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The use of humic acid urea fertilizer for increasing yield and utilization of nitrogen in sweet potato

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ABSTRACT

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Humic acid urea fertilizer (HA-N) is a new type of slow-release nitrogenous fertilizer that can enhance utilization rate of urea, and consequently increases crop yield. However, there were few researches about the effect of HA-N on the nitrogen absorption and utilization in sweet potato production. Hence, the effect of HA-N on nitrogen accumulation and distribution, nitrogen use efficiency (NUE), and yield of sweet potato was studied in the field using the ^{15}N tracer technique. Results showed that HA-N significantly increased the number of storage roots per plant and the average fresh weight per storage root, as well as the yield increased by 29.6% compared with urea fertilizer. Furthermore, nitrogen accumulation of total plant was higher under the HA-N. In addition, HA-N significantly increased nitrogen production efficiency of fertilizer and nitrogen production efficiency. Results of a ^{15}N tracer experiment revealed that the percentage of nitrogen absorbed by plant from fertilizer increased from 31.1% to 38.7% and NUE increased from 33.5% to 44.8% with application of HA-N when compared with single N treatment, respectively. HA-N significantly increased sweet potato storage root yield, nitrogen absorption and NUE, as well as it reduced the loss of nitrogen fertilizer.

Keywords: nitrogen absorption and distribution; nitrogen balance; macronutrient; isotope; *Ipomoea batatas* [L.] Lam.

Nitrogen (N) is one of the most expensive nutrients to supply, and greatly contributes to the increased yield of major food crops (Erisman et al. 2008, Liu et al. 2013). Drastic increases in nitrogen fertilizer application increase crop yield. However, it also reduces nitrogen fertilizer use efficiency (NUE), enhances nitrogen loss and potential to pollute the soil, water bodies, ground water and atmosphere (Baligar et al. 2001, Ju et al. 2002, Spiertz 2009, Stuart et al. 2015). Thus, nitrogen fertilizer management, especially urea fertilizer and minimizing its negative impact on environment, has been a focal point in the world, which have a great significance for high yield and high efficiency and safe production of crops.

Sweet potato can grow well within a wide range of nitrogen concentrations (Ankumah et al. 2003). However, influenced by the idea that 'higher input leads to higher yield', people usually put excessive nitrogen fertilizers into sweet potato yield. It not only negatively affects the differentiation of sweet potato roots into storage roots (Villordon et al. 2012), but also reduces the distribution of dry matter to storage roots, and then ultimately decreases yield and NUE (Hill et al. 1990, Ankumah et al. 2003, Chen et al. 2015). According to Chinese

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actual situation (high population sizes and low area for cultivation), increasing the yield of sweet potato is necessary. Thus, based on socioeconomic conditions and available technologies, new types of nitrogen fertilizer should be developed and utilized to achieve high crop yields and high nitrogen efficiency unification. The organic combination of humic acid (HA) and urea can form stable chemical bonds, which decreases the nitrogen release rate and increases utilization efficiency of fertilizer by crops (Liu et al. 2010). Application of HA-N significantly raised crop yield, promoted nitrogen absorption and accumulation by crops, and increased NUE (Selladurai and Purakayastha 2016). However, few studies have been reported on the effect of HA-N on the nitrogen absorption and utilization and sweet potato production. In the present study, the effect of HA-N on the nitrogen absorption and utilization and yield was examined and it was determined whether there is evidence to support the wider-spread use of HA-N.

MATERIAL AND METHODS

Experimental design. The field experiments were performed from June to October 2014 and from June to October 2015 at the experimental station (33°16'N, 117°45'E), Anhui Agricultural University. Rainfall rate during the sweet potato growing seasons were 634 mm (2014) and 620 mm (2015). No irrigation was applied either year. Sweet potato (*Ipomoea batatas* [L.] Lam.) is the high yield crop and the straw was returned to the field. Cv. Xushu-28 (white-fleshed, widely cultivated in China) was selected in the experiment. The soil was sandy loam, and the 0–20 cm soil layer contained 1.02% organic matter, 0.54 g/kg total nitrogen, 30.09 mg/kg available nitrogen, 18.07 mg/kg available phosphorus, 83.26 mg/kg available potassium, and pH 7.83). Five treatments were designed in this study: control (CK); humic acid urea (HA-N, completely mixed with weathered coal, HA activator and nitrogen fertilizer, extruding granulation, 16% N, 562.5 kg/ha); weathered coal (HA, 135 kg/ha, humic acid content is equal to that in HA-N); urea (urea, 195.7 kg/ha, nitrogen content equal to that in HA-N), and humic acid and urea (HA + N, completely mixed with weathered coal, and nitrogen fertilizer, extruding granulation, 16% N, 562.5 kg/ha). Each treatment was replicated three times in a randomized block design. For all treatments, 150 kg/ha of phosphorus fertilizer and 225 kg/ha of potassium fertilizer were applied. All fertilizers were used as base fertilizers. Other management procedures followed standard agricultural practices. Row spacing was 0.8 m and plant spacing was 0.25 m. Planting density was 50 000 plants/ha with a plot area of 20 m^2. Sweet potato was planted on June 15 and harvested on October 15 in 2014, and planted on June 10 and harvested on October 20 in 2015.

The production procedure of HA slow-release fertilizer resulted in two features of the HA-complexed fertilizer: (1) A specific concentration of sodium hydroxide can increase the activity of HA of weathered coal; (2) activated HA can significantly increase the absorption ability of nutrient ions. These features can be used as slow-release mechanisms of HA slow-release fertilizer. Firstly, weathered coal was activated with a specific concentration of sodium hydroxide. Subsequent to pH adjusting, the weathered coal sample was mixed with nitrogen. Then, the adsorbed sample was fitted with inorganic fertilizer and granulated via disc granulation, which was used as HA-N fertilizer.

The ^{15}N tracer experiment was conducted in 2015. For each treatment, 6 plots (0.8 m in length, 0.25 m in width, one plant in each plot) were established and were separated from each other by 50-cm tall roofing felt. ^{15}N-urea and ^{15}N-humic acid urea fertilizer were applied to each plot, and the nitrogen fertilizer amount and application were identical to the field experiments described above. ^{15}N-urea was produced by the Shanghai Research Institute of Chemical Industry (^{15}N abundance = 5.3%).

Measurement items and calculations. For plants labelled with ^{15}N, the storage roots, leaves, petioles, stems, and fibrous roots were sampled separately at harvest. Samples were dried at 60°C and then total nitrogen content and ^{15}N abundance were measured. Plant nitrogen content of each part was measured by the Kjeldahl method. The N, P and K content of soil were measured following the method as described in Bao (2000). ^{15}N abundance was measured by mass spectrometry.

Equations used for studies on ^{15}N labelled fertilizer are as follows:

$$N_{dff}\% = \text{plant (soil) } ^{15}N \text{ abundance } \%/\text{labelled fertilizer } ^{15}N \text{ abundance } \% \times 100\%;$$

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Nitrogen use efficiency of plant (NUE, %) = plant N_{dff}% × nitrogen absorbed by plant/amount of nitrogen × 100%;

Residue rate of nitrogen in soil (%) = soil N_{dff}% × nitrogen absorbed by soil × weight of soil/amount of nitrogen × 100%;

Dry matter production efficiency of nitrogen in fertilizer (FNDMPE, kg/kg) – dry matter accumulated of the whole plant/amount of nitrogen;

Nitrogen production efficiency (NPE, kg/kg) – fresh yield of storage root/nitrogen absorption of the whole plant;

Nitrogen production efficiency in fertilizer (FNPE, kg/kg) – fresh yield of storage root/amount of fertilizer nitrogen;

Harvest index (HI, %) – dry yield of storage root/dry weight of the whole plant biomass at harvest × 100%.

Statistical analyses. Analysis of variance (three-way ANOVA) was performed with the PASW software (ver. 18.0, SPSS Inc. Chicgao, USA). Data from each sampling date were analysed separately. Means were compared using the Fisher's protected least significant difference at $P < 0.05$ ($LSD_{0.05}$).

Table 1. Yield and its components under different nitrogen (N) treatments

Treatment	No.	Average FW per storage root (g)	Yield (t/ha)	BDM (t/ha)	HI (%)
2014					
CK	2.7^{b}	205.3^{c}	27.8^{d}	10.6^{c}	54.3^{a}
HA	2.8^{b}	195.7^{c}	27.8^{d}	11.5^{b}	54.3^{a}
N	2.7^{b}	220.2^{b}	29.6^{c}	11.8^{b}	54.5^{a}
HA + N	3.0^{a}	221.4^{ab}	32.8^{b}	12.3^{ab}	54.3^{a}
HA-N	3.1^{a}	230.4^{a}	35.5^{a}	12.9^{a}	55.3^{a}
2015					
CK	2.5^{c}	202.2^{b}	25.3^{c}	10.0^{d}	53.1^{a}
HA	2.7^{b}	206.7^{b}	28.2^{b}	11.5^{c}	52.6^{a}
N	2.4^{c}	227.9^{a}	27.1^{b}	12.5^{b}	53.3^{a}
HA + N	2.8^{ab}	230.6^{a}	31.7^{a}	13.7^{a}	52.8^{a}
HA-N	2.9^{a}	232.9^{a}	33.3^{a}	14.4^{a}	53.3^{a}

Means within column followed by different letters are significantly different at $P < 0.05$. No. – number of storage root; FW – fresh weight; BDM – dry matter of the whole biomass; HI – Harvest index; CK – control; HA – humic acid; N – urea

Table 2. Nitrogen (N) uptake and production efficiency

Treatment	TNA (kg/ha)	FNPE (kg/kg)	NPE (kg/kg)	FNDMPE (kg/kg)
2014				
CK	155.6^{b}	–	178.7^{b}	–
HA	164.2^{b}	–	169.3^{b}	–
N	194.6^{a}	263.3^{c}	152.2^{c}	104.9^{b}
HA + N	161.6^{b}	291.2^{b}	202.7^{a}	109.6^{ab}
HA-N	163.0^{b}	315.4^{a}	217.7^{a}	114.8^{a}
2015				
CK	152.7^{c}	–	165.5^{ab}	–
HA	157.6^{c}	–	179.0^{a}	–
N	195.6^{b}	241.0^{b}	138.6^{c}	110.8^{b}
HA + N	199.7^{b}	281.9^{a}	158.8^{b}	121.9^{a}
HA-N	216.9^{a}	295.9^{a}	153.5^{b}	128.2^{a}

Means within column followed by different letters are significantly different at $P < 0.05$. TNA – the total nitrogen accumulation; FNPE – nitrogen production efficiency in fertilizer; NPE – nitrogen production efficiency; FNDMPE – dry matter production efficiency of nitrogen in fertilizer; CK – control; HA – humic acid; N – urea

RESULTS

Yield and its components. Compared with CK, fertilization treatments significantly increased the yield of sweet potato. HA, N, HA + N, and HA-N increased the yield by 5.5, 6.9, 21.5, and 29.6% (average over two years), respectively (Table 1). Compared with HA, HA + N and HA-N increased the yield by 15.1% and 22.8%, respectively (Table 1). Increases in yield from application of HA-N were not significantly larger than those from HA + N. Coordinated application of HA and urea increased the average number of storage roots and the average weight of storage roots especially with a significant level by HA-N. The application of urea alone reduced the average number of storage roots per plant but significantly improved the average weight of storage roots.

Fertilization significantly strengthened DM (dry matter)accumulation (Table 1). Compared with N application alone, HA-N significantly increased the whole plant biomass while HI was also improved but not to a significant level. The results suggested that the increase production mechanism of yield by HA-N was mainly implemented through plant biomass accumulation.

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Table 3. ^{15}N accumulation and distribution in different parts of sweet potato (2015)

Treatment	Storage root		Fibrous root		Leaf		Petiole		Vine	
	DA	DP	DA	DP	DA	DP	DA	DP	DA	DP
N	1640.2^{a}	41.9^{a}	121.7^{b}	3.1^{b}	1245.4^{b}	31.8^{a}	178.8^{c}	4.6^{a}	726.6^{c}	18.6^{c}
HA + N	1479.5^{b}	37.0^{b}	178.5^{a}	4.5^{a}	1215.0^{b}	30.4^{ab}	189.7^{b}	4.8^{a}	931.5^{b}	23.3^{b}
HA-N	1525.7^{b}	35.2^{b}	188.3^{a}	4.3^{a}	1312.3^{a}	30.3^{b}	209.1^{a}	4.8^{a}	1102.7^{a}	25.4^{a}

Means within column followed by different letters are significantly different at $P < 0.05$. DA – distribution amount (mg/plant); DP – distribution proportion (%); HA – humic acid; N – urea

Nitrogen utilization efficiency. Fertilization treatment had no significant effect on nitrogen absorption in 2014 (Table 2). In 2015, all nitrogen applications significantly increased the amount of absorbed nitrogen, with a maximum of 41.9% by HA-N treatment. Compared with N, HA-N and HA + N significantly increased FNPE, NPE, and FNDMPE, with HA-N producing the highest average increases (during the two years) of 21.2, 27.7, and 12.7%, respectively. However, there is no significant difference between HA-N and HA + N.

^{15}N absorption and distribution. At harvest, the amount and ratio of nitrogen in fertilizer distribution in different plant parts under all nitrogen application treatments were ranked as follows: storage root > leaf > stem > petiole or fibrous root (Table 3). For all treatments, the nitrogen distribution ratio was similar between storage roots and leaf, and the order ranked as N > HA + N > HA-N. The nitrogen distribution ratio in fibrous roots, stems, and petioles had the rank of HA-N > HA + N > N.

Soil-plant nitrogen balance. As shown in Table 4, 31.1~38.7% of the nitrogen absorbed by sweet potato was from fertilizer and 61.3~68.9% of that was from soil. Under the HA-N, the absorbed nitrogen showed the maximum ratio from fertilizer and the minimum ratio from soil. Compared with urea, NUE was increased by 11.3% and 5.5% under HA-N and HA + N, respectively, with an equal amount of the applied nitrogen (Table 5). The loss of nitrogen among treatments was ranked as HA-N > HA + N > N. These results indicated that HA-N could increase the nitrogen absorption from fertilizer by sweet potato, decrease the loss of nitrogen from fertilizer, and improve the FNPE.

DISCUSSION

Sweet potato yield formation depends on the number of storage roots and the FW (fresh weight) per storage root. Increasing the number of storage roots and the FW per storage root could increase yield (Ning et al. 2015). Nitrogen application is one of the most important measures to increase yield. Sufficient nitrogen application increased the number of storage root, and the FW per storage root by strengthening leaf photosynthetic capability and promoting the distribution of photosynthetic products (Chen et al. 2015). However, excessive nitrogen application decreased the number of storage roots, reduced the FW per storage root and yield (Kim et al. 2002, Chen et al. 2015). Therefore, the yield-increasing effect of nitrogen fertilization in sweet potato is not always stable (Hill et al. 1990, Ankumah et al. 2003). This study showed that the application of nitrogen fertilizer significantly increased yield. The application of urea fertilizer

Table 4. Source of nitrogen (N) in sweet potato (^{15}N isotope tracing experiment)

Treatment	The total N accumulation (mg/plant)	Nitrogen derived from soil		Nitrogen derived from the fertilizer	
		(mg/plant)	(%)	(mg/plant)	(%)
N	3912.8^{b}	2697.5^{a}	68.9^{a}	1215.3^{c}	31.1^{c}
HA + N	3994.2^{b}	2612.6^{b}	65.4^{b}	1381.6^{b}	34.6^{b}
HA-N	4338.0^{a}	2657.5^{ab}	61.3^{c}	1680.6^{a}	38.7^{a}

Means within column followed by different letters are significantly different at $P > 0.05$; HA – humic acid; N – urea

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Table 5. Nitrogen (N) balance in sweet potato plant-soil system (%)

Treatment	NUE	Residual rate in soil	N recovery rate	Total N loss rate
N	33.5[c]	26.7[a]	60.2[c]	39.8[a]
HA + N	39.0[b]	24.7[b]	63.7[b]	36.3[b]
HA-N	44.8[a]	25.1[b]	69.9[a]	30.1[c]

Means within column followed by different letters are significantly different at $P < 0.05$. NUE – nitrogen use efficiency of plant; HA – humic acid; N – urea

alone significantly increased the FW per storage root but slightly decreased the number of storage roots. HA-N and HA + N significantly increased the number of sweet potatoes and the FW per storage root. However, there is no significant difference between HA-N and HA + N. The results indicated that HA-N significantly increased yield through increasing the number of storage roots and the fresh weight per storage root.

HA-N promotes nitrogen absorption and assimilation and improves crop nitrogen absorption as well as FNUE (Liu et al. 2010). In this study, compared with urea, HA-N significantly increased FNPE, NPE, and FNDMPE by 21.2, 27.7, and 12.7%, respectively. The ratio of nitrogen distributed in leaves, fibrous roots, and stems was significantly higher under HA-N and HA + N. Our results demonstrated that HA-N and HA + N could enhance nutrition absorption at late development stage, promote dry matter accumulation, and increase NPE. However, in FNPE, NPE, and FNDMPE were no significant differences between HA-N and HA + N. The results indicated that HA-N and HA + N increased nitrogen utilization efficiency through increasing dry matter accumulation and nitrogen absorption.

After the application of nitrogen fertilizer to the plant-soil system, the basic fate of nitrogen includes 3 aspects. It can be absorbed by the crop, retained in the soil as inorganic nitrogen molecules or organic compounds, or enter to the surrounding environment through volatilization, leaching or runoff (Ju et al. 2002). Excessive nitrogen loss negatively affects crop growth, lower fertilizer use efficiency, and leads to serious environmental risks (Conley et al. 2009, Guo et al. 2010, Selladurai and Purakayastha 2016). Thus, the nitrogen balance in the plant-soil system and the nitrogen transport mode after fertilization should be employed as important factors to evaluate the effects of fertilization techniques, except for other indexes like yield, economic benefit, and nitrogen absorption and utilization. In the present study, HA-N and HA + N increased nitrogen derived from the fertilizer and improved the utilization coefficient of plant. Compared with HA + N, HA-N significantly increased nitrogen absorption and utilization efficiency of fertilizer nitrogen by reducing nitrogen loss and soil nitrogen fertilizer residue. Therefore, HA-N could maintain higher yield and higher utilization efficiency of fertilizer nitrogen well.

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