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JOURNAL OF RARE EARTHS
JOURNAL OF RARE EARTHS, Vol. 34, No. 6, Jun. 2016, P. 638
www.re-journal.com/en/

Effects of mixed rare earth fertilizer on yield and nutrient quality of leafy vegetables during different seasons

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Received 6 October 2015; revised 6 April 2016

Abstract: Using Chinese cabbage and rape as test material and examining the same soil conditions at different seasons (spring and autumn), the effects of mixed rare earth fertilizer on the yield and nutrient quality of leafy vegetables were studied to provide a theoretical basis for the application of mixed rare earth fertilizer in agriculture. Results showed a seasonal difference in the nutrient quality of Chinese cabbage and rape. For crops planted in autumn, the soluble sugar and vitamin C content were higher, the titratable acid and nitrate content were lower, and the sugar acid ratio was higher relative to crops planted in spring. Mixed rare earth treatments promoted growth of both crops during both seasons. The plot yield, stem and leaf fresh and dry matter weight, and dry and fresh ratio increased. These increases for Chinese cabbage were greater in autumn than in spring while for rape, the increases were greater in spring than autumn. The soluble sugar content, titratable acid content and sugar acid ratio were increased and the nitrate content decreased, in autumn the effects were more obvious than in spring. In spring, the vitamin C content was increased, and the increase was greater for Chinese cabbage than rape. In autumn, the vitamin C content decreased, and the decrease was greater for rape than Chinese cabbage. At the same time, the content of heavy metals such as Cu, Zn, Cd, Pb and Ni in stems and leaves decreased. This decrease was greater in spring for Chinese cabbage and in autumn for rape.

Keywords: mixed rare earth fertilizer; yield; nutrient quality; seasons; Chinese cabbage; rape

Due to irrigation with sewage-contaminated water and the over-application of chemical pesticides and fertilizers, soil pollution has become increasingly serious, resulting in serious contamination of agricultural products[1–4]. Great attention has been paid to the potential threat of nitrate and heavy metals pollution to human health[5,6]. The reduction of nitrate to nitrite can cause methemoglobinemia, in which carcinogens are formed in the digestive system[7,8]. Heavy metals pollution can inhibit plant growth leading to a decline in output, and accumulation of heavy metals in plants can make them unsuitable for human consumption[9–12]. People obtain the majority of their nitrate intake through eating vegetables[13]. The leafy vegetables, such as spinach, rape and cabbage, have a particularly strong tendency to accumulate nitrate and heavy metals[14,15]. Among these heavy metals, the accumulation coefficient of Cd is the highest[16,17]. Thus, the exploration of efficient specific regulatory factors with low toxicity is particularly important.

Rare earth elements (REEs) have been used in agriculture for a long time and have been shown to be beneficial to plants, for example increasing crop yield, improving quality and reducing heavy metals and pesticide residues, thus improving food safety[18–21]. At the same time, the application of appropriate concentrations of REEs and their compounds (La-Gly and La-Gly-VB_6) can enhance stress tolerance and alleviate the stress and damage caused to plants by the environment[22–25]. To evaluate the positive effects of REE on different crops, the season when the fertilizer is applied should be considered. In this paper, we used Chinese cabbage and rape as test material and employed field plot tests under the some soil conditions at different seasons (spring and autumn) to study the effects of mixed rare earth (mixed REE) fertilizer on the yield and nutrient quality of the focal leafy vegetables, in order to inform the application of mixed rare earth in agriculture.

1 Materials and methods

1.1 Materials

Chinese cabbage and rape were chosen as the tested vegetables. The mixed rare earth (mixed REE) fertilizer was purchased from National Rare Earth Agricultural Application Center applied according to supplier instructions. The fertilizer composition was: La_2O_3 (25%–28%), CeO_2 (49%–51%), Nd_2O_3 (14%–16%), Pr_6O_{11} (5%–6%), and other rare earth elements content <1%. The purity

Foundation item: Project supported by Items of Institution of Higher Education Scientific Research of Hebei Province (ZD20131020), Hebei Vegetable Innovation Projects of Modern Agricultural Industry Technology System and Academy of Agricultural Sciences of Qinhuangdao City

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DOI: 10.1016/S1002-0721(16)60073-X

was 38%.

The field plots were located on the experimental farm of Hebei Normal University of Science and Technology, Qinhuangdao, where there was cinnamon soil with a pH value of 7.41, there had been a moderate application of fertilizer and the heavy metals content exceeded the average background level from the Qinhuangdao area[26], indicating that the tested soil was slightly polluted. The physical and chemical properties are provided in Table 1.

Table 1 Physical and chemical indices of tested soil (mg/kg)

Indices	Content
Organic matter	18.60×10^3
Total nitrogen	1.52×10^3
Available nitrogen	87.5
Available phosphorus	35.8
Available potassium	94.6
Cu	18.97
Zn	121.50
Pb	26.5
Cd	1.74
Ni	33.73

1.2 Plant culture and treatments

The experiment was carried out two times, for 28 days each time (spring, from March 30th, 2014 to April 27th and autumn, from September 28th to October 26th), under the same soil conditions. The field plot area was 1 m^2. After the first true leaf emerged, seedlings were final singling. No other fertilizers were applied so that the nutrient indices would not be affected by N, P, K or any other nutrient elements. Soil moisture content was controlled at (75±5)% of the field capacity.

The mixed REE treatments were designed according to Guo et al.[27]. Beginning on the twentieth day, 100 mg/L of mixed rare earth solution were sprayed daily on the Chinese cabbage and rape leaves for 8 d. Each treatment was repeated three times and deionized water was used as the control (CK). On the 28th day the plants were harvested, and the plot yield was determined. From the total yield, two groups of 20 plants each were randomly selected, with one group used to determine biomass yield and heavy metals content, while the other was used to measure nutrient quality.

1.3 Analysis methods

Nutrient quality was measured according to the national standard analytical methods: soluble sugar content (GB/T 6194-86), titratable acid content (GB 12293-90), vitamin C content (GB 6195-86) and nitrate content (GB 5009.33-2010).

Dry samples of approximately 0.2000 g (BS224S, Sartorius Company, Germany) were weighed and then microwave digested (MARS 6, CEM Company, American) with HNO_3-H_2O_2. Heavy metals content was measured with an inductivity coupled plasma optical emission spectrometer (Optima 2100DV, PerkinElmer Instruments Limited Company, American).

The values presented in the text are means ±standard deviation (SD). To determine significance differences among the control group and treatment groups, the results were statistically analyzed using a one-way ANOVA followed by Duncan's multiple range test at the $p<0.05$ significance level.

2 Results and discussion

2.1 Effects of mixed REE treatments on fresh and dry weight of vegetables

As shown in Table 2, sprayed mixed REE promoted the growth of the Chinese cabbage and rape in both spring and autumn. The plot yield as well as the fresh and dry weights of individual plant stems and leaves increased significantly ($p<0.01$). Chinese cabbage growth was higher in autumn (149.72%–160.22%) than in spring (130.90%–139.63%), while rape growth was higher in spring (147.57%–156.33%) than in autumn (129.96%–136.15%). Moreover, the dry weight increase was greater than that of the fresh weight, so the ratio of dry weight to fresh weight increased. This indicates that mixed REE treatments have clear effects on dry matter accumulation.

Table 2 Effects of mixed rare earth (mixed REE) treatments on the stems and leaves fresh and dry weight

Vegetables	Treatment	1st exp (Spring)				2nd exp (Autumn)			
		Plot yield/ (kg/m^2)	Fresh weight/ (g/plant)	Dry weight/ (g/plant)	Dry/ Fresh	Plot yield/ (kg/m^2)	Fresh weight/ (g/plant)	Dry weight/ (g/plant)	Dry/ Fresh
Chinese cabbage	CK	6.41±0.65 (100.00)	7.117±0.301 (100.00)	0.589±0.054 (100.00)	0.083	3.52±0.53 (100.00)	3.910±0.320 (100.00)	0.269±0.030 (100.00)	0.069
	Mixed REE	8.95±0.83* (139.63)	9.320±0.803* (130.90)	0.788±0.054* (133.79)	0.085	5.27±0.40* (149.72)	5.892±0.496* (150.64)	0.431±0.029* (160.22)	0.073
Rape	CK	3.09±0.29 (100.00)	3.320±0.163 (100.00)	0.300±0.007 (100.00)	0.090	3.27±0.30 (100.00)	3.631±0.345 (100.00)	0.260±0.023 (100.00)	0.072
	Mixed REE	4.56±0.46* (147.57)	5.050±0.584* (152.11)	0.469±0.036* (156.33)	0.093	4.32±0.32* (132.11)	4.719±0.267* (129.96)	0.354±0.023* (136.15)	0.075

Note: Data are given as the means±standard deviation; * Represents the difference significant at the 0.05 level ($p<0.05$)