Nutritional Relationship between Nitrogen and Sulfur in Cabbage (*Brassica oleracea* L. var. *capitata* L.)

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Summary

Cabbage plants were grown in nutrient solutions containing 3 levels of nitrogen (as NaNO_3 ; 10, 100, 500 ppm N) combined with 3 levels of sulfur (as Na_2SO_4 ; 1, 10, 50 ppm S), and the effects of the nitrogen and sulfur supply on the growth and the chemical composition of the plants were studied.

Total plant dry weight increased with an increase in the S supply when the N supply was 100 or 500 ppm, but was always small when the N supply was 10 ppm, irrespective of the S supply. The highest cabbage-head yield was obtained at 100 ppm N and 10 ppm S, while little cabbage-head yield was obtained at 10 ppm N or 1 ppm S. The total N content in each organ increased greatly with an increase in the N supply and decreased slightly with an increase in the S supply. The total S content increased greatly with an increase in the S supply and decreased slightly with an increase in the N supply. A total N content below 2% and a total S content below 0.1% on a dry basis in the outer leaves was found to be insufficient for cabbage-head formation. Cabbage-head development was most efficiently when the total N/S content ratio was between 10 and 20, although the ratio fluctuated widely, from 4 to 235. N-deficient plants contained less sugars and more starch as compared with the N- and S-sufficient plants. S-deficient plants contained less sugars and 80% ethanol-insoluble protein N and more 80% ethanol-soluble non-protein N.

Introduction

Sulfur is a macronutrient for higher plants, but the number of studies on sulfur nutrition in crop plants in Japan seems smaller than that on the functions of other nutrients, because sulfur deficiencies in crop plants do not occur widely and frequently: the necessity of studying sulfur nutrition has been small. However, increased incidences of sulfur deficiency of lowland rice in foreign countries have been reported recently, since a larger amount of sulfur-free fertilizers are being produced and used in the world (11). When sulfur-free fertilizers are applied exclusively to crop fields in Japan, sulfur deficiencies may occur in the future. It is thus important to establish guidelines for diagnosing sulfur deficiencies in each crop plant.

Sulfur nutrition in a plant is closely associated with nitrogen nutrition, because both

nutrients are components of proteins. Sulfur deficient plants contain larger amounts of nitrogen, especially non-protein nitrogen, than sulfur-sufficient plants, because protein synthesis is inhibited by lack of sulfur(6). It is reasonable to consider both the nitrogen and the sulfur supply in diagnosing sulfur deficiencies. Because of this, in some crop plants the N/S content ratio has been proposed as a better indicator of sulfur deficiency than the sulfur content(5, 10).

The present study was conducted to determine the interaction between nitrogen and sulfur uptake in cabbage plants, and the subsequent effect of this interaction on cabbage growth and cabbage-head formation.

Materials and Methods

Seeds of Haruhikari No.1 were sown in vermiculite in a green house, and irrigated with tap water. At 19 days after sowing, the seedlings were transplanted to 4 liter pots

containing a nitrogen- and sulfur-free culture solution. The composition of the culture solution, in ppm, was 20 P, 50 K, 100 Ca and 25 Mg. These nutrients were added in the forms of Na_2HPO_4 , KCl, CaCl_2 and MgCl_2 , respectively. All micronutrients were also added to the culture solution(3). One hundred ppm N as NaNO_3 , and 10 ppm S as Na_2SO_4 , were added uniformly before the nitrogen and sulfur treatments. At 29 days after sowing, 3 levels of nitrogen (10, 100, 500 ppm N) combined with 3 levels of sulfur (1, 10, 50 ppm S) were established, using three replications. The culture solution was aerated occasionally and renewed every 7 days, and the pH adjusted to 5.5 using 2 N HCl and 2 N NaOH. Cabbage-head formation in healthy plants started about 60 days after sowing. All the plants were harvested simultaneously at 96 days after sowing, and separated into inner leaves (forming each cabbage-head), outer leaves, stems, and roots. These organs were dried at 70°C, weighed, and milled for chemical analysis.

Total N in the plant samples was determined by the Gunning's method; insoluble N in the residue from 80% ethanol extractions of the samples was determined by the Kjeldahl method. Total N minus insoluble N is soluble N. Total S, insoluble S and soluble S were determined similarly by the turbidimetric method(8). Total sugar and crude starch were determined by the colorimetric anthron-sulfuric acid method, using glucose as a standard; sugar was extracted using 80% ethanol, and crude starch was extracted from the resulting residue using 4.6 N HClO_4 (4).

Results

Plant dry weight.

The total plant dry weight was more or less the same, and small when the nitrogen supply was 10 ppm (Fig. 1). When the nitrogen supply was 100 or 500 ppm, the total plant dry weight increased with an increase in the sulfur supply from 1 to 50 ppm. When the sulfur supply was 10 or 50 ppm, the total plant dry weight (ordered by nitrogen supply) was in the following order : 100>500>10 ppm N. There was a positive correlation between the total dry weight and the dry

weight of each organ. The highest cabbage-head yield (i.e. dry weight of head leaves) was obtained at 100 ppm N and 10 ppm S,

Fig. 1. Effects of the nitrogen and sulfur supply on the dry weight of each organ.

Table 1. Effects of the nitrogen and sulfur supply on the total N content (% on a dry wt basis) in each organ.

N supply (ppm)	S supply (ppm)	Head leaves	Outer leaves	Stem	Roots
10	1	3.66	1.76	1.47	2.84
10	10	3.02	1.51	1.44	2.52
10	50	2.09	1.37	1.25	2.43
100	1	5.43	4.12	3.41	3.96
100	10	3.72	3.69	2.84	3.69
100	50	3.63	3.58	2.54	3.17
500	1	6.26	4.71	3.48	4.62
500	10	4.59	4.33	3.44	4.00
500	50	4.51	4.14	3.33	3.85

Table 2. Effects of the nitrogen and sulfur supply on the total S content (% on a dry wt basis) in each organ.

N supply (ppm)	S supply (ppm)	Head leaves	Outer leaves	Stem	Roots
10	1	0.26	0.03	0.03	0.13
10	10	0.38	0.31	0.22	0.50
10	50	0.46	0.38	0.29	0.59
100	1	0.04	0.02	0.02	0.10
100	10	0.08	0.20	0.09	0.23
100	50	0.13	0.36	0.18	0.32
500	1	0.03	0.02	0.02	0.10
500	10	0.10	0.17	0.07	0.21
500	50	0.12	0.34	0.15	0.33

Table 3. Effects of the nitrogen and sulfur supply on the total N/S content ratio, the soluble N or S content, the insoluble N or S content, and the insoluble N/S content ratio of the outer leaves.

N supply (ppm)	S supply (ppm)	Total N/S	Soluble N (%)	Insoluble N (%)	Soluble S (%)	Insoluble S (%)	Insoluble N/S
10	1	59	0.83	0.93	0.01	0.02	47
10	10	5	0.52	0.99	0.20	0.11	9
10	50	4	0.39	0.98	0.22	0.16	6
100	1	206	2.30	1.82	tr	0.02	91
100	10	18	1.11	2.58	0.07	0.13	20
100	50	10	1.05	2.53	0.18	0.18	14
500	1	235	2.89	1.82	tr	0.02	91
500	10	25	1.45	2.88	0.05	0.12	24
500	50	12	1.32	2.82	0.13	0.20	14

while little cabbage-head yield was obtained at 10 ppm N or 1 ppm S. All the plants at 100 or 500 ppm N and 1 ppm S showed symptoms of sulfur deficiency. Sulfur-deficient leaves turned purple, and the marginal part of each leaf curled inward like a cup, after which necrotic areas developed between the leaf-veins; leaves with severe necrosis gradually fell off.

Total N and S contents in the plants.

The total N content in each organ increased greatly with an increase in the nitrogen supply, and decreased slightly with an increase in the sulfur supply (Table 1). Among the organs, the head leaves had the highest total N content, followed by the roots when the nitrogen supply was 10 ppm, and followed by the outer leaves when the nitrogen supply was 100 or 500 ppm.

The total S content in each organ increased greatly with an increase in the sulfur supply, and decreased slightly with an increase in the nitrogen supply (Table 2). The roots tended to have the highest total S content among the organs independent of the nitrogen supply, except that, at 10 ppm N and 1 ppm S, the head leaves had the highest S content.

Total N/S and insoluble N/S content ratio in the outer leaves.

From the results of the total N and S contents, the total N/S content ratio of the outer leaves was computed (Table 3). The total N/S content ratio increased with an increase in the nitrogen supply and decreased with an increase in the sulfur supply.

Both soluble N and insoluble N contents in the outer leaves increased with an increase in the nitrogen supply (Table 3). The soluble N content was quite high at 1 ppm S and decreased with an increase in the sulfur supply, while the insoluble N content remained at a constant level at each level of the nitrogen supply with the exception of a low value at 1 ppm S and 100 or 500 ppm N. Soluble S and insoluble S contents increased with an increase in the sulfur supply, and the increase in the soluble S content seemed larger than in the insoluble S content. Both contents decreased with an increase in the nitrogen supply. The insoluble N/S content ratio increased with an increase in the nitrogen supply and decreased with an increase in the sulfur supply. This change was similar to but smaller than that in the total N/S content ratio.

Total Sugar and crude starch contents in the outer leaves.

The total sugar content in the outer leaves was higher in plants grown at 100 ppm N than those grown at 10 or 500 ppm N (Table 4). At each level of the nitrogen supply, the total sugar content was lower at 1 ppm S than at 10 or 50 ppm S. The crude starch content was higher at 10 ppm N than at 100 or 500 ppm N, and was unaffected by the sulfur supply. The total carbohydrate (i.e. total sugar plus crude starch)/nitrogen content ratio (Ch/N ratio) of the outer leaves decreased with an increase in the nitrogen supply, and became very low when the sulfur supply was 1 ppm.

Table 4. Effects of the nitrogen and sulfur supply on the total sugar content, the crude starch content, and the total carbohydrate/nitrogen content ratio (Ch/N ratio) of the outer leaves.

N ⁺ supply (ppm)	S supply (ppm)	Total sugar	Crude starch	Total carbohy- drate	Ch/N ratio
		(glucose % on a dry basis)			
10	1	14.1	8.4	22.5	12.8
10	10	20.2	7.6	27.8	18.4
10	50	19.9	7.7	27.6	20.1
100	1	16.0	3.1	19.1	4.6
100	10	32.1	2.4	34.5	9.3
100	50	31.3	2.5	33.8	9.4
500	1	10.8	2.9	13.7	2.9
500	10	16.4	2.3	18.7	4.3
500	50	16.6	2.3	18.9	4.6

Discussion

In order to see how nitrogen and sulfur levels in cabbage plants affect cabbage-head formation, the relationship between the cabbage-head yield and the total nitrogen and sulfur contents in the outer leaves was examined (Fig. 2). Plants grown at 100 ppm N

Fig. 2. Relationship between the cabbage-head yield and the total N or S content in the outer leaves.

and 10 ppm S were chosen as a basis for comparison because they gave the highest cabbage-head yield; the relative yield in Figure 2 is thus the percentage of the dry weight of the head leaves of each plant relative to that at 100 ppm N and 10 ppm S. When the plants become deficient in sulfur due to the low sulfur supply, cabbage-head development does not occur. When the plants contain an adequate amount of nitrogen,

cabbage-head yield increases with an increase in the nitrogen content up to about 3%. A nitrogen content below 2% in the outer leaves is considered to be insufficient for cabbage-head formation, although nitrogen content varies with plant age even at this growth stage(2). Since nitrogen-deficient leaves have a low photosynthetic rate(9), the growth of head leaves depending on the photosynthates of the nitrogen-deficient outer leaves is undoubtedly reduced. A nitrogen content over 4% in the outer leaves also seems to inhibit cabbage-head formation. In this case cabbage-head development does not occur efficiently because the carbohydrate source is limited (Table 4) due to the low photosynthetic rate of nitrogen-excessive leaves(9). It is apparent that cabbage-head development occurs efficiently when the Ch/N ratio is about 9 (Table 4). The cabbage-head of the nitrogen-excessive plants is sometimes deformed(2) or is not rigidly folded by the head leaves. When cabbage plants are supplied with a suitable level of nitrogen, about 100 ppm, cabbage-head yield increases with an increase in the sulfur content up to 0.2%. It has been reported elsewhere(3) that a sulfur content lower than 0.04% in the outer leaves results in a 50% decrease in the cabbage-head yield. Nitrogen accumulates in the sulfur-deficient plants in the forms of low molecular nitrogen compounds such as nitrates, amides and amino acids(7), because protein synthesis is inhibited. In fact, soluble N (which is considered to be composed of low molecular nitrogen compounds) accumulated, and insoluble N (which is considered to be composed of high molecular nitrogen compounds) decreased only a little in the sulfur-deficient leaves (Table 3). Impaired protein synthesis in sulfur-deficient leaves results in lowered production of chlorophyll, and thus in a low photosynthetic rate in the leaves(1). As a result, soluble sugar concentrations in sulfur-deficient plants decrease, as has been reported for corn plants(6).

There is a clear interaction between nitrogen and sulfur uptake by cabbage plants: The uptake of one nutrient causes a decrease in the uptake of the other nutrient and thus

changes the total N/S content ratio to a greater extent. The total N/S content ratio therefore changes so widely that the ratio does not seem to be useful for diagnosing sulfur nutrition of cabbage plants. It can be said however that it is desirable for cabbage plants to have a total N/S content ratio between 10 and 20(3). The insoluble N/S content ratio changes to a smaller extent than the total N/S content ratio, because the fluctuation of nitrogen and sulfur in the non-protein fraction is greater than in the protein fraction(10). The insoluble N/S content ratio may thus be a more reliable guideline for diagnosing sulfur nutrition of plants than the total N/S content ratio(7). However, we feel that percent S analysis is a simple, more reliable, and less costly (11) for crop plants whose pattern of sulfur nutrition with age has been determined.

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キャベツにおける窒素と硫黄栄養の関連性について

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摘 要

春光り一号カンランの幼植物を3段階の $\text{NO}_3\text{-N}$ 濃度 (10, 100, 500 ppm N) と $\text{SO}_4\text{-S}$ 濃度 (1, 10, 50 ppm S) の組合せによる9種類の培養液で67日間栽培し、これらの処理が植物の生育と化学組成におよぼす影響を調査した。

N供給量が100か500ppmの場合にはS供給量の増加にともない植物乾物重は上昇したが、N供給量が10ppmの場合にはS供給量に関係なく植物乾物重は低かった。最高の結球収量は100ppm N・10ppm S区で得られ、1ppm Sか10ppm Nの場合にはほとんど結球収量

は得られなかった。植物の全N含有率はN供給量の増加で大きく上昇し、S供給量の増加でわずかに低下した。植物の全S含有率はS供給量の増加で大きく上昇し、N供給量の増加でわずかに低下した。結球収量と外葉の全Nあるいは全S含有率との関係より、全N含有率が2%以下か全S含有率が0.1%以下の場合には高収量は得ら

れないと考えられた。全N/S含有率比は4から235まで変動したが、10~20の範囲にあるときに結球は効率良く肥大した。N欠乏植物では糖含有率が低く、またS欠乏植物では糖含有率と蛋白(80%エタノール不溶)N含有率が低く、非蛋白(80%エタノール可溶)N含有率がきわめて高かった。