Tosti et al., 2010). Therefore, it can affect the mineralization characteristics of plant residues and the nutrient availabilities for subsequent crops. For example, a mixture of hairy vetch and barley is preferred as a green manure in Korea's rice paddies because of the higher biomass productivity compared with single vetch or barley cropping and the synergies of these crops, such as N supply by vetch and support fixture of barley for creeping vetch (Bayram et al., 2009; Ansar et al., 2010; Lee et al., 2010). The combination of barley and hairy vetch might also optimize the C/N ratio, and this can favor the mineralization of organic substrates in soil (USDA, 2011). However, the effects of the mixing conditions of the two cover crops on the biomass and nutrient productivities and the yield characteristics of the subsequent cash crop rice have not been well studied in mono-rice paddy soil.

We hypothesized that combined seeding of non-legume and legume cover crops could increase the productivities and qualities of biomass as a green manure, and its biomass could effectively serve as a substitute for the chemical fertilizers that are typically required for subsequent cash crop rice cultivation. In this field study, to evaluate the combined seeding effect of non-legumes and legumes on green manure productivities and subsequent crop yield properties, barley and hairy vetch were seeded in different combinations in paddies at the rice harvesting stage, and the value of the biomass as a green manure was compared by characterizing nutrient productivities of the cover crops and yields of the subsequent crop rice.

2. Materials and methods

2.1. Experimental plot preparation and cover crop cultivation

Field experiments were performed during two growing seasons (2011–2012 and 2012–2013) at the Gyeongsang National University Experimental Farm (36°50'N and 128°26'E), in Jinju, South Korea. The selected soil was typical of rice paddies in Korea. The study area shows a typical monsoonal climate within a temperate zone. The annual mean temperature and total precipitation were recorded to be 12.9, 13.0°C and 1753, 1221 mm per year, respectively (Fig. 1) (KMA, 2013). The soil texture was silt loam and classified as typic Haplaquents with somewhat impeded drainage. The main chemical properties of the soil were organic carbon content of $14.0 \pm 2.6 \text{ g kg}^{-1}$, pH (1:5 with H_2O) of 6.5 ± 0.21 , and available P_2O_5 of $32.1 \pm 1.1 \text{ mg kg}^{-1}$.

The grain and straw of rice were removed at the harvesting stage. The experiment consisted of two consecutive phases: the first was cultivation of autumn–winter cover crops until the hard dough stage of barley, and the second was cultivation of two spring–summer rice cash crops. Two species, barley (*Hordeum vulgare* L.) and hairy vetch (*Vicia villosa* R.), were used as cover crops. These species were sown as pure crops at the recommended rates (180 kg ha^{-1} of barley, B100; 90 kg ha^{-1} of hairy vetch, V100) and

as mixtures with varying seed ratios according to the replacement principle (Wit and Van den Bergh, 1965; Connolly, 1986; Tosti et al., 2012). In detail, the following three combinations were chosen: barley at 25% of its full seeding rate + hairy vetch at 75% of its full seeding rate ($45 + 68 \text{ kg ha}^{-1}$; B25V75), barley at 50% + hairy vetch at 50% ($90 + 45 \text{ kg ha}^{-1}$; B50V50) and barley at 75% + hairy vetch at 25% ($135 + 23 \text{ kg ha}^{-1}$; B75V25).

Aside from the cover crop treatments, a chemical fertilization plot (NPK) was added in the experiment field for comparison. The NPK plots were managed under the same conditions except that cover crop was not cultivated during the fallow seasons. Each plot size was $10 \text{ m} \times 10 \text{ m}$. The experimental design was a completely randomized block with 3 replicates.

2.2. Cover crop management and rice cultivation

Cover crop seeds were evenly broadcasted after rice harvesting at the end of October, and were cultivated without additional fertilization. No disease or weed control was performed. The aboveground biomass was manually harvested at the hard dough stage of barley in the following years (2012 and 2013), finely chopped (size 5–10 cm), and mechanically mixed into the surface soil (0–15 cm depth) (Haque et al., 2013; Kim et al., 2013). Prior to harvesting cover crop, biomass samples were collected from three 1 m^2 areas ($n = 3$) in each plot, and oven-dried for estimating biomass productivity.

Under the flooded condition, twenty-one-day-old seedlings (3 plants per hill) of rice (Dongjin cultivar, Japonica type) were transplanted into field plots at a spacing $15 \text{ cm} \times 30 \text{ cm}$ in the early June. The water level was maintained at a depth of 5–7 cm during the growing season and drained 3 weeks before rice harvesting. No chemical fertilizer was applied in all cover crop plots, whereas the recommended rates of chemical fertilizers ($\text{N-P}_2\text{O}_5\text{-K}_2\text{O} = 90\text{--}45\text{--}58 \text{ kg ha}^{-1}$) were applied in the control plot (NPK). The grain and straw yields and yield components such as the panicle number per hill, number of grains per panicle, ripened grains, and 1000-grain weight were determined at physiological maturity from three 3.3-m^2 areas within each plot following the RDA methods (RDA, 1995). Grains were separated from straw using a plot thresher, air-dried, and weighed. Straw weights were expressed on an oven-dry-weight basis (65°C). The grain harvest index was calculated using the following formula: $[\text{Grain harvest index} = (\text{Grain yield})/(\text{Grain} + \text{straw yield})]$.

2.3. Plant and soil analysis

At harvesting stage, the aboveground biomass of vetch and barley in mixtures was separated by hand. The harvested aboveground biomass was weighed, oven-dried at 65°C for 72 h, ground to a fine powder and stored for analysis of its nutrient content. The total C and N contents were analyzed using an elemental analyzer (CHNS-932 Analyzer, Leco, St. Joseph, MI.), and the total P and K contents were determined from digested samples using H_2SO_4 and ternary solution ($\text{HNO}_3\text{:H}_2\text{SO}_4\text{:HClO}_4 = 10\text{:}1\text{:}4$, v/v/v), respectively (Yoshida et al., 1976).

Composite soils were collected from the surface layer (0–15 cm depth) using an auger sampler (50 mm ID) at the rice harvesting stage. The soil samples of approximately 1 kg were collected at 10 sites in each plot, then air dried, and homogenized via sieving ($<2 \text{ mm}$) for chemical analysis. The basic chemical properties were analyzed using the Korean standard method (RDA, 1988). For example, pH (1:5 with H_2O) was measured by pH meter (Orion 3 star, Thermo Electron Corporation, MA, USA). Total C and N concentrations were determined using an elemental analyzer (CHNS-932 Analyzer, Leco, St. Joseph, MI). Available phosphate concentration was determined by the Lancaster method ($0.33 \text{ M CH}_3\text{COOH}$,

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