Effects of a band application of polyolefin-coated diammonium phosphate on the nutritional quality of rhubarb and Swiss chard

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Summary: Dietary intake of large amounts of nitrates and oxalates presents a health hazard. In this study experiments were conducted with two oxalate accumulating vegetables rhubarb *(Rheum rhabarbarum* L.) and Swiss chard *(Beta vulgaris* L. var. cicla L.)) using POC-DAP in order to improve their nutritional quality. In the rhubarb experiment oxalate content was significantly reduced by band application of POC-DAP, while effects on ascorbate and nitrate contents were ambiguous. The improved nutritional quality in the POC-DAP treatment was rather a cause of ammonium nutrition than a cause of less amount of released fertilizer nitrogen. In the Swiss chard experiment oxalate and nitrate contents were reduced, while ascorbate content was increased by a band application of POC-DAP. The improved nutritional quality in the POC-DAP treatment was the cause of both the less amount of released nitrogen and the realised ammonium nutrition. It was also found that by using POC-DAP for Swiss chard cultivation, labour and energy costs of top-dressings could be eliminated without yield decrease. It was concluded that the nutritional quality of rhubarb and Swiss chard could be improved by using a band application of POC-DAP.

Introduction

Although the consumption of leaf vegetables is usually associated with healthy nutrition, some of them can accumulate oxalates *(Libert & Franchesci,* 1987) and/or nitrates *(Maynard* et al., 1976) in large amounts, presenting a health hazard. Dietary intake of nitrates can cause methahemoglobinemia and gastric cancer *(Maynard* et al., 1976). Consumption of oxalates can cause chronic calcium deficiency and can initiate urinary stone formation *(Libert & Franchesci,* 1987).

According to nutrient solution experiments ammonium nutrition decreases both nitrate and oxalate contents in spinach *(Ota & Kagawa,* 1996; *Sugiyama & Okutani,* 1996). Moreover, as in oxalate accumulating plants oxalate is partly synthesised from ascorbate *(Yang & Loewus,* 1975), a lower oxalate content can result in a higher ascorbate content *(Takebe* et al., 1996). According to these facts, with the means of ammonium nutrition the nutritional quality of oxalate and nitrate accumulating vegetables can be improved.

Takebe et al. (1996) achieved long-term ammonium nutrition in soil culture, using a band application of polyolefin-coated diammonium phosphate (POC-DAP). While increasing ascorbate content in spinach, this fertilization method was found to decrease nitrate and oxalate contents.

In our study, the effects of this fertilization method on two other oxalate accumulating leaf vegetables – rhubarb (*Rheum rhabarbarum* L.) and Swiss chard (*Beta vulgaris* L. var. *cicla* L.) – were investigated. Rhubarb is grown for its petioles, which can contain high amount of oxalate *(Libert & Creed,* 1985). Leaves of Swiss chard also contain high amount of oxalate *(Libert & Franchesci,* 1987).

The objective of this study was to investigate if a band application of POC-DAP can improve the nutritional quality of rhubarb and Swiss chard.

Material and methods

Rhubarb and Swiss chard field experiments were conducted at the Experimental Farm of Tohoku University (Naruko, Miyagi Prefecture, Japan). Soil type of the used field is Alic Pachic Mellanudand. EC of the soil was 0.1–0.2 dS/m, pH was 6.6–6.7, inorganic nitrogen content was 11–12 mg/kg dry soil. 2000 kg dolomite, 2270 kg superphosphate and 30 kg FTE microelement fertilizer per hectare were mixed into the soil as soil amendment in April 1997.

Rhubarb experiment

11-week old rhubarb seedlings, having raised from seeds in a greenhouse, were transplanted in the field on July 8, 1997. Distance between the rows was 100 cm and distance between two plants in the row was 60 cm. Size of one plot was 12 m^2, and comprised of 20 plants placed in 4 rows. Treatments were replicated three times. One replicate comprised one plot.

Treatment was composed of two different fertilization methods. For both treatments fertilizer rates were 15 g nitrogen and 15 g K_2O per m^2. In the ammonium nitrate (AN) treatment nitrogen was applied as ammonium nitrate (34.4–0–0), phosphorus as superphosphate (0–17.5–0) at 15 g P_2O_5 per m^2 rate and potassium as potassium sulphate (0 - 0–50). In the POC-DAP treatment nitrogen and phosphorus were applied as 70-day type POC-DAP (16–40–0) and potassium as 70-day type polyolefin-coated potassium sulphate (0–0–42). The term 70-day type means that the fertilizer releases 80% of its nutrient content during 70 days in water at 25 °C *(Gandeza* et al., 1991). In both treatments full amount of fertilizers was placed under the rows in 15 cm wide bands at the depth of 15 cm (5 cm under the planting holes) just before planting.

On August 19 and on October 9 one fully developed young leaf was taken from the central 6 plants of every plot and these petioles were used for analysis. On October 7 soil samples were taken from the depth of 0–20 cm, from four places between the central six plants of each plot.

Swiss chard experiment

Seeds of Swiss chard (cv. Groete gewone) were sown in the field on May 9, 1997. Three seeds per hole were sown at the depth of 2 cm, and plant density was thinned to one plant per hole on June 25. Distance between the rows was 50 cm and distance between two plants in the row was 35 cm. The design of the experiment was the same as in the rhubarb experiment. Size of one plot was 3.5 m^2.

Treatment was composed of two different fertilization methods. For both treatments fertilizer rates were 20 g nitrogen and 30 g K_2O per m^2. In the AN treatment nitrogen was applied as ammonium nitrate, phosphorus as superphosphate at 20 g P_2O_5 per m^2 rate and potassium as potassium sulphate. In the POC-DAP treatment nitrogen and phosphorus were applied as 70-day type POC-DAP and potassium as potassium sulphate. In both treatments whole amount of fertilizers were placed under the rows in 10 cm wide bands 6 cm under the soil surface, except for the ammonium nitrate in the AN treatment. In this treatment 5 g nitrogen per m^2 was placed into the bands, the other 15 g was broadcasted in the rows onto wet soil surface as top-dressings in three equal doses on June 26, July 24 and August 15.

On September 4 the central 6 plants of every plot were cut out. After measuring the weight of these plants, the petioles and leaf blades of young fully developed leaves were separated. On September 2, soil samples were taken from the depth of 0–10 cm, from four places between the central six plants of each plot.

Measurements

After extraction with water or 0.05N HCl, respectively *(Takebe* et al., 1996), water soluble and total oxalic acid contents were determined by ion chromatography (Dionex DX-100; analytical column IonPac AS4A-SC) using 1g of a fresh sample. Ascorbate content was determined by a MERCK RQflex instrument using 5 g of fresh material after extraction with a metaphosphoric acid – acetic acid solution (AOAC, 1980). Nitrate content was measured by the method of *Cataldo* et al. (1975). After a dry ashing procedure, described by *Jones & Case* (1990), cation contents were determined by an atomic adsorption spectrophotometer (Hitachi, Z-6100).

Nitrogen releasing rate of POC-DAP was determined during both experiments. Net bags filled with 3.00 g fertilizer were placed into the soil at the same position as the fertilizer bands. Bags were retrieved at each sampling time for the rhubarb experiment and at each top-dressing time for the Swiss chard experiment, and their remaining nitrogen content was measured.

After extraction with 2M KCl, inorganic nitrogen content of the soil samples was determined by using a magnesium oxid – Devarda alloy steam distillation procedure (Keeney & Nelson, 1982).

Results and discussion

Rhubarb experiment

Total and water soluble oxalate contents were significantly lower in the POC-DAP treatment than in the AN treatment *(Table 1)*. Measured oxalate contents were higher than the usual values (33-95 mg/g DW; *Libert & Creed*, 1985). This was a consequence of using young plants.

At the first sampling time ascorbate content was significantly higher in the POC-DAP treatment than in the AN treatment *(Table 1)*. This result is in good correlation with the results of the oxalate content measurements. However, at the second sampling time there was no significant difference regarding the ascorbate content between the two treatments, despite of a significant difference in oxalate content.

Nitrate content was significantly higher in the POC-DAP treatment than in the AN treatment at the first sampling time *(Table 1)*. This result is in contrary to the other results of this experiment. However, as it is known that petiole nitrate content is highly variable *(Maynard* et al., 1976) this result could be caused by even a temporary difference in nitrate availability between the two treatments, in contrary of the levels of oxalate and ascorbate which are results of more long-lasting processes. At the second sampling time there was no significant difference in nitrate content between the two treatments.

Table 1 Effects of band application of two nitrogen fertilizers on the oxalate, nitrate, ascorbate and cation contents in rhubarb petioles

	Total oxalate mg/g DW	Water soluble oxalate mg/g DW	Insoluble oxalate mg/g DW	Ascorbate mg/100g FW	Nitrate mg/kg FW	Cation meq/g DW
First sampling (August 19)	*	*		*	*	
AN	144,8	109,5	35,4	12,8	2120	3,10
POC-DAP	114,6	87,2	27,4	15,7	3213	2,89
Second sampling (October 9)	*	*				
AN	97,5	78,5	19,0	16,0	473	2,25
POC-DAP	83,5	60,5	22,9	15,4	437	1,95

* Significant difference within columns according to Student's t-test, $P < 5\%$
(AN = ammonium nitrate, POC-DAP = polyolefin-coated diammonium phosphate)

According to these results nutritional quality of rhubarb petioles was improved in the POC-DAP treatment compared to the AN treatment.

Plant cation content, soil inorganic nitrogen content and nitrogen release rate of POC-DAP were measured in order to investigate the causes of the changes in the nutritional quality of rhubarb. Cation content was lower in the POC-DAP treatment than in the AN treatment at both sampling times *(Table 1)*. Lower cation contents at the second sampling time are in close relation with the results of the oxalate and nitrate measurements. In the plants, the synthesis of organic acids is partly in connection with the nitrate reduction *(Imsande & Touraine,* 1994). According to this fact, lower nitrate uptake and reduction result lower cation and oxalate contents *(Libert & Franchesci,* 1987).

Soil inorganic nitrogen content was significantly lower in the AN treatment (3 mg/kg nitrate-N and 1 mg/kg ammonium-N) than in the POC-DAP treatment (31 mg/kg nitrate-N and 57 mg/kg ammonium-N). The relatively high amount of ammonium-N in the POC-DAP treatment indicates realized long-term ammonium nutrition.

Until the first sampling time (cumulative soil temperature was 749 °C) the 70-days type POC-DAP released 52.4% of its nitrogen content. This value was 85.6% at the second sampling time (1921 °C). As nitrate leaching in the AN treatment was presumably higher than in the DAP treatment, available fertilizer nitrogen was not less in the DAP treatment than in the AN treatment during this experiment.

According to these results the improved nutritional quality in the POC-DAP treatment was rather a cause of realized long-term ammonium nutrition than a cause of less amount of released fertilizer nitrogen.

Swiss chard experiment

There was no difference in the total and soluble oxalate contents in the petiole between the treatments *(Table 2)*. However, total and insoluble oxalate contents in the leaf blade were higher in the AN treatment than in the POC-DAP treatment, while the soluble oxalate content was higher in the POC-DAP treatment. This latter result could be a consequence of the mechanism observed in a lettuce study, that organic acids can replace nitrates in the osmoregulation *(Blom Zandstra & Lampe,* 1985). As it is usual for oxalate accumulating plants *(Libert & Franchesci,* 1987) oxalate contents were higher in the leaf blade than in the petiole.

Ascorbate contents were higher in the POC-DAP treatment than in the AN treatment *(Table 2)*. The difference was statistically significant in case of the leaf blade. These results are in close relation with the results of the total oxalate content.

Nitrate contents were about 40% lower in the POC-DAP treatment than in the AN treatment *(Table 2)*. This result can be explained by the higher soil nitrate availability in the AN treatment at harvest time. As it is usual, nitrate contents were

Table 2 Effects of band application of two nitrogen fertilizers on the oxalate, nitrate, ascorbate and cation cotent in Swiss chard plants

	Total oxalate mg/g DW	Water soluble oxalate mg/g DW	Insoluble oxalate mg/g DW	Ascorbate mg/100g FW	Nitrate mg/kg FW	Cation meq/g DW
Petiole					*	
AN	35,1	28,1	7,0	8,5	2993	2,74
POC-DAP	34,6	29,3	5,3	10,5	1873	2,33
Leaf blade		*	*	*		
AN	77,5	38,8	38,7	31,2	522	3,12
POC-DAP	66,1	49,7	16,4	40,2	303	2,84

* Significant difference within columns according to Student's t-test, $P < 5\%$
(AN = ammonium nitrate, POC-DAP = polyolefin-coated diammonium phosphate)

higher in the petiole than in the leaf blade *(Maynard* et al., 1976).

According to these results nutritional quality of Swiss chard was improved in the POC-DAP treatment compared to the AN treatment.

Similar to the rhubarb experiment cation contents were lower in the POC-DAP treatment than in the AN treatment *(Table 2)*, indicating lower nitrate uptake. In accordance with the result of oxalate contents total cation contents were higher in the leaf blade than in the petiole.

Soil inorganic nitrogen content was significantly higher in the AN treatment (45 mg/kg nitrate-N and 31 mg/kg ammonium-N) than in the POC-DAP treatment (10 mg/kg nitrate-N and 7 mg/kg ammonium-N) at harvest time. Higher values in the AN treatment is the result of a top-dressing applied about two weeks before the harvest. For both treatments a considerable part of the inorganic nitrogen was in ammonium form. In case of the AN treatment this could be a cause of rainy weather between the last top-dressing and the harvest.

Table 3 shows the changes in the amount of released fertilizer nitrogen. These data show that during the middle part of the growing period the amount of available fertilizer nitrogen was presumably higher in the POC-DAP treatment than in the AN treatment, while before the harvest there was more available nitrogen in the AN treatment.

Table 3 Changes in the amount of released fertilizer N expressed in g m^{-2} unit during the Swiss chard experiment

	Days after sowing				
	0	48	76	98	117
Ammonium nitrate	5	10	15	20	20
Polyolefin coated diammonium phosphate	0	10.9	15.8	16.8	17,4

According to these results, the improved nutritional quality in the POC-DAP treatment was a cause of both the less amount of released fertilizer nitrogen and of the realized ammonium nutrition.

In spite of eventually less fertilizer nitrogen being available in the POC-DAP treatment, yields were identical in the AN and POC-DAP treatments (6.0 kg/m^2). According to these results, by using a band application of POC-DAP for Swiss chard cultivation, labour and energy costs of top-dressings can be eliminated without yield decrease.

From the above results it was concluded that using a band application of POC-DAP the nutritional quality of rhubarb and Swiss chard can be improved.

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