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Dry Matter Accumulation and Nitrogen Absorption Characteristics of Processed Pepper under Different Nitrogen Levels

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Abstract In order to promote the rational use of nitrogen fertilizer, the dry matter accumulation, nitrogen absorption of processed pepper were studied by substrate culture and quantitative irrigation of nutrient solution under 6 different nitrogen levels (60%, 80%, 90%, 100%, 120% and 140% of the normal N application). It showed that, with the increase of nitrogen application, the dry weight of leaf, dry weight of fruit, dry weight of stem, dry weight of root, and dry weight of plant were increasing; The nitrogen content of each part run up to the maximum at 80%~100% nitrogen level; There was no significant difference between the dry weight of leaf, dry weight of root, and dry weight of fruit, as well as nitrogen content and nitrogen accumulation of these parts at 90%, 100%, 120% and 140% nitrogen level. Correlation analysis showed that nitrogen accumulation showed the highest correlation with the dry weight of leaf, dry weight of stem, dry weight of fruit, dry weight of root, and dry weight of plant, but had little correlation with nitrogen content in each part. In addition, the slight difference in nitrogen content of plant at different nitrogen levels can reflect its nutritional status, while the amount of dry matter can reflect its amount of nitrogen accumulation. This study will provide theoretical reference for rational application of nitrogen fertilizer in processed pepper.

Keywords Nitrogen; Processed pepper; Dry matter; Nitrogen absorption

Pepper has the characteristics of fast growth and high yield per unit. It has a large demand for fertilizer, especially nitrogen fertilizer. However, the problem of blind and excessive application of nitrogen in production is common. Studies have shown that lower or higher than a certain range is detrimental to the yield and quality of pepper. Low nitrogen stress significantly decreased the dry weight, dry weight ratio and nitrogen content of pepper fruit (Wang et al., 2017). With the increase of nitrogen application, plant height, single fruit weight, and yield showed a trend of increasing first and then decreasing. When the nitrogen reached a certain threshold, the growth yield of pepper fruit decreased, and it was not significantly increased. The vitamin C content in pepper fruit under nitrogen application was higher than that without nitrogen application, but the content would decrease when nitrogen application was excessive. The nitrate content increased with the increase of nitrogen application (Yuan et al., 2006; Zhang et al., 2016). Therefore, unreasonable application of nitrogen fertilizer, especially excessive application of nitrogen fertilizer, not only does not increase yield significantly, but also causes a series of problems such as crop quality decline, nitrogen use efficiency decline and waste of resources, and environmental pollution, soil nutrient imbalance (Zhu et al., 2005).

Pepper researchers have carried out some studies on exploring the optimum nitrogen application. The results showed that the growth of Huaxi pepper variety under 3.0 g/hole of nitrogen application amount is normal at the growth prophase in plant height, plant width and stem diameter and the growth under 6.0 g/hole of nitrogen application amount is normal from the growth intermediate stage in plant height, plant width and stem diameter reproductive development and slightly flower drop, which is the best growth performance in tested treatments.

Too much and too little nitrogen application can lead to uncoordinated growth of plant height, plant width and stem diameter, and serious flower drop (Zhu et al., 2008). The plant height and branch number of Chilli pepper were the highest with nitrogen 180 kg/hm^2 treatment, and the yield and output value reached the highest. The highest biomass was observed with nitrogen 240 kg/hm^2 treatment (Han et al., 2010). The economic traits such as plant and branch number, fruit number per plant and fresh weight per fruit of pepper in Xishui County of Guizhou with nitrogen application 18 kg/667 m^2 were the best, and the yield was the highest. According to the actual production, the recommended application was 15~18 kg/667 m^2 (Deng et al., 2019). When the nitrogen application amount was 25.9/667 m^2, the yield of the greenhouse pepper (in Turpan region of Xinjiang) reached the maximum value. The nitrogen utilization efficiency increased at first and then decreased with the increase of nitrogen application rate and the partial productivity of nitrogen fertilizer decreased significantly (Li et al., 2019).

At the previous studies, the growth, yield and quality characteristics of the processed pepper (in Chongqing) under different nitrogen application levels were studied by substrate culture. Accordingly, comprehensiving yield, quality, economic factors, and environmental protection, etc., it was preliminarily determined that the 90% nitrogen level was the optimum nitrogen fertilization scheme (Wang et al., 2019). Based on this, the dry matter accumulation and nitrogen absorption and utilization characteristics of processed pepper under different nitrogen levels were further analyzed in detail, to provide theoretical reference for rational application of nitrogen fertilizer and the realization of nitrogen reduction and efficiency increase in processed pepper.

1 Results and Analysis

1.1 Dry matter accumulation of processed pepper under different nitrogen levels

With the increase of nitrogen application levels, the dry weight of leaf, dry weight of fruit, dry weight of stem, dry weight of root, and dry weight of plant were increasing (Table 1). But there was no significant difference between the dry weight of leaf and dry weight of root at 90%, 120% and 140% nitrogen level. The dry weight of leaf at 90% nitrogen level was significantly higher than that at 100% nitrogen level. There was no significant difference between the dry weight of plant at 80%, 90% and 100% nitrogen level. And there was no significant difference between the dry weight of fruit at 90%, 100%, 120% and 140% nitrogen level.

Table 1 Dry matter accumulation of processed pepper under different nitrogen levels

Nitrogen level (%)	Dry weight of leaf (g/plant)	Dry weight of stem (g/plant)	Dry weight of fruit (g/plant)	Dry weight of root (g/plant)	Dry weight of plant (g/plant)
60	26.00±3.34 c	58.47±6.88 b	38.53±0.59 b	14.87±1.24 c	137.87±9.70 c
80	38.60±5.67 b	73.27±11.91 b	47.77±3.28 b	18.77±2.31 b	178.40±20.72 b
90	44.73±2.25 a	70.83±6.96 b	56.66±4.07 a	18.93±0.75 ab	191.16±8.60 b
100	41.73±5.10 b	81.47±16.64 a	57.61±5.35 a	17.27±0.67 bc	198.08±17.90b
120	51.67±9.50 a	97.73±7.05 a	66.91±11.75 a	19.33±1.39a b	235.64±19.24 a
140	55.73±9.41 a	95.60±6.95 a	66.75±5.68 a	21.30±1.22 a	239.38±5.14 a

Note: Different lower case letters indicate a difference of 0.05 significant level

1.2 Nitrogen absorption and utilization characteristics of processed pepper under different nitrogen levels

The nitrogen absorption and utilization characteristics of different parts of processed pepper were analyzed. The results showed that with the increase of nitrogen application level, there was no significant difference between the nitrogen content of leaf, nitrogen content of fruit, nitrogen content of root and nitrogen content of plant under different nitrogen levels except for the small fluctuation of nitrogen content of stem (Table 2). With the increase of nitrogen levels, the nitrogen accumulation was increasing, but there was no significant difference between nitrogen accumulation of stem and nitrogen accumulation of plant at 80%, 90% and 100% nitrogen level. And there was no significant difference between nitrogen accumulation of leaf, nitrogen accumulation of fruit and nitrogen accumulation of root at 90%, 100%, 120% and 140% nitrogen level (Table 3).

Table 2 Nitrogen content of processed pepper at different nitrogen levels

Nitrogen level (%)	Nitrogen content of leaf (%)	Nitrogen content of stem (%)	Nitrogen content of fruit (%)	Nitrogen content of root (%)	Nitrogen content of plant (%)
60	1.31±0.20 a	0.76±0.09 b	0.94±0.06 a	0.88±0.09 a	0.93±0.03 a
80	1.43±0.08 a	0.84±0.07 ab	0.99±0.02 a	0.82±0.10 a	1.00±0.05 a
90	1.41±0.13 a	0.83±0.09 ab	0.98±0.07 a	0.87±0.03 a	1.01±0.02 a
100	1.43±0.21 a	0.77±0.07 b	0.98±0.05 a	0.90±0.08 a	0.98±0.10 a
120	1.29±0.09 a	0.83±0.03 ab	0.97±0.05 a	0.93±0.04 a	0.98±0.01 a
140	1.33±0.09 a	0.92±0.07 a	0.94±0.13 a	0.82±0.04 a	1.01±0.06 a

Note: Different lower case letters indicate a difference of 0.05 significant level

Table 3 Nitrogen accumulation of processed pepper under different nitrogen levels

Nitrogen level (%)	Nitrogen accumulation of leaf (g)	Nitrogen accumulation of stem (g)	Nitrogen accumulation of fruit (g)	Nitrogen accumulation of root (g)	Nitrogen accumulation of plant (g)
60	0.37±0.05 c	0.45±0.11 c	0.36±0.02 b	0.13±0.02 b	1.28±0.07 d
80	0.55±0.06 b	0.61±0.06 b	0.47±0.03 b	0.15±0.02 ab	1.78±0.12 c
90	0.63±0.06 ab	0.58±0.03 b	0.57±0.07 a	0.16±0.01 a	1.93±0.12 bc
100	0.60±0.13 ab	0.62±0.10 b	0.56±0.02 a	0.15±0.02 ab	1.93±0.02 bc
120	0.67±0.11 ab	0.81±0.04 a	0.65±0.13 a	0.18±0.01 a	2.30±0.14 a
140	0.74±0.08 a	0.88±0.06 a	0.63±0.04 a	0.18±0.01 a	2.42±0.14 a

Note: Different lower case letters indicate a difference of 0.05 significant level

1.3 Correlation analysis among traits

Correlation analysis among traits (Table 4) showed that there was significant correlation between the dry weight of each part, as well as nitrogen accumulation. And there was very significant correlation between the nitrogen accumulation and dry weight of each part. There was no significant correlation between nitrogen accumulation and nitrogen content in other parts except for nitrogen accumulation of stem and nitrogen accumulation of plant.

Table 4 Correlation analysis of dry matter accumulation, nitrogen absorption and utilization

Trait	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14
A2	0.653**	-	-	-	-	-	-	-	-	-	-	-	-	-
A3	0.665**	0.834**	-	-	-	-	-	-	-	-	-	-	-	-
A4	0.694**	0.776**	0.782**	-	-	-	-	-	-	-	-	-	-	-
A5	0.834**	0.940**	0.922**	0.852**	-	-	-	-	-	-	-	-	-	-
A6	-0.180	-0.256	-0.041	-0.059	-0.183	-	-	-	-	-	-	-	-	-
A7	0.544*	0.189	0.292	0.428	0.362	-0.325	-	-	-	-	-	-	-	-
A8	0.150	-0.199	-0.076	-0.064	-0.070	0.149	0.187	-	-	-	-		-	-
A9	-0.119	-0.059	0.068	-0.310	-0.060	0.052	-0.212	0.147	-	-	-	-	-	-
A10	0.439	-0.142	0.154	0.198	0.128	0.420	0.594**	0.637**	0.024	-	-	-	-	-
A11	0.934**	0.564*	0.658**	0.692**	0.773**	0.170	0.436	0.189	-0.137	0.587*	-	-	-	-
A12	0.769**	0.919**	0.812**	0.820**	0.936**	-0.345	0.553*	-0.101	-0.134	0.109	0.649**	-	-	-
A13	0.709**	0.743**	0.942**	0.727**	0.874**	-0.013	0.337	0.255	0.109	0.348	0.708**	0.753**	-	-
A14	0.623**	0.705**	0.829**	0.797**	0.801**	0.014	0.321	0.086	0.308	0.280	0.624**	0.720**	0.821**	-
A15	0.901**	0.837**	0.892**	0.844**	0.965**	-0.081	0.504*	0.106	-0.054	0.379	0.876**	0.906**	0.902**	0.817**

Note: **: Significant correlation at 0.01 level; *: Significant correlation at 0.05 level. A1: Dry weight of leaf; A2: Dry weight of stem; A3: Dry weight of fruit; A4: Dry weight of root; A5: Dry weight of plant; A6: Nitrogen content of leaf; A7: Nitrogen content of stem; A8: Nnitrogen content of fruit; A9: Nitrogen content of root; A10: Nitrogen content of plant; A11: Nitrogen accumulation of leaf; A12: Nitrogen accumulation of stem; A13: Nitrogen accumulation of fruit; A14: Nitrogen accumulation of root; A15: Nitrogen accumulation of plan

2 Discussion

Previous studies showed that there was no significant difference in plant growth index of processed pepper between 90% of normal nitrogen application and 100%, 120% and 140% nitrogen application, as well as the yield characteristics of 80%, 90% and 100% nitrogen application. And finally, comprehensive yield, quality, nitrogen fertilizer saving, etc., it was preliminarily determined that the 90% nitrogen level was the optimum nitrogen fertilization scheme (Wang et al., 2019). Besides the yield characteristics, we analyzed each part of the plant in this study. The results showed that there was no significant difference between the dry weight of leaf, dry weight of fruit, dry weight of root, and the dry weight of plant at 90%, 100%, 120% and 140% nitrogen level except the dry weight of stem, indicating that the dry matter accumulation and yield indexes of processed pepper at 90% nitrogen application basically reached those of normal nitrogen application, which was consistent with the previous results that the 90% nitrogen level was the optimum nitrogen fertilization scheme.

Yue et al. (2014) showed that the total nitrogen content of pepper plants increased with the increase of nitrogen application and reached the maximum under the appropriate nitrogen application treatment. This study showed that the nitrogen content of leaf, fruit, root, and plant run up to the maximum at 80%~100% nitrogen level except stem, which also showed that 90% nitrogen level was close to the theoretical optimum nitrogen level. It is worth noting that there was no significant difference in nitrogen content in the same part under different nitrogen application levels. And there was no significant difference between nitrogen content of leaves and fruits of most pepper genotypes even under 20% of that normal nitrogen treatment (Wang et al., 2018), indicating that the nitrogen content difference of pepper plants under different nitrogen application levels was very slight. The nitrogen content could sensitively reflect the nutritional status, which provided the basis for establishing the critical nitrogen concentration dilution curve by using the relationship between content of nitrogen and dry matter. Correlation analysis showed that nitrogen accumulation significantly positively correlated with dry weight, whereas no significant correlation was found with nitrogen content. Wang et al. (2019) also found that nitrogen accumulation significantly positively correlated with dry matter accumulation in different organs of peanut, whereas no significant correlation was found with nitrogen content. Therefore, the amount of nitrogen accumulation in crops is mainly reflected by the accumulation of dry matter, rather than nitrogen content, because the difference in plant nitrogen content between different genotypes of the same crop is not significant under different nitrogen levels (Cao et al., 2019). In addition, the slight difference in nitrogen content of plant at different nitrogen levels can reflect its nutritional status, while the amount of dry matter can reflect its amount of nitrogen accumulation.

Around the issue of how to rationally apply nitrogen fertilizer, scholars in China and abroad have carried out a lot of basic research and made some progress. Most noteworthy is the establishment of critical nitrogen concentration dilution curves in different ecological regions and varieties of major food crops such as rice, wheat, and maize, reflecting the relationship between crop nitrogen concentration and plant dry matter (Ata-Ul-Karim et al., 2013; Ma et al., 2017; Lu et al., 2019), as well as vegetables such as tomato, cucumber, and garlic (Du et al., 2016; Zhao et al., 2018; Mou et al., 2019). There is no relevant research report in pepper, mainly due to the lack of basic research on nitrogen absorption and utilization of pepper and the lack of systematic data.

This study will provide theoretical reference for establishing the critical nitrogen concentration dilution curve and promoting the rational application of nitrogen fertilizer in processed pepper. However, only the nitrogen utilization characteristics of processed pepper at mature stage were analyzed. To design a complete and rational nitrogen application scheme, it is necessary to understand the dynamic characteristics of nitrogen utilization during the whole growth and development period of plants. The team will gradually carry out such research work in the future.

3 Materials and Methods

3.1 Experimental materials

The processed single Chao-tian Pepper Variety 'Yanjiao 425', bred by Vegetable and Flower Research Institute, Chongqing Academy of Agricultural Sciences (29°5’E, 106°4'N).

3.2 Experimental methods

The substrate was cultivated in greenhouse, and the volume ratio of coir: perlite: vermiculite was 5:3:2. Nutrient solution under 6 different nitrogen levels (60%, 80%, 90%, 100%, 120% and 140% of the normal N application) were set (Wang et al., 2019), with 3 replicates per treatment and 28 plants per replicate. Nutrient solution formula and specific nutrient solution scheme refer to the previous research of the team (Wang et al., 2017; 2018; 2019).

Picking in batches at maturity. The red peppers were picked once every 10 d, and the number and weight of red peppers in each plot were counted for 3 times. The fruit was washed with tap water after picking. De-enzyme at 105°C for 30 min, then dried to constant weight at 70°C, and weighed the dry weight of the fruit.

After each fruit picking, 4 representative plants were selected from each plot to determine dry weight of leaf, dry weight of stem, dry weight of root, nitrogen content of leaf, nitrogen content of stem, nitrogen content of fruit and nitrogen content of root. The specific sampling and determination methods were referred to the previous study of the team (Wang et al., 2017; 2018; 2019). Then calculated the dry weight of plant, root-shoot ratio, nitrogen content of plant, nitrogen accumulation of leaf, nitrogen accumulation of stem, nitrogen accumulation of fruit, nitrogen accumulation of root and nitrogen accumulation of plant:

Dry weight of plant (g)=dry weight of leaf (g)+dry weight of stem (g)+dry weight of fruit (g)+dry weight of root (g);

Nitrogen accumulation of plant (g)=nitrogen accumulation of leaf (g)+nitrogen accumulation of stem (g)+nitrogen accumulation of fruit (g)+nitrogen accumulation of root (g);

Nitrogen content of plant %=nitrogen accumulation of plant (g)/dry weight of plant (g)×100%.

3.3 Data processing

Excel 2010 software was used for data processing. SPSS19.0 software was used for statistical analysis. And LSD test was used for statistical analysis of significant difference.

Authors' contributions

WCP and ZSC designed and carried out the study, completed data analysis, and drafted the manuscript. WH, YXM, TRL, LYF, and JXY participated in the design of the study and performed the statistical analysis. HQZ, LQ, LKR, and HRZ conceived of the project, directed the design of the study, data analysis, draft, and revision. All authors read and approved the final manuscript.

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