Nitrogen use efficiency for green onion (*Allium fistulosum*) in sands of South Central Coastal Vietnam using ^{15}N-labelling

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Abstract

The recovery of nitrogen (N) from N fertilizer is generally poor. Increasing N use efficiency (NUE) on sands is particularly challenging due to low nutrient storage and high percolation rate of water through the root zone. The objectives of the experiment were to assess the change in fertilizer NUE for onion with clay or sugarcane residue amendments, and using ^{15}N labelled urea to determine the recovery of N in the plant-soil system in a deep sand. The experiments were carried out in Ninh Thuan province, Vietnam under flood or sprinkler irrigation. The ^{15}N-labelled urea was applied to 0.72 m^2 mini-plots at 134 kg N/ha and 10.16 % N atom excess. Clay-rich soil or bentonite were applied to raise clay content to 25 g/kg and sugarcane residues were applied at 30 t/ha.

Fertilizer supplied 47.5 to 50.5 % the onion N demand, however, this represented only 3.8 to 19 % of fertilizer N applied. Sugarcane residue was more effective than clay and bentonite additions while sprinkler irrigation increased NUE compared to flood irrigation. After harvesting onion, 19 to 24 % of fertiliser N was found in 0-20 cm top soil. Despite the increases in NUE with sugarcane residue, clay-rich soil or bentonite, 63 to 73 % of fertiliser N was lost from the soil-plant system. In addition to using sprinkler irrigation on sands, we suggest that adding clay and organic materials in combination with postponed application of N fertiliser or fertigation may be needed to further increase soil N retention and fertilizer NUE.

Key words: clay amendment, deep sand, flood irrigation, N use efficiency, sprinkler irrigation

Introduction

Across the world, only 30 – 50 % of N fertilizer is taken up by crops (Cassman et al. 2002). Excessive N fertilizer application will result in gaseous losses by volatilization or denitrification, or by leaching leading to low NUE.

With high temperature, strong winds and the use of flood irrigation, NUE for vegetable production on sandy terrain in South Central Coastal Vietnam is expected to be low. According to Ninh Thuan DARD (2009), the recommendation for onion fertiliser use is 157-234 kg N/ha for each of three to four crops per year. The very high annual N fertiliser rates up to 470-940 kg N/ha in deep sands risk high rates of loss. Amendments such as clay or high C:N organic materials on sands may increase N retention and hence minimise N losses (Bell et al. 2015).

The objectives of the experiment were to assess the amount of N absorbed from fertilizer and fertilizer NUE on onion using ^{15}N labelled urea, while evaluating the recovery of N in the plant-soil system in a deep sand.

Materials and methods

Clay-rich soil (Clay), bentonite (Ben) and sugarcane residue (SR) were chosen as amendments applied to deep sand at: 30 t of sugarcane residue ha^{-1}, 100 t of bentonite and 300 t clay soil ha^{-1} (to achieve 25 g/kg clay content to 20 cm depth), respectively. They were thoroughly mixed to 20 cm depth in an Arenosol in An Hai commune, Ninh Phuoc district, Ninh Thuan province. Further properties related to N are shown in Table 1.

Table 1. Characteristics of the materials used for the experiment

Properties	Sand (0-20 cm)	Clay-rich soil	Bentonite	Sugarcane residue
Organic carbon (g/kg)	1.1	17.8	2.1	362
NH_4+NO_3- N (mg/kg)	13	130	83	2350
Kjeldahl N (mg/kg)	150	1700	300	19700

Four hundred onion bulbs (15 cm x 20 cm spacing) were transplanted in a plot area of 3 m x 4 m with three replications under two types of irrigation: flood and sprinkler. Nitrogen at 134 kg/ha (recommended for onion by Ninh Thuan DARD 2009), in addition to 38 kg P/ha + 99 kg K/ha were applied as fertilizer. A ^{15}N-labelled mini-plot (0.6 x 1.2 m) was demarcated by a galvanised sheet-frame inserted into the sand. These fertilizers were applied from forms of urea (46 % N), compound fertilizers (16-7-7 kg NPK/ha), muriate of potash (50 % K) and ^{15}N-urea (10.16 % atom abundance) in five top-dressed split applications every 10 days after a basal application of 20 t of manure /ha.

Whole onions (bulb, leaf and root) were harvest 60 days after transplanting. They were weighed fresh in the field and dried at 60 ^{o}C for 48 hours in the oven and then milled for analysis of total N and atom ^{15}N abundance. Soil samples at 0-20 cm and 20-40 cm were collected and sieved in air-dry condition for determination of total N and atom ^{15}N abundance.

The ^{15}N analysis was done using the Kjeldahl-Rittenberg oxidation method (IAEA 1990): ^{14}N content and percentage of atom ^{15}N abundance in plant and soil samples were analysed by emission spectrophotometer NOI-7PC at the Center for Nuclear Techniques, Ho Chi Minh, Vietnam. Nitrogen utilization of added fertilizer was calculated according to IAEA (2001).

Two-way ANOVA and least significant difference (LSD) tests at P=0.05 were applied.

Results

The average N concentration in whole onion shoots ranged from 18.5 to 22.2 g/kg, but there was no significant effect of amendment treatments or irrigation system. However, dry matter yields increased from 558 to 2,769 kg/ha with amendment, so that plant N uptake ranged from 11.6 kg N/ha in the control sand to 51.2 kg N/ha with sugarcane residue (P<0.05) (Table 2). Sugarcane residue was more effective compared to clay and bentonite treatments in increasing yield especially with sprinkler irrigation.

Table 2. Dry matter yield and N uptake from onion crop, March-May, 2015

Amend ment	Irrigat-i on*	Dry matter yield	N uptake	N uptake from fertilizer
		kg/ha	kg/ha	kg/ha
0	F	558 d	11.6d	5.2e
Clay	F	940 d	20.8d	10.4de
Ben	F	1705 bc	33.9bc	15.6cd
SR	F	1506 c	32.1 c	16.1bcd
0	S	980d	21.0d	10.4de
Clay	S	2134b	43.8 ab	22.4ab
Ben	S	1879bc	38.6 bc	20.1abc
SR	S	2769a	51.2 a	25.5a
$LSD_{0.05}$		*498*	*10.7*	*6.0*

Note: * F: flood; S: sprinkler; Ben: bentonite clay; Clay: clay-rich soil; SR: sugar cane residue

$LSD_{0.05}$ = least significant difference ($p<0.05$); means followed by the same letter(s) within the columns do not differ significantly at $p<0.05$

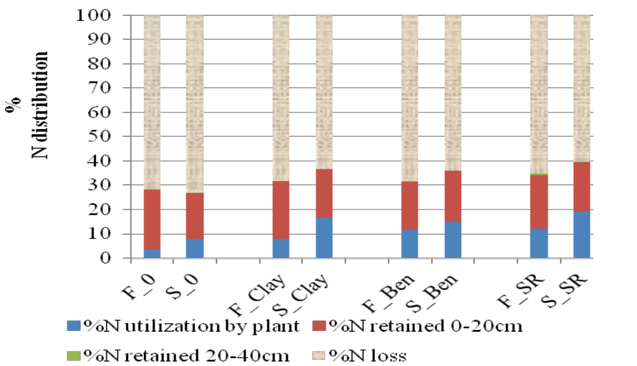

Figure 1. N distribution in N soil-onion system under flood and sprinkler irrigations. F_0: unamended flood irrigation; S_0: unamended sprinkler irrigation; F_Clay: clay soil amendment, flood irrigation; S_Clay: clay soil amendment, sprinkler irrigation; F_SR: sugarcane residue amendment, flood irrigation; S_SR: sugarcane residue treatment, sprinkler irrigation.

Under the flood irrigation, amendments increased N uptake from fertilizer two- to threefold from 5.2 to 10.4 - 16.1 kg N/ha. Sprinkler irrigation even in the control sands doubled N uptake from fertiliser to 10.4 kg N/ha , while with amendment treatments N uptake from N fertilizer increased to 20.1 to 25.5 kg N/ha. However, only 3.8 to 19% of fertilizer nitrogen was recovered by onion irrigated by flood and sprinkler (Figure 1). Sugarcane residue was most effective in increasing fertilizer N recovery, while bentonite and clay had similar but lesser effects in improving fertilizer N use on deep sand.

Soil N recovery ranged from 19.2 to 24.4 % of N fertiliser added. However, overall 63 to 73 % of N applied was lost during onion growth. For sprinkler irrigation, sugarcane residue reduced loss by 13 %, while clay and bentonite saved about 10 % of N loss compared to sand.

Discussion

The fertilizer NUE by onion in deep sand and amended sand soils was very low, 3.8-19 %. Even the highest NUE was still well below the usual range of NUE reported in the literature (30-50 %; Cassman et al. 2002). Sprinkler irrigation greatly increased NUE compared to the current flood irrigation method. Mermoud et al. (2005) showed that decreases in either amount or frequency of water application would lead to an increase in root zone water storage and increase onion yield in the semi-arid zone. In fact, by saving three L/m^2/day, the N accumulation derived from fertilizer under sprinkler irrigation was twofold higher compared to the flood irrigation, 10.4 vs 5.2 kg N/ha. Similarly, clay and sugarcane residue amended sands with sprinkler irrigation increased plant N accumulation by 61 % compared to flood irrigation. Further improvements in irrigation method and scheduling may be able to boost NUE.

Even with the best combination of amendments and irrigation tested, 63- 73 % N fertilizer losses occurred out of the soil-onion system and less than 40 % of the N input was available to crop or retained in soil for subsequent crops. The reasons for losses could be by leaching, volatilization, denitrification and mineralization. While the amounts of N accumulated down to 40 cm depth in sand were negligible, no deeper soil samples were collected because it was below the root system of onion. In combination with the high temperature and irrigation during March to May in Ninh Thuan, N mineralization probably occurred quickly to form nitrate in sand producing a high risk of leaching losses. The strong winds and high temperature of coastal Ninh Thuan may exacerbate the risk of volatilization losses also (Clain et al., 2013).

The C/N ratios of amendments ranged from 7.0, 10.5 and 18.4 for bentonite, clay soil and sugarcane residue, respectively. This meant the N mineralization in sand, clay and bentonite amended soil were faster than that with sugarcane residue additions. Burgos et al. (2006) reported a positive relation between the N immobilization and C/N ratio of residues applied to soil: the higher C/N ratio, the larger the N recovery in organic N forms. Choi et al. (2004) indicated that the combined application of straw and inorganic N could result in N immobilization of crop residues during early stages of growth. Therefore, the dominant influence of higher fertilizer NUE came from sugarcane residue amended compared to clay soil and bentonite amendment, for both flood and sprinkler irrigation methods. There may be an opportunity for greater NUE improvement by combining clay and sugarcane residues. Bell et al. (2015) suggested that adding clay amendments that have increased soil cation exchangeable capacity (CEC) could decrease nitrate leaching. Moreover, from the findings of Sitthaphanit et al. (2010), the application of high CEC materials (e.g. high activity clay such as bentonite) could slow NH_4 nitrification, and hence increase plant N uptake in sandy soils. Sorption of NH_4 on clays may also decrease ammonia volatilization losses. Clay amendments on sands can increase soil organic matter by protecting carbon from the decomposition while also increasing carbon inputs due to higher crop productivity (Hall et al. 2011). Hence over a longer time period, clay amendments may further increase NUE on sands.

Previous research on deep sands indicates that N use efficiency and N uptake would be increased with 3-5 split applications (Sithaphanit et al. 2009). However, split applications were already used in the present study but were not sufficient to achieve high NUE. Postponing a portion of N application until onions are well established may reduce the risks of N leaching and volatilization losses on sands by better matching N supply with crop demand. Using fertigation to apply N according to crop demand is another approach that could be tested to increase NUE. While the fertilizer supplied 47.5 to 50.5 % of onion N demand, it was not necessary to apply the high rate of N recommended for Ninh Thuan (Ninh Thuan DARD 2009). Moreover, Jiang et al. (2015) suggested that reducing chemical N fertilizer in combination with straw and drip-irrigation would enhance recovery efficiency of N from fertilizer but without loss of crop yields.

Conclusion

The amendment of sands with clay-rich soil, bentonite or sugarcane residue reduced N loss and increased both soil N retention and plant N utilization. Sprinkler irrigation on the sand increased fertilizer NUE. However, the fertilizer NUE even with the best combination of amendment and sprinkler irrigation was very low, and 63 – 73 % of fertilizer N was lost from the plant-soil system. Further research is needed to increase NUE on deep sands such as water use-efficient irrigation, changes in N fertilizer application method (e.g. fertigation) and rate, as well as optimal types and rates of soil amendments including combinations of clay with organic materials.

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