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No-till, Legume-rice Farming Systems in Korea and Japan

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Abstract: Conventional rice production yields high amounts of grain, but at considerable economic and environmental costs. The production of safe food and improvement of environmental conditions are the latest major themes in Korean and Japanese agriculture. A low-input, sustainable or organic based system that improves or maintains the natural environment should be developed for the benefit of both farmers and consumers.

Key words: No-till, legume-rice farming

INTRODUCTION

The grain ripening-period of cereal crops grown during winter in Korea is generally too short and poor quality grain is often produced. Nevertheless, the average farm productivity of barley (4.2 t ha^{-1}) and wheat (3.1 t ha^{-1}) is high among Asian countries. To maintain high grain yields of rice and wheat, heavy doses of N fertiliser are applied. As a side effect, excess fertiliser contaminates the surface and ground water, while P fertiliser causes algal blooms in the rice paddy, lakes and the ocean. Frequent spraying of pesticide and herbicide significantly reduces the biotic population including insects and soil microorganisms (Lee, 1998).

By that reason, new crop production systems, based on low-input sustainable agriculture, are being trialled in Korea. The aims are to develop a continuous wheat/vetch-rice cropping system that does not use chemicals for crop growth or pest and disease control. Incorporating a wheat/vetch crop into the traditional rice/fallow system will increase farm productivity and assist Korea to supply its increasing consumption of wheat or animal feed for vetch. Currently these new systems are being applied to an area of just 100ha, but in the future it may be used on more than 1.2 million ha throughout Korea and southern Japan (Cho *et al.,* 2001b). The main features of this system include no chemicals, no-tillage, direct sowing of rice and wheat onto uncultivated soil and the recycling of cereal residues both to provide cover to improve germination and seedling establishment and to recycle nutrients.

No-till, direct-sown inter-relaying rice cropping systems: In comparison with the fertilized, conventional rice system, the introduction of an unfertilized, no-till, wheat-rice system had only small effects on rice grain yield (Cho *et al.,* 2001a). This result is surprising since the conventional rice crop received 110 kg N ha^{-1} and P and K fertilizers each year and the harvest of wheat and rice grain over 2, 4 and 7 year periods would have depleted nutrients from the field. In a 14 year experiment, Yadav *et al.* (2000) found that both the yield and partial productivity (how well crops utilize inputs) of rice and wheat crops, grown in rotation, declined under conditions of no fertilizer or green manure, or sub-optimal fertilizer inputs. The yields of unfertilized rice in their experiments ranged from 965 to 2545 kg ha^{-1} and only their best-fertilized treatments produced yields equivalent to those in our experiments. Differences between the results of these experiments appear to relate to the level of soil OM and available P and K, which were much higher in the current work. Also, in the current work, levels of soil OM increased with 0 to 7 years of high-yielding wheat and rice cropping; possibly in response to the C input of high C:N ratio wheat and rice residues. In Yadav *et al.* (2000) there was much less residue from unfertilized rice and wheat crops and soil organic matter generally stabilized at only 1%.

The large rice grain yields in the unfertilized wheat-rice system during 1998 and the lack of a major yield decline after seven years of continuous wheat-rice cropping appears to be associated with the annual mineralization of large amounts of soil N (Cho *et al.,* 2001b). Soil mineralization probably occurred mostly during the rice crop when soil temperatures were high (Cassman and Munns, 1980) and during this time the N in the wheat residue (about 25 kg ha^{-1}) might also have been available. In total, the annual N supply appears to have been sufficient to meet the N demands of the rice crop. N may have been the factor limiting rice yield.

However no-till, no-fertilized, wheat/barley-rice cropping systems a little decreased rice grain yield after 4 years and it mostly originated from the low soil nutrients condition, especially N (Cho *et al.*, 2001b).

N source of legumes: Cereal and legume crop residues can be an important source of N for rice (Ockerby *et al*., 1999a). In the past, however, farmers have been reluctant to re-cycle cereal residues for maintaining soil fertility. When added to the soil, cereal residue or organic materials with high C/N ratios (>80) generally decompose slowly and they immobilize native soil-N resulting in N deficiency in the following crop during the early phase of growth (Ockerby *et al*., 1999b). Nitrogen supplementation through fertilizers at the time of residue incorporation may narrow the C:N ratio and accelerate the decomposition process, resulting in faster mineralization of residue N (Yadav, 1997)

Chinese milk vetch (*Astragalus sinicus* L.) is useful as a green manure in China, Korea and Japan (Cho *et al*., 2001a; Cho *et al.,* 2001b; Yasue 1991). However, two problems limit its use in no-till, direct-sown, rice production. First, toxic anaerobic decomposition products and the low oxidation-reduction potentials of the soil inhibit rice germination and delay seedling growth (Cho and Choe, 1999a) and secondly, weeds, particularly barnyard grass (*Ehinochloa crus-galli*) and early water grass (*Echinochloa oryzicola*) are noxious paddy weeds that cannot be controlled by Chinese milk vetch (Mineta *et al*., 1997: Miyahara 1988; Seong *et al*., 1997). Vetch straw mulching, however, offers various benefits to external low input sustainable agriculture (ELISA) including the supply of nutrients from decomposed materials.

Although Chinese milk vetch (*Astragalus sinicus* L. Vetch) performs well as a green manure (Yasue 1991), two problems limit its use in a no-tillage, direct-sown, rice-vetch cropping system. Firstly, toxic anaerobic-decomposition products and the low oxidation-reduction potentials of the soil inhibit rice germination and slow seedling growth (Cho and Choe 1999a). Secondly, weeds, particularly barnyard grass (*Echinochloa crus-galli* Beauv.), are difficult to control (Mineta *et al.,* 1997). Vetch straw mulching, however, offers various benefits to External Low Input Sustainable Agriculture (ELISA) including the supply of nutrients from decomposed materials. The aboveground residues of legume crops represent a major source of nutrients for following rice crops (Becker *et al.,* 1994; Cho and Choe 1999b; Ockerby *et al.,* 1999a; Schultz *et al.,* 1999) and to maintain soil fertility (Schultz *et al.,* 1999). In Korea, vetch also grows well, but the incorporation of rice and vetch residues is rarely practiced, since, despite having low palatability (Kim *et al.,* 1993a), residues are often fed to livestock. We are interested in increasing the grain yield of rice in ELISA, since low yield is the major issue limiting the adoption of no-tillage practices. To do this we are developing management practices that retain and optimize the benefits of vetch residues in the rice-cropping system.

ELISA farming practice: The increasing rice yield in no-tilled ELISA is innovation for rice cultivation. This is because low yield is the main issue limiting the adoption of no-till production methods. The above ground residues of legume crops represent a major source of nutrients for following crops (Becker *et al*., 1994; Cho and Choe 1999b; Ockerby *et al*., 1999; Schultz *et al*., 1999) and Cho *et al.* (2001a) have developed new management practices that retain and optimize the benefits of vetch residues in a rice cropping system. White clover can grow well in temperate and sub-tropical zones and was introduced in this experiment both; to test its weed control capacity during winter and spring and because it has one of the highest N_2 fixation capacities (Cho *et al*., 2002). However, unlike Chinese milk vetch, white clover should be sown every year because seed ripening occurs after the start of the rice-cropping season (late July to October).

The main constraint to direct-seeded rice under lowland conditions is poor seedling establishment primarily due to the lack of seedling tolerance to the paddy soil's low O_2 content. Cover from cereal residues provides a more stable soil moisture condition and protects the seed from birds (Choe 1998). As with the wet-sown rice system, anaerobic decomposition of products in the flooded soil may reduce seedling establishment. Losses may be minimised if the residue of previous crops or green manure, incorporated in the soil, is fully decomposed (Cho and Choe 1999a).

In Japan, no-till, direct-seeding legume, especially Chinese milk vetch, is more difficult than Korea by the insect dame in flowering stage (Cho *et al*., 2002).

In order to increase rice yield, it is also important to shorten the duration of growth and to limit the growth of non-productive tillers. To this end, rice cultivars that produce few tillers are used, so that growth can be favorably partitioned to increase the panicle size (Schinier *et al*., 1990). The various management practices, including seeding rate, tillage and top-dressing with fertilizer N affect yield and yield components (Cho *et al*., 2001a). Tillage increases the availability and uptake of soil N by rice and no-till systems may require additional N to produce the same yield levels as in tilled paddy (Ohyama and Yoshizawa, 1976). Chinese milk vetch supplies up to 7-10 g N m^{-2} in Korea (Jeaong *et al*., 1996), which is 1-4 g N m^{-2} less than the amount required by rice in tilled cropping (Cho and Choe 1999b). However. Kim *et al.* (1993b) found that 7 g m^{-2} of N fertilizer was required for direct-sown rice. Cho *et al.* (2002) also found that white clover as live mulch can supply enough N for rice cultivation (13.02 g N m^{-2}). The fate of white clover-bound N in paddy should be considered however, because the rapid decomposition after flooding unique to white clover tissue may accelerate N loss via nitrification, de-nitrification and volatilization (Bacon and Osborne, 1987). Organic fertilizers, especially legumes can be the main source of N in paddy and could replace inorganic N fertilizer (Cho and Choe 1999a). It is known that only 30-40% of the total fertilizer N applied to flooded rice is utilized by the crop (Patrick and Mahapatra, 1968; Gilliam *et al.*, 1985). Consequently, 60-70% of the N assimilated by lowland rice originates from the soil or irrigation water (Patric and Reddy, 1976; Broadbent, 1979; Murayama, 1979).

A major concern in implementing a no-till direct-sown cropping system is that seedlings germinating from seed dropped from last year's rice crop will infest the current crop leading to unevenness in crop maturity. In the wheat-rice system this problem was overcome by slightly delaying the wheat harvest. A late harvest also defoliated any rogue rice plants. In the wheat-rice system, when rain does not occur at sowing, sprinkler irrigation would be necessary to germinate the rice seed. Sprinkler irrigation is unlikely to invoke damage to rice seedlings due to toxic by-product produced by the degradation of organic matter submerged in paddy.

Rice seed germination is improved by white clover cultivation as a result of better moisture retention. However, seedling establishment is hampered by the dense white clover biomass on the soil surface that interferes with seedling stability with the progressive decay of white clover biomass after flooding. This means that rice seed placement will prove crucial to seed germination and seedling establishment. Irrigation should also be delayed until after seed germination and seedling establishment because flooding facilitates the evolution of organic acids that will reduce the oxidation-reduction potential (Eh) which will cause seedling injury (Cho *et al.*, 1999a; Esaki *et al.*, 1993; Kimura *et al.*, 1993). However after seedling establishment, water management should be as in conventional rice cultivation, though the depth of irrigation should be regulated. Deep irrigation could cause problems in weed control during summer and impact negatively on natural enemy populations. White clover cultivation prior to rice seeding and management strategies that favor a more gradual degradation of WC biomass would be beneficial, though the lower temperatures due to the dense WC canopy might delay seedling growth as compared with bare paddy (Drury *et al.*, 1999).

Sowing in direct-seeded systems occurs at the same time as transplanting, so the growing season of direct-sown rice is effectively shorter. Earlier sowing is not feasible as the paddy would be submerged before the vetch crop matured and this would limit the regeneration of vetch in the next winter. Re-sowing vetch each year is not considered viable. Earlier submergence may also result in seedling damage due to reduced soil conditions and rice dwarf disease. A shorter growing season also requires that strategies be devised to limit the growth of non-productive tillers. To this end, rice cultivars that produce few tillers are used, so that growth can be favorably partitioned to increasing the panicle size (Schnier *et al.*, 1990).

The yield of rice was considerably higher in 1997 than 1996, most likely reflecting the greater number of established seedlings and panicles in 1997. Increased seedling establishment might have been associated with later submergence in 1997, reducing reduction damage and seedling disease (Choe *et al.*, 1998). Cho *et al.* (2001) also reported that rice yield declined in the early years after a change from a transplanted to a direct-sown, wheat-rice cropping system. Temperatures during the growing season in 1997 were warmer and less rain fell during the mid-season drainage period. In Korea, mid-season drainage is a common practice to oxygenate the soil. In 1996, the soil in the paddy during mid-season drainage was quite wet, but in 1997 it was drier. We think that more sunshine, better oxygenation of the soil and increased N mineralization as the soil dried during mid-season drainage in 1997 all contributed to increased uptake of fertilizer and residue N by the rice crop in that year. The greater rice yield in 1997 compared with 1996 was clearly associated with an increase in the shoot N content of the rice crop and this was expressed in increased panicle and spikelet numbers and higher shoot and individual grain weight.

The use of varieties that are less susceptible to lodging may overcome this problem. Managing the release of N from vetch residues to coincide with crop demand is identified as an issue requiring further study to minimisse fertilizer N applications in ELISA.

Soluble soil N was low in the WC plots immediately after rice seeding but increased rapidly 15-d after flooding because organic N was being liberated in large quantities with WC biomass degradation (Cho *et al.*, 2002). The clover cultivation had lower soluble soil N at just after rice seeding and it may be originated from the white clover's soil N uptake during the no or low-N_2 fixation time. The N released from WC biomass after irrigation is far greater than the seedling requirement and flooding will result in the loss of the surplus N via leaching, denitrification, volatilization and runoff (Jackson, 2000). In this experiment, shallow irrigation was done to improve organic N uptake by rice plants. The lowest level of soluble-N was observed in the CONTROL probably due to the high C/N ratio of the weeds and soil microorganisms that had immobilized the soil N (Dalal, 1992; Wang *et al.*, 1997). Thirty days after flooding, soil N rapidly decreased in CONV and WCDRH treatments with increasing plant uptake coinciding with rapid growth prior to heading.

In the wheat-rice treatments, consistent decreases in rice leaf blade and sheath N and the number of spikelets per panicle yet increases in rice panicle N suggest that the wheat crop, in part, regulated N supply. It seems likely that wheat residue had little impact on rice N nutrition when initially mulched on the soil surface, but during rice reproductive development it limited the N supply and during rice grain-filling it enhanced the N supply. Similar patterns of N availability were found when maize crop residues were incorporated into the soil before planting a rice crop Ockerby ***et al.*** (1999b). In rice soils, repeated flooding and drying releases soil N and microbial N to plant-available form (Harada and Hayashi, 1968). After flooding and drying of the wheat-rice system, soluble soil N during the growth period from 30 to 50 days after sowing (Cho *et al.*, 2001), coinciding with panicle initiation, was greater in the 4 and 7-year treatments than in conventional rice and the 2-year wheat-rice treatment. Thus, N uptake ability and not N supply may have been limiting the number of spikelets per panicle in 4 and 7-year wheat-rice systems. Other factor may limit rice growth and the uptake of N under flooded and drained irrigation systems including phosphate sorption (Power 1990) and the decline in vesicular-arbuscular mycorrhizal fungi under flooding. Levels of available P and K in the soil were lower after 4 and 7 years than in the conventional rice treatment, which was fertilized each year (Cho *et al.*, 2001a). Although symptoms of P or K deficiencies were not observed on any rice crops, these issues may have impacted on the wheat-rice cropping system after 4 years and contributed to the small decline in yield in the 7-year wheat-rice treatment. The evidence suggests that the availability of P and K may limit the sustainability of the wheat-rice system after 7 years.

Organic matter levels in the soil were greater after four and seven years of the wheat-rice system. Relative to organic C levels for other soils and, in contrast to expected responses (Yadav *et al.*, 2000), initial levels of OM were high and rose with continued wheat-rice cropping. An increasing level of soil OM is indicative of a sustainable production system (IITA 1992).

The soil physical characteristics also were improved by the wheat-rice system. Increases in bulk density in the 0-15 cm layer occurred after only two years and are consistent with the absence of cultivation in no-till systems on loamy soils (Kim *et al.*, 1992). Increases in the soil's permeability to air and water took four years to accrue and remained constant after seven years. These measures suggest that soil structure had changed and stabilised after four years of the wheat-rice system with changes most likely reflecting a more defined and stable pore structure. Soil structure may impact on crop growth (Kim *et al.*, 1992) and drainage characteristics of the field, although are likely to be limited to the surface 20 cm soil.

Our observation during the experiment revealed several ancillary benefits and problems in growing an unfertilized, no-till rice wheat system instead of a conventional, transplanted-rice system. Returning the residues of wheat and rice crops to the soil as a mulch appeared to protect the seed from birds, conserve soil moisture during dry periods and control weeds in the rice and wheat crops (Comfort and Doll, 1996). Delaying the flooding of the rice crop had negative and positive effects; early growth of the rice crop was certainly delayed but seedling establishment was enhanced by the aerobic condition. Seedling establishment did not decrease over time in the wheat-rice system despite dry conditions during initial growth stages (Cho and Choe, 1999b). The direct-sown rice crop, however, required 120 kg seed ha^{-1}, two to three times more than conventional rice. Overall there was little net effect of direct-sowing and delayed irrigation compared to the transplanted system. In an earlier comparison of directly-seeded and transplanted rice, Schnier ***et al.*** (1990) found that directly-seeded rice grew too much leaf biomass during the reproductive stages and this diluted the foliar N at heading resulting in lower grain yield. In the current experiments, leaf area development was not excessive in the wheat-rice system compared with the conventional transplanted system, possibly because it was not irrigated for 3 weeks.

In the second year, top-dressing with N did not improve rice yield in transplanted rice-WC as opposed to the direct sown rice-WC plots. This is because nutrient uptake is likely to be more efficient in the more mature seedlings transplanted to coincide with WC decay as opposed to the young seedlings arising from direct seeding. The delayed initial growth in direct-sown rice also means that the seedlings have not accumulated enough nutrients in the non-productive tillers for late growth (Jackson, 2000; Ghosh *et al.*, 1998).

White clover is a better competitor against weed infestation as compared with rye. White clover/rye mixed culture had a lower coverage than WC monoculture. In addition, WC/rye mixed culture is not economical because of low yields and difficulties in management. We recommend that white clover or rye should be mono cropped in near the experimental area. The weed control capacity of WC is not fully control weeds that sprout after WC biomass decay compete with the rice crop at later stages of growth. As in CONV, *Echinochloa crus-galli* was the major paddy weed (Becker and Johnson, 1999; Chae and Guh, 1999).

As reported by Dalal (1992), the apparent nutrient recovery in a soil-plant system can be increased by disease control (for example, resistant cultivars and winter-summer crop rotations) and optimum utilization of soil water (opportunity cropping) to minimize losses of NO^-_3 N leaching and NH^+_4 volatilization and to maximize crop biomass production.

Rye was less effective that white clover in weed control and as a source of N in both mono and mixed cropping. Rye mono cropped as winter crop did not also perform as well as wheat in Korea (Cho *et al.*, 2001b) probably due to lower soil fertility and higher rainfall in Japan relative to Korea. Rye is not useful as a preceding crop in no-till, direct-sown rice cropping in southern Japan. On the other hand, WC can be a useful winter and spring pre-crop in view of the weed control effect and N supply. As a N source, white clover is sufficient for rice cultivation and other deficient minerals should be supplied as needed with continued white clover-rice cultivation. Low seed germination and low seedling establishment could be improved through better seeding-tools and improved water management.

In the wheat-rice, direct-sown system, the yields of rice grown for 2, 4 and 7 years were high and similar to that in the conventional transplanted-rice system that is widely grown in Korea. Lower yields after 2 and 7 years, associated with reduced mineralized N and possibly reduced availability of P and K and higher yield after 4 years suggest that there are opportunities to improve the initial adjustment phase and the loner-term sustainability of the wheat-rice system. Soil chemical and physical parameters improved during the period of wheat-rice cropping, indicating that the system was more sustainable than the conventional transplanted-rice system. However, heavy seeding rate, delayed initial growth, mixed rice seeds should be solved for satisfying the farmers and consumers. For over-coming these problems, shallow-tillage after several cropping years is needed and agro-chemicals by standard of sustainable agriculture also recommended in partly.

The use of direct-sowing practices in a vetch cropping system were recommendable in view of rice grain yield and improvement of soil nutrient conditions but lower seedling establishment ratio should be over-come for the stable rice production in ELISA.

A mono crop rye or rye/white clover mixed cropping is not recommended because of difficulties in management, low productivity rye and reduced WC biomass as observed in this experiment. However, a white clover-rice cropping system could be useful because it is economical, environmentally friendly and socially agreeable in the experiment target areas.

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