Agricultural Water Management 186 (2017) 139–146

Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Effects of two slow-release nitrogen fertilizers and irrigation on yield, quality, and water-fertilizer productivity of greenhouse tomato

Yanmei Li[a,b,c], Yanxin Sun[a,b,c,*], Shangqiang Liao[a,b,c], Guoyuan Zou[a,b,c], Tongke Zhao[a,b,c], Yanhua Chen[a,b,c], Jungang Yang[a,b,c], Lin Zhang[a,b,c]

[a] Institute of Plant Nutrition and Resource, Beijing Academy of Agricultural and Forest Science, Beijing 100097, China
[b] Key Laboratory of Urban Agriculture (North), Ministry of Agriculture, Beijing 100097, China
[c] Beijing Engineering Technology Research Center for Slow/Controlled-release Fertilizer, China

ARTICLE INFO

Article history:
Received 6 November 2014
Received in revised form 25 October 2016
Accepted 4 February 2017

Keywords:
Tomato
Carbon-based urea
Polymer-coated urea
Conventional irrigation
Reduced irrigation
Interactive effects

ABSTRACT

Technical research on efficient water and nitrogen use is crucial for sustainable agricultural development. A field experiment was conducted to investigate the combined effects of two slow-release nitrogen fertilizers (polymer-coated urea (PU) and carbon-based urea (CU)) and two different irrigation water levels (conventional irrigation, CI; 90% of conventional irrigation, RI) on tomato yield, quality, and water-fertilizer productivity. Tomato yield and irrigation water productivity improved when nitrogen fertilizer was applied. Compared with U application, CU application increased tomato fruit diameter, volume, single-fruit weight, yield, and water-fertilizer productivity, therefore increasing yield by 4600 kg ha^{-1} and net income from tomato cultivation by 6313 yuan ha^{-1}. Treatment with the two slow-release nitrogen fertilizers increased soluble sugar and lycopene contents and reduced nitrate content in fruits. Compared with U treatment, PU and CU treatments decreased total nitrate nitrogen residue in the 0–100 cm soil layer. Compared with CI, RI significantly reduced tomato yield and net incomes under PU treatment, whereas RI did not significantly reduce tomato yield and net income under CU treatment. RI increased fruit Vc (vitamin C) and lycopene contents. Results of the study indicated that polymer-coated slow-release fertilizers may have great potential for widespread use because they improved tomato fruit quality while reducing the environmental risks caused by soil nitrogen. In addition, carbon-based, slow-release nitrogen fertilizers promise to improve fruit quality, yield, water-fertilizer productivity, and benefits associated with tomato cultivation. These fertilizers also reduce environmental risks caused by soil nitrogen and help reduce irrigation water consumption while sustaining normal tomato growth and fruit yield, making their promotion extremely beneficial.

1. Introduction

The demand for tomato products at home and abroad continues to increase annually, creating considerable space for the development of the tomato market. Excessive irrigation, a common phenomenon in tomato production, wastes irrigation water and worsens the supply-demand balance for water resources while undermining tomato quality and encouraging the transfer of soil nitrogen to the lower soil layers. Utilizing water-saving irrigation modes and reduced-irrigation measures has become inevitable. Previous studies showed that trickle irrigation is superior to traditional furrow irrigation in conserving water, with ideal effects on large-area planting (Hayrettin et al., 2014). Moreover, reducing furrow irrigation water levels decreases tomato yield while improving tomato quality (Yin et al., 2011). However, the effect of appropriately reduced trickle irrigation water levels on tomato yield, quality, and other indicators remains unclear. Additionally, applying appropriately selected, slow-release nitrogen fertilizers under trickle irrigation to maximize the synergies between water and nitrogen is also important for saving water.

Excessive nitrogen fertilizer input in tomato production driven by yield and economic benefit is common (Fan et al., 2014), but decreases yield and quality and increases soil environmental risks (Zhang et al., 2011; Kuscu et al., 2014). Compared with conventional nitrogen fertilizers, slow-release nitrogen fertilizers distribute nitrogen more evenly, thus reducing unnecessary nitrogen loss dur-

* Corresponding author at: Institute of Plant Nutrition and Resource, Beijing Academy of Agricultural and Forest Science, Beijing 100097, China.
E-mail addresses: liyanmei0101@163.com (Y. Li), Sunyanxin@sohu.com (Y. Sun).

http://dx.doi.org/10.1016/j.agwat.2017.02.006
0378-3774/

Table 1
Design for the irrigation and nitrogen managements.

Factors	Level of the factors and abbreviation	Description
Irrigation water levels	Conventional irrigation, CI	Total irrigation at 345 mm ha^{-1}
	Reduced irrigation, RI, (90% of CI)	Total irrigation at 312 mm ha^{-1}
Nitrogen fertilizer types	Nitrogen level 1, CK	Without N application
	Nitrogen level 2, U	Conventional Urea at 300 kg N ha^{-1}
	Nitrogen level 3, PU	Polymer-Coated Urea at 300 kg N ha^{-1}
	Nitrogen level 4, CU	Carbon-Based Urea at 300 kg N ha^{-1}

Table 2
Tomato chlorophyll content, fruit diameter, volume, single weight, and yield under different irrigation and nitrogen managements.

Waterlevels	Nitrogentypes	Chlorophyll†(SPAD)	Fruit diameter/mm	Fruit volume/mL	Fruitweight/g	Yield/kg·ha^{-1}
CI	CK	54.0 ± 4.36	59.2 ± 3.11	216 ± 8.62	229 ± 9.98	88572 ± 1155
	U	52.7 ± 3.85	60.6 ± 1.82	218 ± 8.16	230 ± 9.74	91000 ± 1195
	PU	52.2 ± 4.83	62.9 ± 1.80	221 ± 10.1	231 ± 10.8	91355 ± 1270
	CU	51.8 ± 4.18	71.3 ± 3.84	281 ± 15.6	267 ± 22.0	93876 ± 1390
RI	CK	53.2 ± 2.92	53.9 ± 2.32	195 ± 8.23	200 ± 7.55	82472 ± 1556
	U	50.9 ± 3.61	60.3 ± 1.89	216 ± 12.0	224 ± 8.61	87000 ± 1680
	PU	51.1 ± 4.32	60.8 ± 3.28	220 ± 12.2	225 ± 8.34	88172 ± 1068
	CU	50.2 ± 2.32	65.5 ± 3.52	244 ± 8.93	253 ± 10.5	93328 ± 1200
Factors	Levels					
W	CI	52.6 ± 0.61a	63.5 ± 0.57a	234 ± 1.79a	239 ± 1.95a	91200 ± 380a
	RI	51.3 ± 0.61a	60.0 ± 0.57b	218 ± 1.78b	225 ± 1.92b	87743 ± 383b
N	CK	53.6 ± 0.86a	56.5 ± 0.81c	205 ± 2.53c	214 ± 2.75c	85522 ± 540c
	U	51.7 ± 0.85a	60.5 ± 0.80b	217 ± 2.50b	227 ± 2.71b	89000 ± 540b
	PU	51.6 ± 0.86a	61.6 ± 0.80b	220 ± 2.52b	228 ± 2.76b	89763 ± 541b
	CU	50.9 ± 0.87a	68.3 ± 0.82a	262 ± 2.55a	260 ± 2.72a	93602 ± 541a
ANOVA	L_W	NS	S	S	S	S
	Eta-$_W$	0.032	0.313	0.358	0.276	0.717
	L_N	NS	S	S	S	S
	Eta-$_N$	0.066	0.734	0.816	0.698	0.875
	$L_{W \times N}$	NS	NS	S	S	S
	Eta-$_{W \times N}$	0.003	0.158	0.364	0.151	0.456

Notes: † Data are means ± standard errors. L_W means the significant level of the irrigation water effect; L_N means the significant level of the nitrogen effect; $L_{W \times N}$ means the significant level of the water and nitrogen cross effect. Eta-$_W$, Eta-$_N$, and Eta-$_{W \times N}$ means the contribution of each factor to the total variance of the parameter in the same column. S means significant, NS means no significant. The same definitions apply to Tables 3–5.

ing the early stage of fertilization, increasing nitrogen supply at the peak stage of nitrogen demand, and reducing labor input associated with top dressing application (Carson et al., 2014a; Chen et al., 2008). As a result, these fertilizers have gained increasing attention. Previous studies confirmed that compared with conventional nitrogen fertilizers, polymer-coated, slow-release nitrogen fertilizers promote tomato growth and increase tomato yield (Zhu et al., 2012; Koivunen and Horwath, 2005). However, the poor degradation of the coating material and secondary environmental contamination are some problems associated with this type of nitrogen fertilizer. Exploring new channels for slow-release nitrogen fertilizers are important to promote sustainable agricultural development. Biochar, a porous, carbon-rich, solid product generated by high-temperature pyrolysis of agricultural and forestry residues, may potentially improve soil and soil water retention capacity. A new carbon-based, slow-release nitrogen fertilizer produced from biochar was reported to increase the yields of wheat (Gao et al., 2012), corn (Lu et al., 2011), and rice (Chen et al., 2013). This biochar-based fertilizer also produces good effects on canola, Chinese cabbage, pepper, peanut, sweet potato, sorghum, and soybean (Qiao, 2014; Liao et al., 2015). However, until now, the effects of this new carbon-based, slow-release nitrogen fertilizer on tomato are unknown. There are no studies comparing the applications of the carbon-based, slow-release nitrogen fertilizer with that of the polymer-coated, slow-release nitrogen fertilizer.

When water and nitrogen nutrients enter the rhizosphere, synergy, superposition, and antagonism occur (Mu, 1999). Previous studies demonstrated that coordination between the polymer-coated, slow-release nitrogen fertilizer and irrigation water level reduces irrigation input, increases yield, improves tomato quality, reduces nitrogen residue in the soil, and mitigates leaching risk (Li et al., 2014; Gao et al., 2008). However, there are few studies on the interaction between the new carbon-based, slow-release nitrogen fertilizer and irrigation water levels. The biochar carrier and the polymer-coated, slow-release materials are different by nature. The dissolution rate of the polymer-coated, slow-release nitrogen fertilizer decreases significantly when soil water content is lower than 30% (Xiao et al., 2002); however, biochar may potentially regulate soil-water content (Uzoma et al., 2011). Therefore, the two slow-release nitrogen fertilizers may differently affect the reactions of yield, quality, and water-fertilizer productivity to variations in irrigation water levels.

Based on the introduction, this study selected a greenhouse tomato variety for spring cultivation in suburban Beijing. Through a field experiment, we investigated the effects of the combinations of two slow-release nitrogen fertilizers (polymer-coated urea (PU) and carbon-based urea (CU)) and two irrigation water levels (conventional and reduced) on yield, fruit quality, water-fertilizer productivity, economic benefits, and soil nitrate nitrogen residue. The water-nitrogen interaction effects of PU and CU fertilizers on tomato cultivation were clearly explained to provide theoretical guidance for optimizing water-nitrogen management measures in greenhouse tomato cultivation.

2. Materials and methods

2.1. Experimental design

The experiment was conducted in a greenhouse at a vegetable base in Taihualu Village, Doudian Township, Fangshan District, Beijing. The soil was of the cinnamon type with a loamy texture. Two greenhouse tomato crops were cultivated by continuous crop-