Impacts of Planting Density on Nutrients Uptake by System of Rice Intensification under No-tillage Paddy in Korea

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The System of Rice Intensification (SRI) is a new concept of increasing the yield of rice produced in farming. Therefore, we investigated the impacts of planting density on nutrient uptake as affected by SRI under no-till cropping system. The field was prepared as a randomized complete block design with three treatments: 10×10 cm, 20×20 cm and 30×30 cm planting densities. The root dry mass was significantly increased in the wider planting densities (p<0.05%). The highest grain yield was obtained in 20×20 cm planting density plot (p<0.05%) due to higher plant density per unit area and spikelets number per panicle. The total uptake amounts by rice plant were significantly higher in 20×20 cm planting density plot as 94.8 kg ha^{-1} for T-N and 29.9 kg ha^{-1} for P than other planting densities plots, but K and Mg uptake were significantly higher in 10×10 cm planting density plot (p<0.05%). In this study, our findings suggest that SRI should be considered as a new practice for the rice productivity.

Key words: System of rice intensification, Rice, No-till, Planting density, Nutrient uptake

Introduction

System of rice intensification (SRI) farming (Uphoof, 1999) was first introduced to Republic of Madagascar and has been practiced in several other countries as an alternative sustainable low-cost system to the conventional farming systems (Batuvitage, 2002). SRI farmers have reported that their cost of production is usually half that of conventional system and their yield were higher (Shao-hua et al., 2002). Researchers have used several concepts to explain the higher yields obtained with SRI. Productivity gains are accomplished, first, by inducing larger root systems on rice plants that are not crowded together and whose roots do not suffocate in flooded (hypoxic) soil (Kar et al., 1974). Second, aerobic soil conditions with plentiful soil organic matter enhance not only root health and performance, but also the abundance, diversity and activity of soil organisms which provide both nutrients and protective services to plants (Bonkowski, 2004; Dobbelaere et al., 2003). The principles that have determined SRI practices are: 1) rice is not an aquatic plant, 2) rice plants loose growth potential when transplanted at an older age, 3) enough spacing to grow fully, 4) careful transplanting and 5) specific soil amendment practices to facilitate the growth and development of microorganisms. The SRI practices introduced to farmers in Myanmar are: 1) planting younger seedlings, 2) planting seedlings one by one, 3) planting with wider spacing, 4) planting seedlings as immediately as possible, 5) using compost, 6) alternate irrigation and 7) mechanical weeding (Kabir, 2006).

No-tillage is a relatively recent practice and its effects on changes in soil microbe have been investigated extensively. Plant growth in organic systems greatly depends on the functions performed by soil microbes, particularly in nutrient supply. In comparison with conventional farming, organic farming has potential benefits in promoting soil structure formation (Wright et al., 1999), enhancing soil biodiversity (Mäder et al., 2002; Oehl et al., 2003), alleviating environmental stress (Altieri, 2002), and improving food quality and safety (Torjusen et al., 2001). Chinese milk vetch (*Astragalus sinicus* L.) is popular green forage grown as

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an off-season crop in paddy field to improve rice culture in China, Japan and Korea for a long time (Yasue, 1982). Crop residues mulched on the soil surface reduces evaporation, thereby conserving soil water (Moody et al., 1961; Smith and Lillard, 1976). Jones et al. (1969) reported that mulch improved water infiltration, resulting in conservation of rainfall. The rapid economic growth, and the modernization of agriculture, especially the transition in the technology of rice culture with spread of chemical fertilizer along with mechanization, caused quick decline in the culture and use of Chinese milk vetch (Yasue, 1982). Recently, it has been reassured for promoting and maintaining soil productivity, and considered to be very efficient for establishment of low-input sustainable crop production systems (Yasue, 1982; Choe et al., 1998; Lee et al., 2010). In a no-tillage system, grain yield was increased in Chinese milk vetch application plots compared with rye application plots due to higher miss-planted rate (Lee et al., 2009).

The purpose of this study was to find out impacts of planting density on nutrient uptake, grain yield and yield components as affected by SRI under no-till cropping system.

Materials and Methods

Experimental site description The experiment was conducted at Agriculture Research and Extension Services in Jinju, Gyeongsangnam-do, South Korea in 2008 (35°12'17"N and 128°07'13"E). The average temperature and rainfall amounts during rice growing periods were presented in Fig. 1. The soil texture of experimental field was silt loam (8.2% sand, 73.2% silt, and 18.6% clay) as Ihyeon series which is a member of the fine silty over coarse silty, mixed, mesic family of Dystric Fluventic Eutrudepts (Alluvial soils). The chemical properties of the paddy soil before treatment are shown in table 1. Selected soil chemical properties in the experimental sites were 5.1 for soil pH (1:5), 30 g kg^{-1} for soil organic matter, 191 mg kg^{-1} for available phosphorus concentration, 0.25, 7.3 and 2.1 $cmol_c\ kg^{-1}$

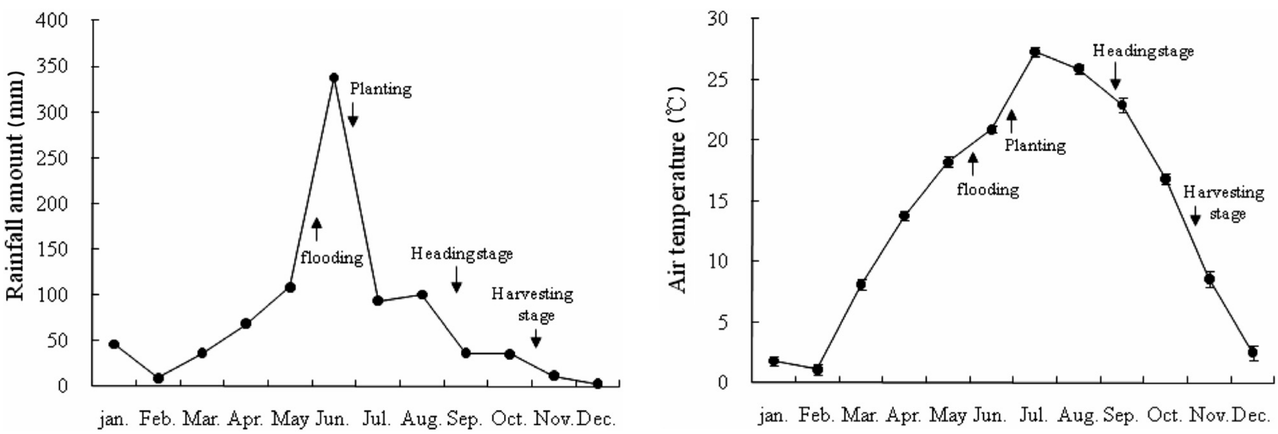

Fig. 1. The average temperature and rainfall amounts during rice growing periods. Vertical bar indicates mean SE.

Table 1. Chemical properties of soil before experiment.

Soil	pH	OM	Avail. P_2O_5	K	Ca	Mg	NH_4-N	NO_3-N
	(1:5)	g kg^{-1}	mg kg^{-1}	------- Exch.	Cation ($cmol_c$ kg^{-1})	-------	--------- mg	kg^{-1} ---------
Average	5.1	30	191	0.25	7.3	2.1	48	44
SD	0.1	1.6	18.1	0.026	0.44	0.05	3.1	1.8

Table 2. Nutrients amount of Chinese milk vetch before experiment.

Chinese milk vetch	Dry weight	T-N	P_2O_5	K_2O	CaO	MgO	Na_2O
	kg ha^{-1}	-------------------	-------------------	------------ %	------------	-------------------	-------------------
Average	3,273	2.66	0.55	2.33	1.62	0.49	0.44
SD	238.0	0.093	0.002	0.074	0.934	0.194	0.132

Table 3. Chemical properties of pig slurry.

Pig slurry	T-N	P_2O_5	K_2O	CaO	MgO	Na_2O
	------------------------	------------------------	------------------------ %	------------------------	------------------------	------------------------
Average	0.88	0.03	0.61	0.21	0.11	0.46
SD	0.059	0.003	0.009	0.000	0.004	0.003

for exchangeable K, Ca, and Mg concentrations, and 48 mg kg^{-1} for NH_4-N content. The total nutrients in Chinese milk vetch (3.27 Mg ha^{-1} dry weight) were 87, 18, 76, 53, 16 and 14 kg ha^{-1} for T-N, P_2O_5, K_2O, CaO, MgO and Na_2O, respectively (Table 2). In addition, the pig slurry (N-P_2O_5-K_2O-CaO- MgO-Na_2O = 0.88-0.03-0.61-0.21-0.11-0.46%) sprayed at the rate of 15 Mg ha^{-1} was applied before transplanting (Table 3).

Treatments and plot design Triplicate experimental plots were 100 m^2 (10 m × 10 m) in size and were laid out in a randomized complete block design with three treatments: 10×10 cm, 20×20 cm and 30×30 cm spacings. Rice cultivar used experiment was Sobibyeo. Seedlings grown in seedbed for 15 days were transplanted on 14 June at a rate of one seedling per hill (Stoop et al., 2002). Hand weeding was done twice during the growing season before and after tillering, and weeds were incorporated with soil by simultaneous stirring up. To reduce water wastage, transplanting was performed in the rice paddy that was in muddy and not flooded condition. Then, irrigation was controlled to improve soil aeration by draining water from the rice field or by keeping the rice field from being continuously flooded and saturated during the vegetative growth phase. Irrigation was stopped 10 days prior to harvest.

Determination of soil chemical properties and yield components Soil samples were collected from the topsoil (0-15 cm in depth) at the tillering, heading and harvesting stages. The chemical properties of the soil were determined using standard methods of RDA (NIAST, 2000). Soil samples were collected in triplicate, air-dried and sieved (< 2 mm) before analysis. Rice grain and straw were separated after harvesting and oven-dried at 70°C for 72 hours. Rice grain, straw, Chinese milk vetch, and pig slurry were dissolved in sulfuric acid for determination of total nitrogen and in a ternary solution of nitric acid:sulfuric acid:percloric acid = 10:1:4 (vol:vol:vol) for determination of nitrogen, phosphorous, potassium, calcium and magnesium using RDA methods (NIAST, 2000). Rice grain yield and yield components were determined using the RDA methods (RDA, 1995).

Statistical analyses Statistical analyses were conducted using SAS 9.1 software (SAS Institute, 2002). Properties of plant nutrient uptake, soil chemical contents, root biomass, yield components and yield were analyzed by employing least significant difference (LSD) at a probability level of 5% for the comparison of means.

Results and Discussion

Root development There were significant effects of different planting densities on root dry weight in Sobibyeo (Fig. 2). The widest planting density of 30×30 cm produced significantly greater root dry mass over other planting densities (p<0.05%). The root dry weight was 10.6 g hill^{-1} for 30×30 cm, 7.3 g hill^{-1} for 20×20 cm, and 2.2 g hill^{-1} for 10×10 cm planting density. Deeper and stronger root systems were developed due to intermittent irrigation practiced on soil without physical barriers to root growth, transplanting of young and single seedlings at wider planting density, and application of slowly releasing nutrient sources such as compost (Stoop et al., 2002). Oxygenation in wider planting density with SRI leads to better development of rice root systems (Armstrong and Webb, 1985). Also, aerobic soil conditions with plentiful soil organic matter enhance not only root health and performance, but also the abundance, diversity and activity of soil organisms which provide both nutrients and protective services to plants (Dobbelaere et al., 2003; Bonkowski, 2004).

Soil chemical properties Soil chemical properties were affected by different planting densities during growing stages (Table 4). The soil chemical properties of 20×20 cm planting density at heading stage were significantly increased 202 mg kg^{-1} for available P_2O_5, 0.24 $cmol_c$ kg^{-1} for exchangeable K, 6.4 $cmol_c$ kg^{-1} for exchangeable Ca, 1.8 $cmol_c$ kg^{-1} for exchangeable Mg, and 28.2 mg kg^{-1} for NH_4-N compared with other planting densities ($p<0.05$), while there were not significant differences in soil organic matter. Meanwhile, 30×30 cm planting density plots at harvesting stage showed significantly higher exchangeable K of 0.52 $cmol_c$ kg^{-1}, exchangeable Ca of 6.3 $cmol_c$ kg^{-1}, and exchangeable Mg of 1.8 $cmol_c$ kg^{-1} due to wider planting density.

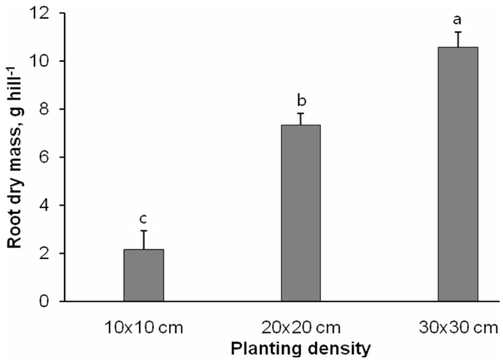

Fig. 2. Root dry mass per hill as affected by different planting densities measured at full heading stage. Vertical bar indicates mean SE. Means were analyzed by employing least significant difference (LSD) at a probability level of 5%.

Nutrients uptake of rice plant and grain yield Grain yield was significantly affected by different planting densities (Table 5). The lowest grain yield was observed in 30×30 cm planting density plot ($p<0.05\%$) due to lower number of panicle per unit area, but ripened rate was highest in that plot. The highest grain yield was obtained in 20×20 cm planting density plot ($p<0.05\%$) due to higher of plant density per unit area and spikelets number per panicle.

Table 4. Changes in soil chemical properties at different growth stages.

Growth stage	Planting density	pH	OM	Avail. P_2O_5	K	Ca	Mg	NH_4-N
		(1:5)	g kg^{-1}	mg kg^{-1}	--- Exch.	Cation ($cmol_c$	kg^{-1}) ---	mg kg^{-1}
Tillering	10×10 cm	5.7	26	164	0.32	5.9	2.1	21.3
	20×20 cm	5.5	28	179	0.35	4.8	1.8	27.8
	30×30 cm	5.6	26	166	0.28	4.8	1.7	28.4
	LSD (p<0.05)	0.04	NS	2.9	0.015	0.78	0.30	NS
Heading	10×10 cm	6.3	23	189	0.16	5.7	1.8	26.7
	20×20 cm	6.3	25	202	0.24	6.4	1.8	28.2
	30×30 cm	6.2	23	178	0.17	5.4	1.7	22.8
	LSD (p<0.05)	0.04	NS	8.5	0.007	0.11	0.05	4.86
Harvesting	10×10 cm	6.1	27	176	0.30	5.8	1.7	20.9
	20×20 cm	6.1	26	196	0.32	5.6	1.7	18.0
	30×30 cm	6.1	28	158	0.52	6.3	1.8	16.0
	LSD (p<0.05)	NS	NS	8.8	0.009	0.08	0.01	NS

Table 5. Grain yield and yield components by different planting densities.

Planting density	Panicle	Spikelets	1,000 grain weight	Ripened rate	Grain yield	Straw
	No. m^{-2}	No. $Panicle^{-1}$	g	%	--------- Mg	ha^{-1} ---------
10×10 cm	633	123	34.3	82.9	5.72	7.13
20×20 cm	350	133	38.3	84.6	6.10	6.02
30×30 cm	136	120	37.8	89.5	3.50	4.43
LSD (p<0.05)	35.9	NS	NS	NS	0.803	0.770

Table 6. Nutrients uptake of rice plant affect by planting density.

Planting density	Grain (kg ha^{-1})					Straw (kg ha^{-1})					Total (kg ha^{-1})				
	T-N	P	K	Ca	Mg	T-N	P	K	Ca	Mg	T-N	P	K	Ca	Mg
10×10 cm	47.8	6.2	5.1	0.1	1.4	40.5	2.6	118.1	21.4	12.2	88.3	8.8	123.2	21.6	13.6
20×20 cm	56.9	8.6	8.1	0.2	2.8	37.9	4.5	105.3	17.5	8.7	94.8	13.1	113.4	17.7	11.5
30×30 cm	34.4	5.4	4.5	0.1	1.5	29.0	3.8	84.7	16.0	6.6	63.4	9.1	89.2	16.1	8.1
LSD (p<0.05)	7.35	3.05	2.37	0.08	1.04	7.91	0.91	19.49	NS	2.20	13.43	2.98	21.12	NS	2.25

At harvesting stage, the uptake of nutrient amounts in 20×20 cm planting density were significantly higher for T-N, P, K, Ca and Mg in the rice grain as well as P_2O_5 in the rice straw (Table 6). Generally, the uptake amounts of T-N and P were higher in rice grain than rice straw. The total uptake amounts by rice plant were significantly higher in 20×20 cm planting density plot as 94.8 kg ha^{-1} for T-N and 13.1 kg ha^{-1} for P than in other planting densities plots, but K and Mg uptake were significantly higher in 10×10 cm planting density plot (p<0.05%). This is due to higher planting densities that resulted in higher plant population per unit area. A larger root system is more likely to capture some of the essential nutrients and other nutrients that are important for plant growth, and no-tillage soil under direct seeding mulch-based cropping systems (DMC) leads to an increased protection of soil organic matter in aggregates that may provoke lower rates of soil N mineralization (Balesdent et al., 1990; Kristensen et al., 2000). On the other hand, DMC systems increase soil total N stocks, thereby also increasing the pool of mineralizable N (Balesdent et al., 2000; Sanchez et al., 2001).

Conclusion

In this study, we investigated the impacts of planting density on nutrient uptake as affected by SRI under no-till cropping system. The root dry mass was significantly increased in the wider planting densities (p<0.05%). The highest grain yield was obtained in 20×20 cm planting density plot (p<0.05%) due to higher plant density per unit area and spikelets number per panicle. The total uptake amounts by rice plant were significantly higher in 20×20 cm planting density plot as 94.8 kg ha^{-1} for T-N and 13.1 kg ha^{-1} for P than those of other planting densities plots, but K and Mg uptake were significantly higher in 10×10 cm planting density plot (p<0.05%). Our findings suggest that SRI should be considered as a new practice for the increase in rice productivity although this experiment was performed under no-tillage during only one growing season.

References

Altieri, M.A. 2002. Agroecology: the science of natural resource management for poor farmers in marginal environments. Agr. Ecosyst. Environ. 93:1-24.

Armstrong, W. and T. Webb. 1985. A critical oxygen pressure for root extension in rice. J. Exp. Bot. 36:1573-1582.

Balesdent, J., C. Chenu, and M. Balabane. 2000. Relationship of soil organic matter dynamics to physical protection and tillage. Soil Till. Res. 53:215-230.

Balesdent, J., A, Mariotti, and D. Boisgontier. 1990. Effects of tillage on soil organic carbon mineralization estimated from ^{13}C abundance in maize fields. Soil Sci. 41:587-596.

Batuvitage, G.P. 2002. Adaptation of the system of rice intensification in Sri Lanka. Cornell International Institute for Food, Agriculture and Development (on line), Internet http://ciiffad.cornel.edu/sri; 607-255-0831.

Bonkowshi, M. 2004. Protozoa and plant growth: The microbial loop in soil revisited. New Phytol. 162: 616-631.

Choe, Z.R., J.B. Kim, and Y.S. Cho. 1998. Practices of sustainable agriculture in Korea with references for the development of sustainable rice production systems, Proceedings Korean Society of Crop Science, Korean Breeding Society Symposium for 50th anniversary Gyeong Sang National University, Korea.

Doebbelaere, S., J. Vanderleyden, and Y. Okon. 2003. Plant growth-promoting effects of diazotrophs in the rhizosphere. Crit. Rev. Plant Sci. 22:107-149.

Jones Jr., J.N., J.E. Moody, and J.H. Lillard. 1969. Effect of tillage, no-tillage, and mulch on soil water and plant growth. Agron. J. 61:719-721.

Kabir, H. 2006. Adaptation and adoption of the system of Rice Intensification (SRI) in Myanmar using the Farmer Field School (FFS) approach. Phd dissertation, University of Honolulu. p. 124.

Kar, S., S.B. Varade, T.K. Subramanyam, and B.P. Ghildyal. 1974. Nature and growth pattern of rice root system under submerged and unsaturated conditions. II Riso (Rome) 23:173-179.

Kristensen, H.L., G.W. McCarty, and J.J. Meisinger. 2000. Effects of soil structure disturbance on mineralization of organic soil nitrogen. Soil Sci. Soc. Am. J. 64:371-378.

Lee, Y.H., B.K. Ahn, and J.H. Lee. 2010. Impacts of rice straw application and green manuring on selected soil physical properties and microbial biomass carbon in no-till paddy field, Korean J. Soil Sci. Fert. 43:105-112.

Lee, Y.H., D. Son, and Z.R. Choe. 2009. Effects of Rice-Winter Cover Crops Cropping Systems on the Rice Yield and Quality in No-tillage Paddy Field, Kor. J. Environ. Agric. 28: 53-58.

Mäder, P., A. Fliebach, D. Dubois, L. Gunst, and U. Niggli. 2002. Soil fertility and biodiversity in organic farming. Science 296:1694-1697.

Moody, J.E., G.M. Shear, and J.N. Jones Jr. 1961. Growing corn without tillage, Soil Sci. Soc. Am. Proc. 25:516-517.

NIAST. 2000. Methods of soil and plant analysis. National Institute of Agricultural Science and Technology, RDA, Suwon, Korea (in Korean).

Oehl, F., E. Sieverding, K. Ineichen, P. Mader, T. Boller, and A. Wiemken. 2003. Impact of land use intensity on the species diversity of arbuscular mycorrhizal fungi in agroecosystems of central Europe. Appl. Environ. Microbiol. 5:2816-2824.

RDA (Rural Development Administration, Korea). 1995. Standard investigation methods for agricultural experiment. RDA, Suwon, Korea (in Korean).

Sanchez, J.E., T.C. Willson, K. Kizilkaya, E. Parker, and R.R. Harwood. 2001. Enhancing the mineralizable nitrogen pool through substrate diversity in long term cropping systems. Soil Sci. Soc. Am. J. 65:1442-1447.

SAS. 2002. SAS System for Window™, Release 9.1. SAS Institute, Cary, NC.

Smith, E.S. and J.H. Lillard. 1976. Development of no-tillage cropping systems in Virginia, Trans. of Am. Soc. Agric. Eng. 19:262-265.

Shao-hua, W., J. Dong, D. Tingbo, and Z. Yan. 2002. Physiological characteristics and high yield techniques with SRI rice. Cornell International Institute for food, Agriculture and development (on line). Internet http://ciiffad.cornell.edu/sri 607-255-0831.

Stoop, W., N. Uphoff, and A. Kassam. 2002. A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: Opportunities for improving farming systems for resource-poor farmers. Agr. Syst. 71:249-274.

Torjusen, H., G. Lieblein, M. Wandel, and C.A. Francis. 2001. Food system orientation and quality among consumers and producers of organic food in Hedma country, Norway. Food Qual. Prefer. 12:207-216.

Uphoff, N. 1999. Agroecological implications of the system of rice intensification (SRI) in Madagascar. Environment Development and Sustainability, 1(3/4):297-31.

Yasue, T. and U. Tsutiya. 1982. Chinese milk vetch and its history of cultivation. Kyoiku Shupan, Gifu. 52-107.

Wright, S.F., J.L. Starr, and I.C. Paltineanu. 1999. Changes in aggregate stability and concentration of glomalin during tillage management transition. Soil Sci. Soc. Am. J. 63: 1825-1829.