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Decomposition and ^{15}N Fate of Rice Straw in Paddy Soil

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ABSTRACT : The rice straw managements are essential for maintaining soil fertility as well as reducing chemical fertilizer application in paddy field. A field experiment was conducted on moderately well draining alluvial paddy soil to investigate the decomposition pattern of rice straw. The mesh bags containing the rice straw harvested in the previous year were placed at soil surface and buried into around 10 cm depth and recovered periodically for determining the straw decomposition. Pot experiments were conducted to investigate the fates of N released from ^{15}N-labeled rice straw under different levels of N fertilizer application. The overall decomposition patterns of rice straw were similar for the two incorporation depths in transplanted paddy field. The straw incorporated at transplanting date showed weight loss of about 50%, 70% and 90% after 2 months, 5 months, and 2 years, respectively. The decompositions of straw cell wall components showed somewhat different pattern. The decompositions of cellulose and silica were similar to that of dry weight while the decomposition of lignin was slower than that of cellulose and silica. N was released from rice straw 42% and 65% of the initial N after one month and after five months, respectively. P release was faster than N release. Recoveries of rice straw-^{15}N by rice plants were 10.2, 13.4 and 14.9% in 0, 120 and 240 mg N pot^{-1}, respectively. Soil recoveries of rice straw-^{15}N were 17.3, 20.6 and 18.9% in 0, 120 and 240 mg N pot^{-1}, respectively.

Keywords : rice straw, crop residue decomposition, nitrogen recovery, phosphorus

The modern rice farming method has based on heavy application of agrochemicals such as chemical fertilizers, pesticides and herbicides to obtain a high yield. Increased input of fertilizers in rice farming, however, have changed ecological environment and deteriorated soil quality (Yoo, 1999).

To sustain soil fertility and to reduce the side effect on the environment, a variety of organic materials like crop residue, winter green manure, compost, livestock waste and organic waste have been used as organic supplier to the farmyard.

Since rice straw can be easily and economically returned into paddy soils, it must be considered as a main soil organic supplier. The suitable paddy soil for rice straw incorporation has been known as moderately well draining soil because of rapid decrease of oxidation-reduction potential induced by the straw decomposition (Lee *et al.*, 1984).

The decomposition of rice straw is an important factor for the nutrient recycling and soil fertility maintenance in paddy soil. Several researchers have studied the effects of rice straw application on rice yield, soil characteristics and nitrogen transformation (Huh and Lee, 1981; Kim and Kim, 1984a, b, c; Yoo *et al.*, 1988a, b; Lee *et al.*, 1995). However, there were only a few reports on rice straw decomposition and its nutrients releases. Sain and Broadbent (1977) indicated that soil-incorporated rice straw decomposed more rapidly than the straw spread on the soil surface during winter and spring months. The decomposition loss of rice straw applied to submerged soil was about 40% of initial weight in pots during one rice growing season (Kim and Kim, 1984). Decomposition rates of rice straw in the tilled paddy field tended to be higher than that in no-tillage paddy field during rice growing season (Saigusa *et al.*, 1999).

Several studies have been reported on the fates of N released from rice straw in paddy soil using ^{15}N tracer method. Transformation of rice straw N in various soil fractions was traced over 2 years (Kanazawa and Yoneyama, 1980). Hwang (1995) reported that recovery by rice plants and losses of rice straw N ranged 6 to 11% and 59 to 89%, respectively. In field study, Saigusa *et al.* (1999) reported that recovery of nitrogen released from rice straw was 3 to 4% until the maximum tillering stage and 9 to 10% until harvesting time both in tilled and no-tillage paddy fields.

The objective of this study was to investigate the decomposition pattern and the fates of N derived from rice straw for the efficient use of the straw in paddy field.

MATERIALS AND METHODS

Straw decomposition in paddy fields

A field study was conducted on silt loam soil of paddy fields at College Farm, Seoul National University, Suwon. The field was moderately well drained and soil plow layer

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contained 2.0% organic matter. The field was applied with 100 kg N ha^{-1}, 80 kg P_2O_5 ha^{-1} and 80 kg K_2O ha^{-1}. Nitrogen fertilizer was split-applied with urea as basal N of 50 kg N ha^{-1}, topdressed N of 25 kg N ha^{-1} at tillering stage and 25 kg N ha^{-1} at panicle initiation stage.

Eight grams of rice straw that was chopped into 10 cm length after oven-dried, was put into 10×20 cm, 0.5 mm mesh nylon bag. Chemical compositions of the straw were 8.4 mg N g^{-1}, 0.9 mg P g^{-1} and 85 mg Lignin g^{-1}. The bags were placed at soil surface with three replications and buried into around 10 cm depth with six replications in transplanted paddy or in dry-seeded paddy on June 1.

Mass and nutrient loss were determined from mesh bag recovered after a given time interval. The samples recovered from soil were washed of adhering soil particles with water, and then dried at 70°C for more than 2 days, weighed and ground to pass a 1-mm sieve for chemical analysis. Total nitrogen was determined by the Kjeldahl method (Kjeltec auto sampler system 1035 analyzer). Phosphorus was determined by Molybdenum-blue method after digestion with 1 M HCl solution. Cellulose, lignin and silica contents were determined by Van Soest method with Fibertec system (Tecator Co., Sweden).

Fate of rice straw-^{15}N

A pot experiment was conducted to measure the fate of the straw-^{15}N under different N fertilization levels between June and October, 1999. Pots of 1/5000a were filled with 4 kg of air-dried, sieved (1 cm) loam soil with 14.9 mg total organic C g^{-1}, and 1.7 mg total N g^{-1}.

The ^{15}N labeling of rice straw was carried out during the previous year. Pots of 1/2,000a were filled with ten kilograms of the air-dried silt loam soil of paddy field, and three hills of three 35 days old rice seedlings (cv. Hwaseongbyeo) were transplanted and cultivated under the greenhouse condition. Twenty grams of $(NH_4)_2SO_4$ labeled with ^{15}N by 10 atom % were split-applied with the ratio of 50%, 25% and 25% as basal, 1st top-dressing and 2nd top-dressing fertilizer.

^{15}N-labeled rice straw with 9.3 mg N g^{-1} and 12.3 atom % ^{15}N was cut into 1 cm pieces and thoroughly mixed with the soil at the rate of 16 g pot^{-1}. And then pots were submerged 3 days before transplanting and kept submerged with a 5 cm water layer afterward. On June 1, two hills of three 35 days old rice seedlings (cv. Hwaseongbyeo) were transplanted in each pot.

Nitrogen fertilization levels were 0, 120 and 240 mg N pot^{-1}. Nitrogen was split-applied as basal fertilizer, tillering fertilizer and panicle initiation fertilizer with the ratio of 50%, 25% and 25% respectively. Phosphate and potash were applied with the same amount of 80 mg pot^{-1} in 120 mg N pot^{-1} and 160 mg pot^{-1} in 240 mg N pot^{-1}.

The experiment was replicated four times in a randomized complete design. Pots were grown under field weather condition and there were not shading between pots. At harvest, plant samples were oven dried at 70°C to a constant weight, weighed and ground to pass a 0.5 mm sieve. Soil samples, from which fresh organic matter was excluded fresh organic matter were air-dried and ground to pass a 0.5 mm sieve to determine total N and ^{15}N. And then sub samples of the soil were shaken with 2 M KCl solution for 1 hour and residual soils were air-dried to determine KCl nonextractable ^{15}N. Total N and ^{15}N of plant and soil were analyzed with stable isotope mass spectrometer (Isoprime-EA, Micromass co. UK).

RESULTS AND DISCUSSION

Decomposition of rice straw

The overall decomposition of the straw incorporated at transplanting date followed a exponential decrease regardless of incorporation depth (Fig. 1). During the first month rice straw was decomposed 39~41%, its rate being the highest. The loss in straw weight was about 70% and 90% of initial weight during one rice growing season in the 1st year and after 2 years, respectively. Though straw consisted of various compounds with different decomposability, it is natural that easily decomposable compounds decay fast in initial period. Rapid decomposition after soil incorporation was probably due to easily decomposable fraction and water extractable fraction of the straw (Gilmour *et al.*, 1998; Christensen, 1985).

The straw at soil surface was more rapidly decomposed than those of buried during initial decomposition period.

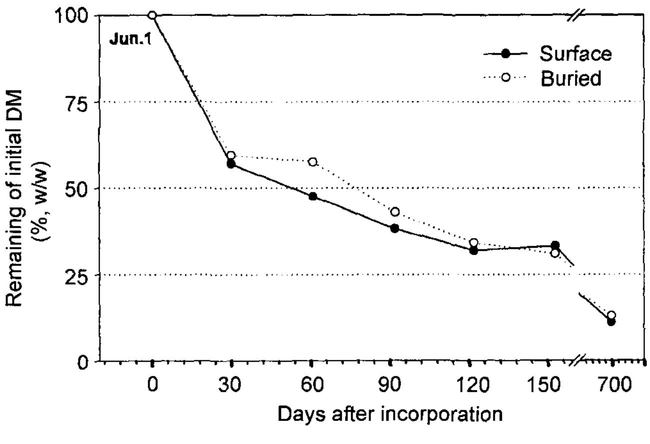

Fig. 1. Decomposition of rice straw in transplanted paddy field.

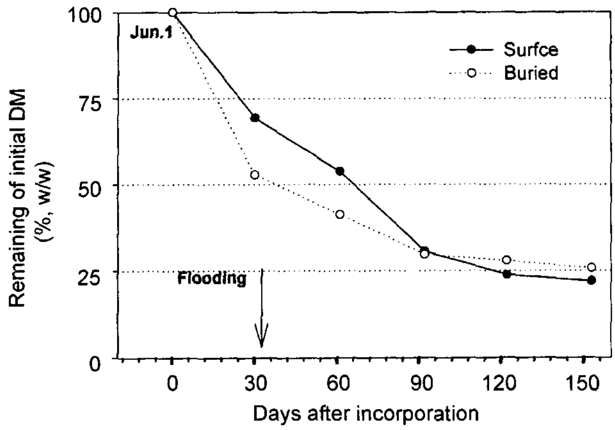

Fig. 2. Decomposition of rice straw in dry-seeded paddy field.

This result might have been caused by the better aerobic condition of soil surface. D_{50}, indicating 50% decomposition in dry straw was reached at 50 days after incorporation in surface spread and at 70 days in buried.

Decomposition of the straw incorporated into dry-seeded paddy, which was flooded in one month also showed the same pattern of exponential decay (Fig. 2). The straw showed weight loss of 74~78% during a rice growing season. The straw spread at soil surface was more slowly decomposed than buried straw for the initial two months. After flooding, however, the surface straw was decomposed faster than the buried straw, which resulted in the similar decomposition to buried straw in later stages. This result was attributed to that the straw on soil surface did not have enough moisture to decompose at early stage of spreading.

Straw component degradation

The weight loss of straw components followed the similar patterns to the dry weight decreased (Fig. 3). The decrease of cellulose was most rapid, being similar to that of dry weight. The decrease of lignin was slower than that of cellulose and silica. Lignin, which is very resistant to microbial degradation, persisted in the decomposing straw. These results were in general agreement with those of other researchers (Summerell and Burgess, 1989).

The losses of N and P from the straw are shown in Fig. 4. Both physical and biological decomposition were responsible for the significant changes in dry weight and nutrient contents. The fraction of microbial biomass was separated from the decomposing straw by washing and thus, the measured values mainly represented the nutrient contents of residue itself. The decrease pattern of N was similar to that of dry weight. Total amount of N released from the straw were 42% and 65% of the initial N after one month and five

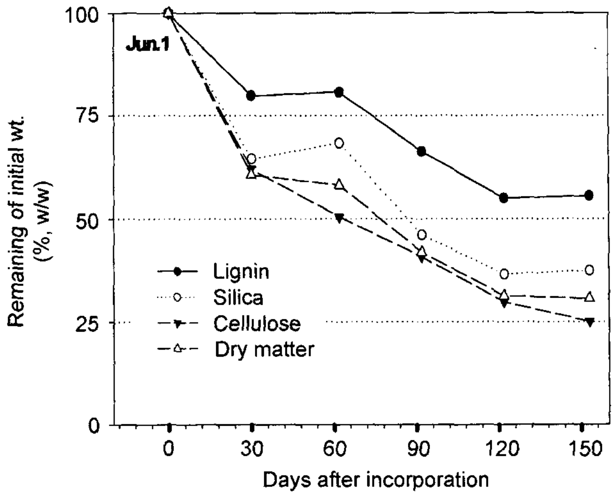

Fig. 3. Decreases in initial lignin, silica and cellulose of buried rice straw in transplanted paddy field.

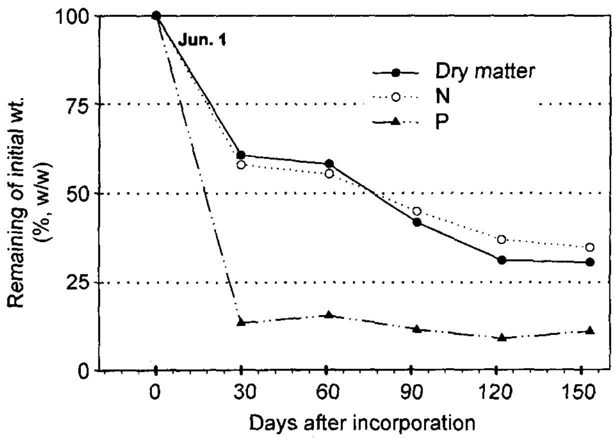

Fig. 4. Decreases in N and P contents of buried rice straw in transplanted paddy field.

months, respectively. P release from the straw was faster than N release. Total amounts of P released from the straw was about 89% during the first month and thereafter there was little release. In the case of barley straw, about 20% of the straw N and nearly 60% of the straw P were found to be readily leachable (Christensen, 1985). It was also found that about 9% dry weight of the straw powder could be leached with cold water extraction, indicating that leaching may have contributed to the initial weight loss (Christensen, 1985).

Fates of Nitrogen from ^{15}N-labeled rice straw

The pot experiment, which was incorporated with ^{15}N-labeled rice straw, was conducted to investigate the fate of nitrogen released from rice straw decomposition under the three nitrogen fertilization levels.

Table 1. Recoveries of rice straw-^{15}N under different nitrogen fertilization levels in transplanting culture of rice.

Treatments		Plant N uptake[§] (mgN/hill)	Recovery of ^{15}N (% of rice straw ^{15}N)				
			By plant[§]	By soil[‡]			Plant + Soil
Rice straw (g/pot)	Urea N (mgN/pot)			KCl Extractable	KCl Non-extractable	Total	
16	0	157.1b[†]	10.2c	6.1	11.2	17.3a	27.5b
16	120	220.2a	13.4b	6.2	14.4	20.6a	34.0a
16	240	250.5a	14.9a	4.0	14.9	18.9a	33.8a

[†]Values followed by the same letter within a column are not significantly different by DMRT at 5% possibility level.
[‡]Values excluded root debris and undecomposed rice straw.
[§]Above ground portion.

Nitrogen uptake increased with N fertilization compared to that without N fertilization, but there was no significant difference between the two levels of N fertilization (Table 1).

The ^{15}N released from rice straw labeled with ^{15}N previous year was absorbed by rice plants (Table 1). Plant ^{15}N recovery ranged from 10 to 15% and increased with N fertilization. N fertilization effect on increased ^{15}N recovery by rice plant was probably attributed to the more vigorous growth with N fertilization than without N fertilization.

Soil recoveries of the straw-^{15}N, which ranged 17 to 21%, had the tendency to increase with N fertilization. However there was no significant difference among the three fertilizations. Hwang *et al.* (1995) reported that N fertilization reduced the soil recoveries of the straw-N and enhanced the losses of the straw-N because of the stimulated decomposition and N release of the straw, which was somewhat different from our results. Therefore, it is necessary to elucidate the N fertilization effect on decomposition and N release of rice straw. The quantity of KCl non-extractable ^{15}N, which is considered mostly organic N, was higher than potentially labile KCl extractable ^{15}N.

Rice straw-N was recovered with low level by rice plants and much of that was not readily available during the first year of incorporation. However, soil residual N of the straw was fairly high compared with plant uptake so that N residual effects were expected. Therefore, in order to reduce mineral fertilizer application it is necessary to elucidate residual effects of the straw including its incorporation effects on soil N transformation.

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