Reducing nitrate content in lettuce using polyolefin-coated fertilizers

INTERNATIONAL JOURNAL OF HORTICULTURAL SCIENCE

AGROINFORM Publishing House, Hungary

Ombódi A.[1] and Saigusa M.[2]

[1]*Szent István University, Department of Horticultural Technology, Páter K. str. 1., H-2103 Gödöllő, Hungary*

[2]*Experimental Farm of Tohoku University, Kawatabi, Naruko, Tamatsukuri, Miyagi, 989-6711, Japan*

Key words: lettuce, nitrate content, polyolefin-coated fertilizer, ammonium nutrition,

Summary: Pot experiments were conducted in order to investigate the effects of the controlled-release characteristic, nitrogen form and application method of polyolefin-coated fertilizers on the nitrate content and yield of lettuce (*Lactuca sativa* L.). Comparing broadcast application of polyolefin-coated urea (POCU) and urea at four fertilization levels, it was found that application of POCU decreased the nitrate content and increased the yield, due solely to its controlled-release characteristic. Comparing band applications of POCU or polyolefin-coated diammonium-phosphate (POC-DAP) to broadcast application of ammonium nitrate, it was found that a band application of both urea and ammonium containing polyolefin-coated fertilizers can decrease nitrate content in lettuce, without causing any significant yield decrease. This was a combined effect of the controlled-release characteristic and realized ammonium nutrition. Comparing effects of broadcast, band and spot applications of POC-DAP, it was found that nitrate content was the lowest in the spot application treatment. However, considering both nitrate content and yield, band application was found to be the most effective application method.

Introduction

Dietary intake of higher amount of nitrates can cause methahemoglobinemia and gastric cancer *(Maynard et al.,* 1976). Vegetables comprise 70 to 80% of the total dietary nitrate intake *(Isermann in Prasad & Power,* 1995). Lettuce (*Lactuca sativa* L.) is the most important salad vegetable in Europe, which can accumulate big amounts of nitrates. In order to protect the consumers, legislation sets the maximum allowable nitrate content in lettuce. That is why it is of considerable importance to produce lettuce having lower nitrate content.

Maynard et al. (1976) concluded that all thing being equal, nitrate contents in plant tissues are in some relationship with the availability of nitrate in the root zone. Replacing nitrate with ammonium in the nutrition or maintaining constant low levels of nitrate, offers the possibility of reducing nitrate content in lettuce without causing yield decrease *(Van der Boon* et al., 1990; *Gunes* et al., 1994).

Use of controlled-release fertilizers can maintain a constant low level of nitrogen in the soil and in this manner decreasing nitrate content in lettuce while maintaining good yield *(Arce* et al., 1996). *Takebe* et al. (1996) found that a band application of ammonium containing polyolefin-coated fertilizer (POCF) resulted in long-term ammonium nutrition in a spinach field experiment. This fertilization method combines ammonium nutrition with the controlled-release characteristic, and could be successfully used for reducing nitrate content in lettuce while maintaining good yield.

The objective of this study was to investigate the effects of the controlled-release characteristic, nitrogen form and application method of POCFs on the nitrate content and yield of lettuce.

Material and methods

Three pot experiments were conducted. In every experiment one butterhead lettuce (*Lactuca sativa* L. cv. Rachel) seedling per pot (3.5 l volume, 200 cm^2 surface) was transplanted at the 4–5 true leaf stage. The soil (Alic Pachic Mellanudand) having used in this experiment was taken from a cultivated field of the Experimental Farm of Tohoku University. The first experiment was conducted outdoors, while the second and the third experiments in a greenhouse. Table 1 summarises the experimental conditions.

Treatments were composed of various nitrogen fertilizers and fertilization methods. Treatments were replicated three times. Each replicate comprised one pot. In every experiment potassium was applied as potassium-sulphate (0–0–50). Phosphorus was applied as superphosphate (0–17.5–0) except in the polyolefin-coated diammonium phosphate (POC-DAP) (16–40–0) treatments. Broadcast application means mixing of fertilizers into the whole amount of soil of the given pot. Band application means applying fertilizers in a 10 cm wide band at a depth of 8 cm. Spot application means applying fertilizers in a spot placed just under the planting hole.

In the first experiment effects of the controlled-release characteristic were investigated. Broadcast application of 30-day type polyolefin-coated urea (POCU) (40–0–0) was compared to broadcast application of urea (46–0–0) at four different fertilization levels (0.5 g, 1 g, 2 g and 3 g of N, P_2O_5 and K_2O per pot). The term 30-day type means that it takes 30 days for the fertilizer to release 80% of its total nitrogen content in water at 25 °C (*Gandeza* et al., 1991).

In the second experiment effects of the nitrogen form of the POCF were investigated. As control treatment 1 g nitrogen per pot was applied as ammonium nitrate (AN) (34.4–0–0). Two-thirds of the AN was applied with broadcast application method and the remaining one-third was solved in 200 ml water and poured onto the soil surface at the beginning of head formation (October 23, 1997). In the POCF treatments 1g nitrogen per pot was applied using band application method as 40-day type POCU or as 40-day type POC-DAP. In every treatment 1 g P_2O_5 and 1.25 g K_2O per pot were also applied using broadcast application method. In this experiment fertilizer nitrogen use efficiency was calculated with the difference method using the data of nil nitrogen treatment.

In the third experiment effects of application methods were investigated. 1 g nitrogen per pot was applied as 40-day type POC-DAP using broadcast, band or spot application method. For every treatment 1.25 g K_2O per pot was also applied.

In order to determine the nitrogen release rate of the POCFs, net bags filled with 3.00 g fertilizer were placed at a depth of 8 cm. The bags were retrieved at the end of the experiments and their remaining nitrogen content was measured. In the third experiment, two soil samples per pot – one from the bottom of the pot, the other from the place of the fertilizer placement – were taken. After extraction with 2M KCl nitrogen content of the soil samples was determined by a magnesium oxid – Devarda alloy steam distillation procedure *(Keeney & Nelson, 1982)*. Plant nitrate content was measured using dry samples by the method of *Cataldo* et al. (1975). After decomposition with concentrated salicylic acid – sulphuric acid mixture and thiosulphate, total nitrogen content was measured by using a regular Kjehldahl method *(Matsunaga & Shiozaki*, 1989).

Table 1 Summary of the experimental conditions

	Experiment 1	Experiment 2	Experiment 3
Planting	1997.04.29.	1997.09.20.	1997.11.26.
Harvest	1997.06.11.	1997.11.23.	1998.02.15.
Average air temperature (°C)	13.7	13.6	11.1
Cumulative soil temperature (°C)	621	866	869
Amonut of dry soil (kg/pot)	2.5	2.4	2.15
pH	6.44	6.20	6.20
EC (dS/m)	0.11	0,12	0.12
Inorganic N content (mg/kg)	15	26	26

An analysis of variance was performed on the data, using Excel 7.0 computer software. Statistically significant differences among the treatments were determined at 95% probability level according to the least significant difference method.

Results and discussion

First experiment

Both fertilizer rate and fertilizer type significantly affected nitrate content of the lettuce heads *(Table 2)*. Higher fertilizer rates resulted in higher nitrate contents. Nitrate contents were lower in the POCU treatments than in the corresponding urea treatments. The 30-day type POCU released 61.5% of its nitrogen content during the experiment. Investigating plant nitrate content plotted against the amount of released fertilizer nitrogen, it was found that same amount of available fertilizer nitrogen resulted in similar plant nitrate contents for both fertilizers used *(Figure 1)*. According to these results broadcast application of POCU reduced nitrate contents of lettuce heads due solely to its lower release rate.

Table 2 Effects of broadcast application of urea and polyolefin-coated urea on lettuce plantsat four different fertilization levels

		Nitrate content (mg/kg FW)	Fresh weight (g/plant)	Nitrogen uptake (mg/plant)
Urea	0.5g	1920 ^{c*}	173 ^{bc}	348 ^{b}
	1g	2855 ^{b}	174 ^{bc}	323 ^{bc}
	2g	3734 ^{a}	143 ^{c}	356 ^{b}
	3g	4283 ^{a}	139 ^{c}	343 ^{b}
POCU	0.5g	502 ^{d}	172 ^{bc}	255 ^{c}
	1g	1686 ^{c}	202 ^{ab}	345 ^{b}
	2g	3109 ^{b}	208 ^{ab}	437 ^{a}
	3g	3833 ^{a}	228 ^{a}	476 ^{a}
Significance				
Fertilizer type		+++	+++	+
Fertilizer rate		+++	+++	NS
Type x rate		NS	+	+++

NS = statistically not significant effect; +, ++, +++ = statistically significant effect, $P < 5\%$, $P < 1\%$, $P < 0.1\%$, respectively
* Means separation within columns by LSD, $P < 5\%$
(POCU = polyolefin coated urea)

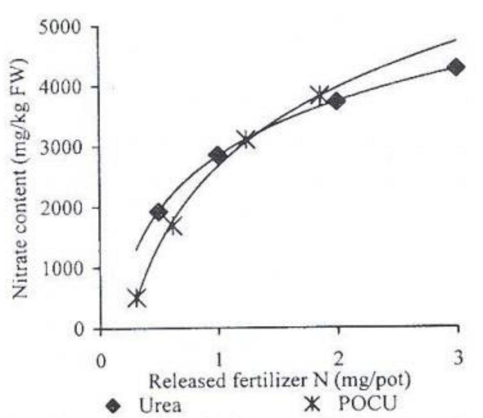

Figure 1 Nitrate content in lettuce plants plotted against the amount of released fertilizer nitrogen

In spite of less fertilizer nitrogen being available, head fresh weight was similar or higher in the POCU treatments than in the corresponding urea treatments *(Table 2)*. There were no significant differences in nitrogen uptake among the urea treatments, but increased nitrogen availability resulted in decreased fresh weight at the higher fertilizer rates. In the POCU treatments nitrogen uptake increased with increasing fertilizer rate, but differently from the urea treatments, increased fertilizer nitrogen availability also resulted in increased head fresh weight *(Table 2)*. This effect was presumably a merit of the controlled-release characteristic of POCU.

Second experiment

Nitrate content of lettuce heads was significantly higher in the AN treatment than in the POCU and POC-DAP treatments *(Table 3)*. Although the difference was not statistically significant, head fresh weight in the POCU treatment was about 10% lower than in the POC-DAP and AN treatments.

Table 3 Effects of band application of polyolefin-coated urea and polyolefin-coated diammonium phosphate on lettuce plants

	Nitrate content (mg/kg FW)	Fresh weight (g/plant)	Nitrogen uptake (mg/plant)
Ammonium nitrate	1646 a*	340	700 a
POCU band	395 b	314	575 b
POC-DAP band	355 b	334	580 b

* Means separation within columns by LSD, P < 5%
(POCU = polyolefin-coated urea, POC-DAP = polyolefin-coated diammonium phosphate)

During this experiment, nitrogen release rates were 61.8% and 70.6% for 40-day type POCU and POC-DAP, respectively. Fertilizer nitrogen use efficiencies, based on the amount of released fertilizer nitrogen, were 49%, 59%, and 52% in the AN, POCU, and POC-DAP treatment, respectively. The lower nitrate content in the POCF treatments was presumably mainly a consequence of realized ammonium nutrition, as fertilizer nitrogen use efficiencies of these two treatments were not so different from that of the AN treatment.

Third experiment

Band application of POC-DAP resulted in significantly lower nitrate content than broadcast application *(Table 4)*. This result is in agreement with the findings of Takebe et al. (1996). Further concentrating the applied fertilizer in the spot application treatment resulted in a further, significant decrease in the nitrate content.

There was no statistically significant difference in head fresh weight between the broadcast and band application treatments, while spot application significantly decreased the head weight of lettuce *(Table 4)*. In the latter treatment the lower fresh weight was a consequence of lower nitrogen uptake.

Table 4 Effects of different application methods on lettuce plants using polyolefin-coated diammonium phosphate

	Nitrate content (mg/kg FW)	Fresh weight (g/plant)	Nitrogen uptake (mg/plant)
POC-DAP broadcast	1947 a*	338 a	632 a
POC-DAP band	1012 b	316 a	608 a
POC-DAP spot	381 c	258 b	463 b

* Means separation within columns by LSD, P < 5%
(POC-DAP = polyolefin-coated diammonium phosphate)

Data of soil inorganic nitrogen content *(Table 5)* provides an explanation for these results. In the spot application treatment, the released ammonium gradually accumulated at the fertilizer spot and its concentration exceeded the toxic level for bacterial and root activities. Eventually the roots could take up nutrients only from areas outside of the fertilizer placement, where nitrogen availability was low. Thus, in this treatment the low nitrate content was more a result of low nitrogen availability than a result of ammonium nutrition. However, in the band application treatment, decreased nitrate content in the lettuce head was a consequence of high, but not toxic amount of ammonium being present in the fertilizer band. In the broadcast application treatment the released ammonium was quickly converted to nitrate, and nitrate became the dominating nitrogen form in the soil, resulting high nitrate content in the plant.

Table 5 Effects of different application methods on soil inorganic nitrogen content asing polyolefincoated diammonium phosphate

	Fertilizer placement		Bottom of the pot	
	Nitrate-N (mg/kg)	Ammonium-N (mg/kg)	Nitrate-N (mg/kg)	Ammonium-N (mg/kg)
POC-DAP broadcast	6 c*	3 c	27 a	3
POC-DAP band	229 a	517 b	14 ab	6
POC-DAP spot	91 b	6031 a	3 b	4

* Means separation within columns by LSD, P < 5%
(AN = ammonium nitrate, POC-DAP = polyolefin-coated diammonium phosphate)

It was concluded that by using POCF, nitrate content in lettuce could be reduced without any significant yield decrease. For this purpose, among the combinations investigated by us, band application of POC-DAP proved to be the most effective method.

References

Arce, A., Vallejo, A., Lopez-Valdivia, L.M. & Hoyos, P. (1996): Influence of the type of nitrogenous fertilizer on nitrate-N levels in lettuce leaves (Lactuca sativa L. cv. Rubia hortelana). Agricoltura Mediterranea. 126: 186–193.

Cataldo, D.A., Haroon, M., Schrader, L.E. & Youngs, W.L. (1975): Rapid colorimetric determination of nitrate in plant tissue by nitrification of salicylic acid. Com. Soil Sci. Plant Anal. 6:71–80.

Gandeza, A.T., Shoji, S. & Yamada, I. (1991): Simulation of crop response to polyolefin-coated urea: I. Field dissolution. Soil Sci. Soc. Am. J. 55: 1462–1467.

Gunes, A., Post, W. N. K., Kirkby, E.A. & Aktas, M. (1994): Influence of partial replacement of nitrate by amino acid nitrogen or urea in the nutrient medium on nitrate accumulation in NFT grown winter lettuce. J. Plant Nutr. 17: 1929–1938.

Keeney, D. R. & Nelson, D. W. (1982): Nitrogen – Inorganic forms. in: Page, A. L. (Ed), Methods of soil analysis Part 2, Soil Science Society of America, Madison, WI. pp: 643–692.

Matsunaga, T. & Shiozaki. H. (1989): Sulfuric acid – hydrogen peroxide digestion for the determination of total nitrogen in plant material containing nitrate nitrogen. Jpn. J. Soil Sci. Plant Nutr. 60: 458–460.

Maynard, D. N., Barker, A. V., Minotti, P. L. & Peck, H. P. (1976): Nitrate accumulation in vegetables. Adv. Agron. 28: 71–118.

Prasad, R. & Power, J. F. (1995): Nitrification inhibitors for agriculture, health and the environment. Adv. Agron. 54: 233–281.

Takebe, M., Ishihara, T., Ishii, K. & Yoneyama, T. (1996): Effect of slow-releasing nitrogen fertilizers on the content of oxalic acid, ascorbic acid, sugars and nitrate in spinach (Spinacia oleracea L.). Jpn. J. Soil Sci. Plant Nutr. 67: 147–154.

Van der Boon, J., Steenhuizen, J. W. & Steingröver, E.G. (1990): Growth and nitrate concentration as effected by total nitrogen and chloride concentration, NH4/NO3 ratio and temperature of the recirculating nutrient solution. J. Hort. Sci. 65:309–321.

This work was supported partly by a program of Research for the Future from Japan Society for the Promotion of Science (JSPS-97L00604).