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Article

Dry Matter Yield and Nutrients Uptake of Sorghum×Sudangrass Hybrid Grown with Different Rates of Livestock Manure Compost

Sang-Sun Lim[1], Sang-Mo Lee[2], Seung-Heon Lee[3], and Woo-Jung Choi[1,4]*

[1]*Department of Rural & Biosystems Engineering, Institute of Agricultural Science & Technology, Chonnam National University, Gwangju 500-757, Korea*

[2]*National Instrumentation Center for Environmental Management, Seoul National University, Seoul 151-742, Korea*

[3]*Rural Research Institute, Korea Rural Community Corporation, Ansan 426-170, Korea*

[4]*Environment-Friendly Agriculture Research Center, Chonnam National University, Gwangju 500-757, Korea*

To investigate the growth and nutrient uptake response of sorghum×sudangrass (S×S) hybrid to different rate of livestock manure compost, a field experiment was conducted in the experimental grassland of Chonnam National University. Six treatments were laid out in a randomized block design with triplicates; control (no input), synthetic fertilizer (20 g N m^{-2} and 20 g P_2O_5 m^{-2}), compost 1 (3.4 g N m^{-2} and 3.6 g P_2O_5 m^{-2}), compost 2 (6.8 g N m^{-2} and 7.2 g P_2O_5 m^{-2}), compost 4 (13.4 g N m^{-2} and 14.4 g P_2O_5 m^{-2}), and compost 6 (20.2 g N m^{-2} and 21.6 g P_2O_5 m^{-2}). Ninety days after treatment, above-ground parts of the plants were harvested and measured for dry matter yield (DMY) and amounts of nutrients (N and P) uptake. Synthetic fertilizer application achieved the greatest DMY (2.4 kg m^{-2}) and nutrient uptake (38.3 g N m^{-2} and 15.3 g P_2O_5 m^{-2}). Increasing compost application rate tended to enhance DMY accumulation and nutrient uptake (P<0.01), but DMYs of compost 4 (1.9 kg m^{-2}) and 6 (1.8 kg m^{-2}) treatments were not different. Therefore, it was suggested that application compost alone may not achieve DMY of S×S hybrid compatible to synthetic fertilizer application. As nutrient uptake efficiency data showed that availability of compost P could be better than SF, it might be a strategy to apply compost as P source with supplementary N application such as liquid manure, SF or green manure if necessary considering availabilityof N input and the yield goals.

Key words: Compost application rate, Forage crop, Livestock manure compost, N uptake, P uptake

Introduction

In South Korea, the number of beef cattle increased from 1,480,000 heads in 2003 to 2,430,000 in 2008 (by 64%), meanwhile forage production increased by only 25% from 4,048,000 ton to 5,054,000 ton during the same period (MIFAFF, 2009). Therefore, it is inevitable to import forage to meet forage demands and thus the Korean government has been making an endeavor to improve forage self-sufficiency by encouraging cultivation of forage crops (Joo, 2006).

Sorghum (*Sorghum bicolor* L. Moench.) × sudangrass (*Sorghum sudanense* Piper) (S×S) hybrid is one of the forage crops that are suitable for southern Korea (Chun et al., 1995; Yoon et al., 2007) as its yield is better than other crops probably due to its tolerance to drought, hot temperature, and diseases (Uzun and Cigdem, 2005; Uzun et al., 2009). Due to the high suitability of S×S hybrid in southern Korea, several factors that can affect S×S hybrid yields have been tested since1990s; the factors include seeding rate (Lee et al., 1991; Han and Kim, 1992), cutting time (Jeon and Lee, 2005; Lee, 2005), cutting height (Lee et al., 1992), N fertilization rate (Han and Kim, 1992), and fertilizer type (Shin et al., 2005)

Most of these studies were conducted with using synthetic fertilizer as nutrient sources. However, with increasing interests in environmentally sound livestock production, using livestock manure as nutrient input

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*Corresponding author : Phone: +82625302153
E-mail: wjchoi@chonnam.ac.kr

becomes more attractive as it allow recycling of nutrients by linking forage production and livestock farming (Seo et al., 2000; Kim et al., 2001; Ketterings et al., 2007). In this context, informationon on the changes in dry matter yield (DMY) and nutrients (N and P) uptake of S×S hybrid in responding to compost application rate is crucial for evaluation of the long-term sustainability of nutrients recycling between the livestock farming and forage production. The objective of this study was to investigate DMY and nutrient (N and P) uptake responses of S×S hybrid to different rates of compost application in comparison with synthetic fertilizer application.

Materials and Methods

Experimental site This experiment was conducted at experimental livestock farming station of Chonnam National University between May and August, 2008. The soil was classified to fine loamy, mesic family of Dystric Fluventic Eutrudepts (Baeksan series) in USDA Soil Taxonomy (RDA, 2000). The selected properties of the soil are provided in Table 1. During the experimental period, the daily mean air temperature was 23.6ºC (min. 19.8 ºC and max. 28.5 ºC), and cumulative precipitation was 851.4 mm.

Experimental settings and cultivation Six treatments were laid out in a completely randomized block design with triplicates; synthetic fertilizer (SF), four different rates of compost application (C1, C2, C4, and C6) (Table 2, and see Table 1 for compost properties), and no applications of SF and compost (control). In our study, compost was applied at relatively lower rate than

Table 1. Selected properties of soil and compost used.

Parameters		Soil	Compost
Particle size distribution (%)	Sand	55.0 (1.1)	NA
	Silt	25.6 (0.5)	
	Clay	19.4 (0.3)	
Texture		Sandy loam	
$pH_{1:5}$		4.5 (0.1)	9.3 (0.1)
Organic C (g kg^{-1})		26.9 (5.8)	379.0 (12.5)
Total N (g kg^{-1})		1.8 (0.4)	14.9 (0.5)
NH_4^+ (mg N kg^{-1})		17.5 (3.2)	406.0 (15.8)
NO_3^- (mg N kg^{-1})		11.8 (2.1)	518.1 (14.6)
T-P (g P_2O_5 kg^{-1})		2.7 (0.2)	16.1 (0.5)
Avail P (mg P_2O_5 kg^{-1})		438.9 (18.6)	ND

Values are the means of triplicated measurement with the standard error in the parenthesis.
NA, not applicable; ND, not determined.

Table 2. Details of the treatments laid out.

Treatment code	Application rate (g m^{-2})		Remarks
	N	P_2O_5	
Control	0	0	
Synthetic fertilizer (SF)	20.0	20.0	Fertilizer ($N:P_2O_5:K_2O$=20:20:17)
Compost level 1 (C1)	3.4	3.6	Dry matter basis (kg m^{-2}): 0.228
Compost level 2 (C2)	6.8	7.2	0.456
Compost level 4 (C4)	13.2	14.4	0.913
Compost level 6 (C6)	20.4	21.6	1.369

synthetic fertilizer or compatible to that as application of compost at high rate may cause nutrients accumulation, leading to soil nutrient imbalance and subsequent water contamination (Ketterings et al., 2007).

Six plots (5 m × 5 m) were laid out in a block (totally 3 blocks for triplicates), and each plot was set to be distant from each other by 5 m. Fertilizer or compost were applied to the surface of each plot, and hand-mixed with soils, and seeds of S×S hybrid was sown at 3 g m^{-2} 5 days after the inputs application.

Sampling and chemical analyses At 85 days after sowing, all the above-ground plants in each plot were harvested and fresh weight was measured on-site. Sub-samples (around 5 kg) were transported to laboratory and fresh weight was recorded again, and oven-dried at 65ºC to a constant weight. The oven-dried samples were weighed and a portion of the samples (around 500 g) were ground roughly with a mechanical chopper and further ground with a ball mill (MM200, Retsch GmbH, Haan, Germany) to fine powder for chemical analyses. Total N concentration of the plant samples was determined by combustion method with an elementary analyzer (FLASHEA-1112, Thermo, USA). Total P concentration analysis was performed by ammonium paramolybdate-vanadate method with a spectrophotometer (Genesys 6, Thermo, USA) after digestion with HNO_3-$HClO_4$ (Kuo, 1996).

The C isotope ratio ($^{13}C/^{12}C$, expressed as $\delta^{13}C$) of plant sample was analyzed with a stable isotope ratio mass spectrometer (IsoPrime-EA, Micromass, UK) to test if different rate of fertilization results in different photosynthetic gas exchange. The $\delta^{13}C$ of plant samples have been successfully used as an indicator of gas exchange response of plants to environmental conditions including nutrient availability (Choi et al., 2005a).

Calculations and statistical analysis Total N and P uptake was calculated by multiplying the nutrient concentration with the DMY of plants. The amount of N and P assimilated by plants that derived from the applied N was obtained by subtracting the amount of N and P in the control from those in the treatments with SF or compost.

The effect of SF and compost application on DMY and nutrient uptake was statistically evaluated via analysis of variance using the general linear model procedure of the SPSS 15.0 package (SPSS Inc., Chicago, IL) for a completely randomized design with three replications. When the treatment effects were significant, the means were separated with Duncan's multiple range test. The significance level was set at α=0.05 for all statistical tests.

Results and Discussion

δ^{13}C and dry matter yield The $\delta^{13}C$ (calibrated against Pee Dee Belemnite) was not different among the treatments ranging from -12.1 to -12.6‰ (data not shown), indicating that N source type (SF and compost) and compost application rate did not cause significant changes in gas exchange performance of S×S hybrid (Choi et al. 2005a; 2005b). However, the $\delta^{13}C$ around -12‰ shows that S×S hybrid is C_4 plant ($\delta^{13}C$ range: -15 to -10‰) that has more efficient carboxylation pathway than C_3 plant ($\delta^{13}C$ range: -27 to -23‰) and thus explains why S×S hybridis more tolerant to hot temperature than others (Choi et al., 2005b).

Dry matter yield increased with either SF or compost application over the control, and the highest DMY was achieved in SF treatment (P<0.05, Fig. 1). Specifically, with respect to the control, SF application increased DMY by 92.3% and compost application did by over 16.4% with variations being affected by compost application rates. The DMY observed in our study (1.3 to 2.4 kg m^{-2}) is compatible to some other studies e.g. from 1.3 to 2.3 kg m^{-2} for eight S×S hybrid cultivars by Uzun et al. (2009), from 1.3 to 2.4 kg m^{-2} for four cultivars by Chun et al. (1995), and from 1.6 to 2.2 kg m^{-2} for one cultivar with different cutting time by Lee (2005).

In our study, however, compost application did not result in DMY compatible to SF application even when the same amount of N was applied as in C 6 (Table 2). Such discrepancy between SF and compost application was probably due to the lower bioavailability of compost N because only 6.2% of total N (0.9 g kg^{-1} of 14.9 g

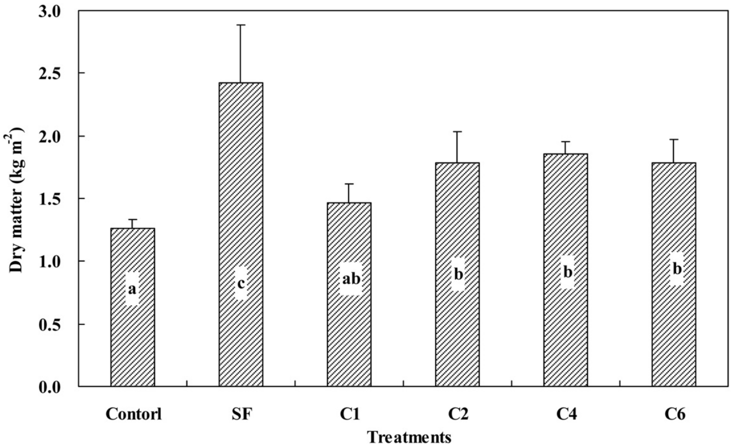

Fig. 1. Dry matter yield of sorghum×sudangrass hybrid treated with fertilizer and different rate of compost. Treatment codes are described in Table 2. Vertical bars are the standard errors of the mean (n=3) and bars with the same letter are not statistically different at α=0.05.

kg^{-1}) in the compost was mineral N (NH_4^+ and NO_3^-) that is directly available for plant uptake (Table 1). Due to the limited N availability of compost, a greater DMY of several plant species in SF application than that in compost application has been reported for various crop species including S×S hybrid (Sleugh et al., 2006). Meanwhile, Lim et al. (2006) reported that application of liquid and composted swine manure produced DMY of S×S hybrid compatible to or more than SF application. In their study, N concentration of liquid and composted swine manure were 0.4 and 0.8%, respectively, that is less than that of the compost used in our study (1.49%, see Table 1). As the liquid and composted manure were applied based on N standard application rate in both studies (Lim et al., 2006 and our study), much more amount of compost should have been applied in Lim et al. (2006)'s study than our study. As compost application has many beneficial effects on soil environments (biological, chemical, and physical) (Woodbury, 1992), such side effects (not the direct effect of N as nutrient) might lead to a great DMY in the study of Lim et al. (2006).

The response of DMY of S×S hybrid to increasing rate of compost application was best fit with a quadric relationship (Fig. 2). Although DMY tended to increase with increasing compost application rate up to C4 treatment (0.913 kg m^{-2} as dry basis); thereafter it tended to decrease in C6 treatment. Such relationship suggests that increasing compost application rate may not be a good fertilization strategy for better DMY of S×S hybrid. Therefore, it may be necessary to combine both solid composted manure with slowly available N and other N sources (such as liquid manure, green manure, or SF) with readily available N to achieve DMY compatible to SF application (Choi et al., 2001; Lim et al., 2007).

Nutrient uptake Patterns of N and P uptake by S×S hybrid as affected by SF and compost application mirrored that of DMY; the greatest N and P uptake in SF (Fig. 3) and a quadric relationship with compost N and P application rate (Fig. 4). As uptake of N or P was linearly correlated DMY of S×S hybrid (Fig. 5),

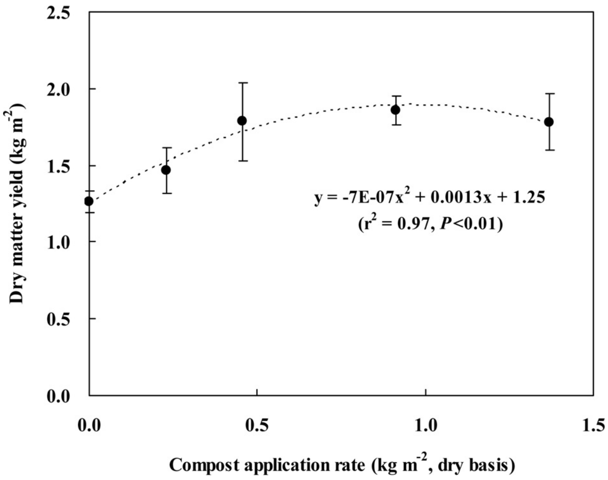

Fig. 2. Changes in dry matter yield of sorghum×sudangrass hybrid with increasing rate of compost application. Vertical bars are the standard errors of the mean (n=3).

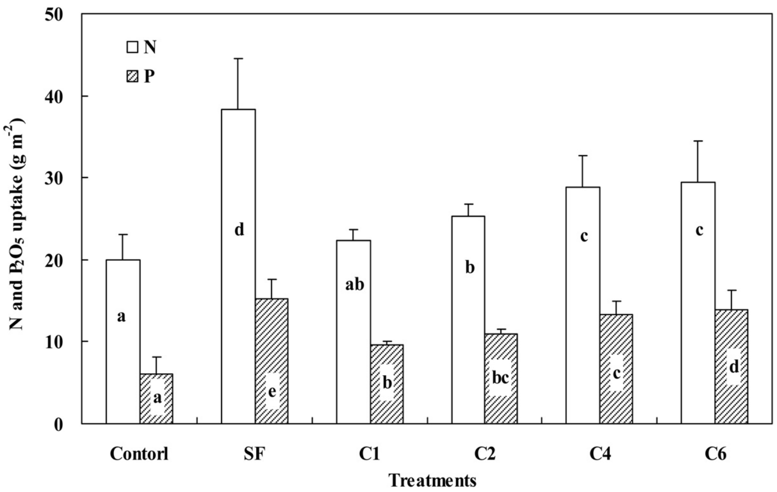

Fig. 3. Amount of N and P uptake by sorghum×sudangrass hybrid treated with fertilizer and different rate of compost. Treatment codes are described in Table 2. Vertical bars are the standard errors of the mean (n=3) and bars with the same letter are not statistically different at α=0.05.

the lower DMY of S×S hybridgrown with compost (even when virtually the same amount of compost N and P to SF treatment was applied as in C6) than that with SF was attributable to the lower amount of N and P available for plant uptake in the compost applied soils than in the SF treated soil. Many studies have shown that N and P availability of nutrients in livestock manure compost were lower than SF due to stabilization of nutrients in the manure during composting (e.g. Hadas and Portnoy, 1994).

Nutrient uptake efficiency with SF treatments was 92.1% for N and 46.2% for P, and those with compost

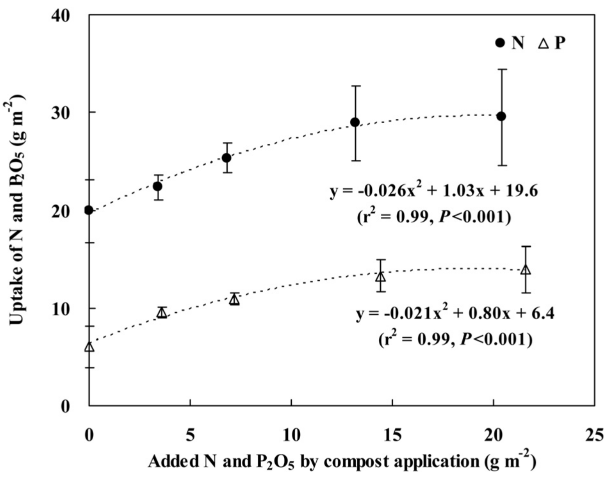

Fig. 4. Changes in the amount of N and P_2O_5 uptake by sorghum×sudangrass hybrid with increasing rate of nutrientaddition by compost application. Vertical bars are the standard errors of the mean (n=3).

treatments ranged from 47.0 to 79.7% for N and from 36.5 to 97.7% with decreasing tendency with increasing compost application rate (Fig. 6). Both N and P uptake efficiency for SF calculated in our study by difference method using the control as the reference was relatively higher than fertilizer uptake efficiency reported for other plant species (around 40% for N and 20% for P) (e.g. Choi et al., 2001). Such a high uptake efficiency of SF could be attributed to the limitation of difference method used in our study as SF application may enhance root growth and thus allow uptake of more soil derived nutrient via so-called “priming effect” (Jenkinson et al., 1985). Since contribution of soil derived nutrient to total plant nutrient uptake was assumed to be the same across all the treatments, this might lead to over-estimation of SF uptake efficiency (Kuzyakov et al., 2000).

Although N uptake efficiency of compost was consistently lower than that of SF across all the compost application levels, that of compost P was higher than SF except for C6. In addition, with SF treatment, N uptake efficiency was almost double of P uptake efficiency; however, such difference became smaller in the compost treatments and P uptake efficiency was even higher than N efficiency in C1 (see Fig. 6). These findings suggest that compost P availability is better than that of SF because P in SF is inorganic P which is likely to be less available form via sorption and precipitation process in soil matrix; meanwhile P in

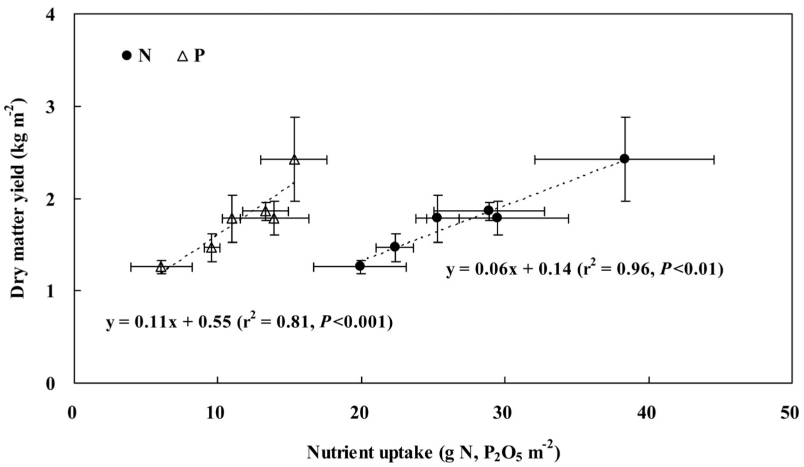

Fig. 5. Linear relationship between nutrient (N and P) uptake and dry matter yield of sorghum×sudangrass. Vertical bars are the standard errors of the mean (n=3).

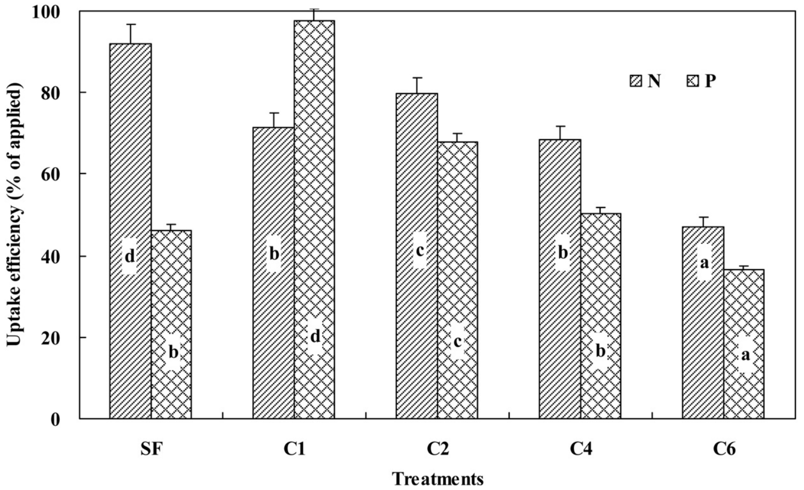

Fig. 6. Uptake efficiency of N and P by sorghum×sudangrass hybrid treated with fertilizer and different rate of compost. Treatment codes are described in Table 2. Vertical bars are the standard errors of the mean (n=3) and bars with the same letter are not statistically different at α=0.05.

compost is largely in organic form that is less susceptible to immobilization in soils (Lim, 2009).

Conclusions

Our study clear shows that application of compost at the recommended N rate or lower rate than that may not produce DMY of S×S hybrid compatible to SF application. As DMY of S×S hybrid was in proportion to nutrient (both N and P) uptake amount and uptake efficiency of P was higher than that of N, it would be necessary to apply compost as P source with supplementary application of additional N sources such as SF, liquid manure, and green manure.

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가축분퇴비 시용 수준에 따른 수수×수단그라스 교잡종의 건물생산 및 양분 흡수

임상선[1] · 이상모[2] · 이승헌[3] · 최우정[1,4]*

[1]전남대학교 농업생명과학대학 지역바이오시스템공학과, [2]서울대학교 농생명과학공동기기원, [3]한국농어촌공사 농어촌연구원, [4]전남대학교 친환경농업연구사업단

가축분 퇴비 시용 수준에 따른 수수×수단그라스 (S×S hybrid)의 수량 및 양분 (N, P)흡수 변이를 조사하기 위해 전남대학교 부속 농장 초지에서 3반복 난괴법으로 실험을 실시하였다. 6개 처리 (무비구, 화학비료관행구, 퇴비 1, 2, 4, 6 수준)를 두었는데, 화학비료관행구의 비료 처리량은 질소 20 g N m^{-2}과 인산 20 g P_2O_5 m^{-2}이고, 가축분 퇴비는 6 수준을 기준 시비량 (20.2 g N m^{-2}과 21.6 g P_2O_5 m^{-2})으로 두고 퇴비 1, 2, 4 수준은 그 비율대로 감비하였다. 처리 90일 후 최종 지상부 건물중과 양분 (N, P) 흡수량을 조사하였다. 화학비료 처리구의 건물중 (2.4 kg m^{-2})과 질소 (38.3 g N m^{-2}) 및 인산 (15.3 g P_2O^5 m^{-2}) 흡수량이 가장 높았으며, 퇴비 시용량이 증가함에 따라 건물중과 양분 흡수량이 증가하는 경향을 보였다 (P<0.01). 하지만, 퇴비 4와 6 수준의 건물중은 각각 1.9 kg m^{-2}과 1.8 kg m^{-2}으로 차이가 없었다. 따라서, 가축분 퇴비 단독 시비로는 화학비료와 대등한 건물 생산이 어려울 것으로 판단되었다. 양분흡수효율 분석 결과에 의하면 퇴비의 인산흡수효율이 화학비료보다 높았기 때문에, 퇴비를 인산 급원으로 시용하고 부족한 질소는 농가의 비료자원 수급 가능성과 목표 수량을 고려하여 액비, 화학비료, 녹비 등으로 공급하는 것이 적절한 시비 전략으로 판단된다.