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SUITABILITY OF SOME NITROGEN FERTILIZERS FOR THE CULTIVATION OF EARLY CABBAGE

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Abstract

Early cabbage was grown in a field experiment in two treatments, with and without weed control, to test the following fertilizers: ammonium nitrate and Entec 26-a, a new formula nitrogen fertilizer containing a DMPP nitrification inhibitor, applied in single preplant or split doses, and calcium cyanamide (Perlka), supplied only prior to the planting of cabbage. All the sources of N were used in amounts supplying 150 kg N ha^{-1}. The fertilizer Perlka was applied 2 weeks before planting cabbage transplants, while Entec 26 and ammonium nitrate were introduced to soil 3 days before that. All the fertilizers were incorporated into the soil by harrowing. In the treatments with split N application, top dressing was conducted just after the cabbage plants were uncovered, which took place 3-4 weeks after transplanting. The experiment was established in a one factorial design with four replications.

The results proved high efficiency of nitrogen fertilization, which – when applied at a dose of 150 kg N ha^{-1} - enhanced the yield of early cabbage by about 50% compared to the treatment without N fertilization and weed control. Ammonium nitrate and Entec 26 appeared to be equally valuable sources of this nutrient, both in single and split doses, in each year of the investigation. Calcium cyanamide produced the highest marketable yield of heads with a significantly lower mean content of nitrates in edible parts. Another big advantage of this N source is its high efficiency in reducing weed infestation during the whole vegetation period.

Key words: cabbage, ammonium nitrate, Entec 26, calcium cyanamide, yield, plant composition.

PRZYDATNOŚĆ WYBRANYCH NAWOZÓW AZOTOWYCH W UPRAWIE KAPUSTY WCZESNEJ

Abstrakt

W doświadczeniu wegetacyjnym saletrę amonową i nawóz azotowy Entec 26 zawierający inhibitor nitryfikacji DMPP stosowano w całości przedwegetacyjnie lub w dawkach dzielonych, natomiast cyjanamid wapnia (Perlka) wyłącznie przed sadzeniem rozsady kapusty wczesnej

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w dwóch kombinacjach: z odchwaszczaniem i bez usuwania chwastów. Wszystkie badane nawozy stosowano w łącznej dawce 150 kg N ha^{-1}. Nawóz Perlka wysiewano 2 tygodnie przed sadzeniem rozsady kapusty, zaś saletrę amonową i Entec 26 bezpośrednio przed sadzeniem rozsady kapusty, pod bronę. W obiektach, gdzie stosowano dawki dzielone, nawożenie pogłówne wykonywano 3-4 tygodnie po posadzeniu rozsady, po usunięciu włókniny, którą osłaniano rośliny. Doświadczenie założono w układzie jednoczynnikowym w 4 powtórzeniach. Potwierdzono wysoką skuteczność nawożenia azotem, które w dawce 150 kg N ha^{-1} spowodowało wzrost plonu kapusty uprawianej na zbiór wczesny o ok. 50% w porównaniu z obiektem bez nawożenia i odchwaszczania. Saletra amonowa i nawóz Entec 26 miały zbliżoną wartość jako źródło azotu dla kapusty, niezależnie od metody stosowanej w każdym roku badań. Użycie cyjanamidu wapnia przyczyniło się do uzyskania wyższego plonu handlowego kapusty oraz istotnego zmniejszenia średniej zawartości azotanów w częściach jadalnych, w porównaniu z pozostałymi nawozami. Dużą zaletą tego nawozu jako źródła azotu jest jego wysoka efektywność w redukcji zachwaszczenia przez cały okres uprawy kapusty.

Słowa kluczowe: kapusta, saletra amonowa, Entec 26, cyjanamid wapnia, plon, skład chemiczny.

INTRODUCTION

Nitrogen fertilization is a major factor affecting the yield and nutritional value of vegetable crops. As an elementary constituent of amino acids, proteins, nucleic acids and numerous secondary metabolites, nitrogen plays a crucial role in the metabolism of plants, their growth and development. Suboptimal supply of this element can lead to delayed maturation, inhibited protein synthesis and high reduction of the yield (Rahn et al. 1998). The economic consequences of failing to produce target yield are bad enough to tempt farmers to apply more nitrogen than necessary (Rahn 2002). It is not always easy to ascertain whether nitrogen has been overfertilized because the borderline between optimal and excessive N supplies is rather vague (Peck 1981). An oversupply N fertilization invariably leads to stimulated vegetative growth and may negatively affect the crop's nutritional value by limiting the synthesis of sugars, enhancing the accumulation of nitrates accumulation and contributing to high nitrogen leaching from the soil (Sorensen 1999, Rahn 2000, Neeteson, Carton 2001, Dzida et al. 2013). For white head cabbage, the negative consequences of nitrogen overfertilization are such as inferior storability and worse processing quality due to decreased dry matter and sugar content. Typically, in a temperate climate, no more than 50% of N applied to the soil is effectively used by plants while much nitrogen is leached, causing the contamination of ground and surface water.

Loss of nitrogen can be partly counteracted by split application of N fertilizers, with 50% introduced in a preplant dose, followed by one or two top dressings. However, in the case of cabbage grown for early harvest, the common practice is to apply a single preplant N dose because such cabbage grows for a short time in the field.

Extensive field research has been conducted on sulphur coated urea (Kołota 1982, Wiedenfeld 1986, Brown et al. 1988, Guertal 2000, Hochmuth

2003, Pack, Hutchinson 2003, You Sheng et al. 2005) and polymer coated urea (Drost et al. 2002) as nitrogen sources for vegetables. High production costs and similar or sometimes lower efficiency in comparison to conventional N fertilizers are the reason why these types of fertilizer have not found broad use in practice.

Another way to reduce N losses from soil is to add nitrification inhibitors reducing the conversion of ammonium N form to nitrates, which are most likely to leach. Research on nitrification inhibitors conducted with products such as nitrapyrin (2- chloro 6- trichloromethyl pyridine) and DCD (dicyanamide) did not translate into a widespread commercial use in vegetable crop production (Hendrickson et al. 1978, Kołota, Dobromilska 1985, Amberger 1986, Frye et al. 2002, Hochmuth 2003). Recently, a new formula of a nitrogen fertilizer containing DMPP nitrification inhibitor (3, 4 dimethylpyrazole phosphate) has been developed and made available under the commercial name ENTEC 26 (Hähndel, Zerulla, 2000, 2001, Hähndel, Strohm 2001, Pasda et al. 2001, Paschold et al. 2008, Chohura, Kołota 2011, Kołota, Chohura 2008, Li et al. 2008, Adamczewska-Sowińska, Krygier 2014, Smoleń et al. 2013). Many field studies have demonstrated its higher efficiency than soluble N sources, expressed either by an increased yield level or a lower demand for N application. Another advantage of the use of a nitrification inhibitor together with nitrogen fertilizers is the considerable limitation of the negative impact of NO_3^- on the environment, mainly by reducing its leaching from soil (Li et al. 2008).

Another source of nitrogen highly resistant to leaching is calcium cyanamide, produced by AlzChem Company under the commercial name Perlka, containing 19.8% N. Fertilizer of this type, named Azotniak, was manufactured in Poland and used as an efficient herbicide for the control of dicotyledonous weeds in vegetable and agriculture crops (Hahn 1951). Its production was discontinued in the 1960s because the powder form of the fertilizer was inconvenient for application, causing frequent cases of eye and skin irritation (Brzozowski et al. 1953). Currently, calcium cyanamide is offered in the granulated form, which is safe for people, well adopted to precise application and recommended as preplant fertilizer for a wide range of vegetable crops grown in open field.

The aim of the present study was to evaluate the efficiency of conventional fertilizer compared with one containing nitrification inhibitor and with calcium cyanamide in the cultivation of white head cabbage for early harvest in the spring.

MATERIAL AND METHODS

A field experiment with white head cabbage Reactor F_1 cultivar was conducted in 2009-2011, at the Piastów Horticultural Experimental Station (long.1700 E; lat. 51.05 N) on sandy clay soil with pH of 7.2 and organic matter content of 1.8%. Available forms of phosphorus and potassium expressed in 1 dm^3 of soil were replenished by early spring fertilization up to the standard level for cabbage. i.e. 50 mg P and 150 mg K. The fertilization was composed of triple superphosphate and potassium chloride. The mineral nitrogen content in soil was 24-30 mg N dm^{-3}, depending on the year of study.

The following nitrogen fertilization treatments were included in the study:

1) ammonium nitrate (34% N) applied in a single preplant dose – 150 kg N ha^{-1};
2) ammonium nitrate applied in a split dose (100 kg N ha^{-1} as preplant fertilization and 50 kg N ha^{-1} as top dressing);
3) ENTEC 26 (7.5% N-NO_3, 18.5% N-NH_4, 13% S+DMPP inhibitor) applied in a single preplant dose 150 kg N ha^{-1};
4) ENTEC 26 applied in a split dose (100 kg N ha^{-1}as preplant fertilization and 50 kg N ha^{-1} as top dressing);
5) Perlka (calcium cyanamide) containing 19.8% N applied in a single preplant dose – 150 kg N ha^{-1};
6) Perlka applied in a single preplant dose – 150 kg N ha^{-1}, to the plots without weed control during the whole growing period;
7) treatment with neither nitrogen application nor weed control during the whole growing period.

As recommended, Perlka was applied 2 weeks, while ENTEC 26 and ammonium nitrate were given 3 days before the transplanting of cabbage and incorporated into the soil by harrowing. In treatments with the split N application, top dressing was conducted just after the removal of covers from plants, i.e. 3-4 weeks after transplanting. The experiment was established in a one factorial design with four replications and a plot area of 8.64 m^2 (2.7x3.2 m).

Seeds of an early cabbage cultivator called Reactor F_1, whose growing period in open field is said to last 55-58 days from planting, were sown at the end of February into multicell trays filled with standard peat moss substrate. A single cell capacity was 80 cm^3. The transplants produced in a greenhouse were hardened in an unheated plastic tunnel for the last ten days before planting in a field. Well-developed seedlings at the stage of 5-6 leaves were transplanted in a field in the first decade of April, in a spacing pattern of 45x40 cm. Immediately after planting, the cabbage plants were covered with nonwoven crop cover of 17 g per 1 m^2 thickness, which was kept for the period of 3-4 weeks, depending on the actual weather conditions.

Weed infestation, defined as the number and weight of weeds per unit area, was assessed four weeks after planting. In the later part of the plant growing period, all the plots weeded except treatments 6 and 7, where weeds were left until harvest and evaluated at that time. The final level of weed infestation allowed us to determine the weed control effects caused by Perlka at the end of the growing period.

First harvest of cabbage heads was conducted in mid-June, and the subsequent two were carried out in one-week intervals. Each time, the heads which weighed >1.5 kg and fulfilled the requirements for marketable yield were picked up. The content of dry matter (by drying at 105°C to the constant weight PN-90/A-75101/03), vitamin C (the Tillman's method PN-90/A-7501/11) total and reducing sugars (the Loof-Shoorl method PN-90A/7501/07) and nitrates expressed by the amount of NO_3-N in fresh weighs (Orion ion selective electrode) were determined in samples of edible parts.

The results of the field experiment and chemical analyses were evaluated statistically using analysis of variance for a two-factorial design and the least significant differences were calculated by the Tukey's test at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Cabbage is a species with high nutritional demand for nitrogen, which strongly affects the yield and crop quality. According to SADY et al. (1999), production of a ton of marketable cabbage yield is associated with an uptake of approximately 2.0 kg of N. The recommended dose of this nutrient, depending on the duration of a plant growing season, varies from 150 kg N ha^{-1} for cultivars harvested in early spring up to 250 N ha^{-1} for those grown for autumn harvest.

In our study, there was a marked response of early cabbage to this nutrient, which when applied at the dose of 150 N ha^{-1} raised the marketable yield by about 50% on average, irrespective of the form of fertilizer and method of its application, in comparison to the treatment neither N fertilized nor weeded (Table 1). Furthermore, the use of the above N dose caused

Table 1

Effect of different nitrogen fertilization on white head cabbage marketable yield (t ha^{-1})

Type and dose of fertilizer	Year			Mean
	2009	2010	2011	
Ammonium nitrate 150 kg N ha^{-1}	91.9	94.5	85.5	90.6
Ammonium nitrate 100+50 kg N ha^{-1}	87.9	91.7	81.8	87.2
Entec 26 150 kg N ha^{-1}	92.6	93.7	86.2	90.8
Entec 26 100+50 kg N ha^{-1}	90.2	91.6	83.9	88.6
Perlka 150 kg N ha^{-1}	96.3	97.3	89.5	94.4
Perlka 150 kg N ha^{-1} without weeding	94.9	96.3	88.3	93.2
Treatment without N fertilization and weed control	52.8	50.9	35.1	46.2
Mean	86.7	88.0	78.6	84.4

$LSD\alpha_{0.05}$ for: years – 6.2, fertilization – 5.3, interaction – 7.6

a considerable change in the nutritional value of the crop at harvest. Plants grown on plots without N application and with 24-30 mg dm^{-3} of mineral N in the soil at the time of transplanting contained substantially higher amounts of dry matter and vitamin C, while having a lower content of nitrates compared to those supplied with 150 N ha^{-1} (Tables 2, 3). Such a response is in accordance with the findings of Sorensen (1999) in studies on cabbage, broccoli and leek. The adverse effect of nitrogen fertilization on the content of vitamin C in vegetables has been reported by others (Lisiewska, Kmiecik 1996, Gajewski, Rdzanowska 2004, Kołota, Adamczewska-Sowińska 2009, Chohura, Kołota 2011). Variable effects of nitrogen fertilization were observed in the case of total and reducing sugar content in cabbage heads. The cabbage yield in 2011 was significantly lower than in the other years due to the shortage of rainfall during the stage of head formation in June.

The split application of nitrogen, expected to minimize environmental losses by matching the time of crop nitrogen supply to crop nitrogen demand,

Table 2

Effect of different nitrogen fertilization on the content of nitrate in white head cabbage edible parts (mg NO_3^- kg^{-1} f.w.)

Type and dose of fertilizer	Year			Mean
	2009	2010	2011	
Ammonium nitrate 150 kg N ha^{-1}	600	895	568	688
Ammonium nitrate 100+50 kg N ha^{-1}	542	740	610	631
Entec 26 150 kg N ha^{-1}	475	825	820	707
Entec 26 100+50 kg N ha^{-1}	563	715	930	736
Perlka 150 kg N ha^{-1}	553	555	680	596
Perlka 150 kg N ha^{-1} without weeding	667	620	626	638
Treatment without N fertilization and weed control	450	520	428	466
Mean	550	696	666	637

LSD$\alpha_{0.05}$ for: years – 38, fertilization – 32, interaction – 51

Table 3

Effect of different nitrogen fertilization on dry matter, vitamin C and sugars content in white head cabbage edible parts (mean for years 2009-2011)

Type and dose of fertilizer	Dry matter (%)	Vitamin C (mg 100g^{-1} f.w.)	Sugars (% f.w.)	
			total	reducing
Ammonium nitrate 150 kg N ha^{-1}	6.81	33.9	3.97	3.18
Ammonium nitrate 100+50 kg N ha^{-1}	7.08	34.2	4.12	3.86
Entec 26 150 kg N ha^{-1}	7.18	31.7	4.30	3.96
Entec 26 100+50 kg N ha^{-1}	7.35	34.7	3.74	3.39
Perlka 150 kg N ha^{-1}	7.40	31.5	4.08	3.71
Perlka 150 kg N ha^{-1} without weeding	7.06	34.6	3.81	3.61
Treatment without N fertilization and weed control	7.54	44.9	4.03	3.59

LSD$\alpha_{0.05}$ n.s. 3.7 n.s. n.s.

appeared to be inefficient for cabbage yield. Both fertilizers, ammonium nitrate and Entec 26 used in one dose prior to planting, assured slightly higher marketable yields of cabbage than the treatments in which 1/3 of the total dose was applied as top dressing. Similar effects were observed by Smit et al. (1996) in a study on Brussels sprouts, which – like white head cabbage – take up most of nitrogen early in the growth period and have roots penetrating deeply into the soil. The above authors indicated that a positive response to split N application could be expected in cultivation of vegetable crops with a shallow and rather poorly developed root system e.g. leek, that is plants which should be given small amounts of nitrogen regularly throughout the growth. A split dose of ammonium nitrate supplied as preplant and top dressing fertilization was associated with a significant decrease of nitrates in cabbage in two out of the three years of the study, while a reverse effect was found in the case Entec 26 use. Dry matter, vitamin C, and sugars in edible parts of cabbage were unaffected by the method of nitrogen application. The highest content of dry matter and vitamin C was observed in the treatment which had been neither nor weeded.

Irrespective of the weather conditions in the particular years and methods of fertilizer application, the efficiency of Entec 26, a new concept nitrogen fertilizer with an added DMPP nitrification inhibitor, was similar to that of ammonium nitrate. Similarly to another study conducted on early leek by Kołota and Adamczewska-Sowińska (2007), the size of marketable yield, level of nitrate accumulation and content of dry matter, vitamin C and sugars in cabbage did not differ significantly under the influence of these N sources. Contrary data are presented by Hähndel, Zerulla (2001), who found an overall 10% yield increment of different vegetable crops, including a 20% yield rise of lamb lettuce and small radish affected by Entec 26. The above researchers indicate that a fertilization system with DMPP containing fertilizers is less sensitive to unfavorable weather conditions and reduces the risk of surface and ground water pollution.

According to Pasda et al. (2001), positive effects of fertilizers containing a DMPP nitrification inhibitor on crop yield can be especially pronounced at sites with a high precipitation rate or intensive irrigation, and on light sandy soils. Such conditions did not occur in our study, conducted on heavy clay soil with high amounts of water, and for this reason supplemental watering of the plants was unnecessary.

The maximum yield of early cabbage marketable heads in the study was obtained from the treatments supplied with calcium cyanamide, although the difference with the yields from plotss treated with a single preplant dose of ammonium nitrate or Entec 26 were not significant. Practically, it was very important to find that an equally high cabbage yield was harvested from plots without weed control throughout the whole growing period. The results of our field trial confirmed the previous observations by Hahn (1951), indicating that calcium cyanamide was a very efficient compound for weed control. The weed infestation assessment conducted four weeks from the date of planting cabbage transplants on plots supplied with 150 kg N ha^{-1} in the form of calcium cyanamide showed that the number of weeds was reduced by 46.1-49.7% and their fresh weight was 61.8-64.8% lower in comparison to treatments with ammonium nitrate or Entec 26 (Tables 4, 5). This positive effect was even stronger at the end of the growing period, when the number of weeds declined by 64.1% to 68.4% and their aerial biomass decreased by 62.2% to 68.4% of the respective results in the non-weeded control.

The other advantage of calcium cyanamide is the substantial reduction of nitrate accumulation in edible parts of cabbage at harvest. In 3-year average values, the amount of this compound was 688 mg kg^{-1} f.w. in the treatment with 150 kg N ha^{-1} of ammonium nitrate supplied in a single preplant dose, 596 and 638 mg kg^{-1} f.w. in the case of calcium cyanamide use in weed free and non-weeded treatments, respectively. These results coincide that the report by Venter and Fritz (1976), who observed lower accumulation of

Table 4

Effect of different nitrogen fertilization on the number of weeds per 1 m^2

Type and dose of fertilizer	Year			Mean
	2009	2010	2011	
4 week after planting				
Ammonium nitrate 150 kg N ha^{-1}	341	363	324	342
Ammonium nitrate 100+50 kg N ha^{-1}	332	348	315	332
Entec 26 150 kg N ha^{-1}	351	371	345	356
Entec 26 100+50 kg N ha^{-1}	346	359	348	351
Perlka 150 kg N ha^{-1}	192	165	179	179
Mean	312	321	301	312
At harvest time				
Perlka 150 kg N ha^{-1} without weeding	164	142	180	162
Treatment without N fertilization and weed control	284	271	304	286

Table 5

Effect of different nitrogen fertilization on weight of weeds (g m^{-2})

Type and dose of fertilizer	Year			Mean
	2009	2010	2011	
4 week after planting				
Ammonium nitrate 150 kg N ha^{-1}	368	394	385	382
Ammonium nitrate 100+50 kg N ha^{-1}	348	364	355	356
Entec 26 150 kg N ha^{-1}	380	392	376	383
Entec 26 100+50 kg N ha^{-1}	340	354	349	348
Perlka 150 kg N ha^{-1}	145	135	125	135
Mean	298	309	301	303
At harvest time				
Perlka 150 kg N ha^{-1} without weeding	650	509	620	593
Treatment without N fertilization and weed control	1 719	1 620	1 842	1727

nitrates in kohlrabi fertilized with the same source of nitrogen. A relatively high content of nitrates in cabbage fertilized with Entec 26 was probably due to that fact that most nitrogen occurred in the form stabilized by DMPP ammonium and less prone to leaching than from other N sources. For this reason, in early spring season characterized by heavy precipitation, the uptake of this nutrient and the NO_3-N content in plants may be substantial higher. This was especially evident in 2011, when in April and May, i.e. immediately after planting, there were abundant rainfalls. The content of dry matter, vitamin C and sugars was unaffected by calcium cyanamide.

Calcium cyanamide was the first artificial nitrogen fertilizer manufactured industrially, but because of some difficulties with its use in the powder form, its production in Poland was stopped in 1960s. Now, its granular formulation produced mostly by AlzChem, Bavaria, (Germany) gains more interest as a slow-release fertilizer, quite an efficient herbicide for weed control and a beneficial agent improving soil chemical properties by enhancing soil pH level. Its preplant application may eliminate the need of herbicide use for weed control in cabbage as well as the use of fungicides against clubroot (*Plasmodiophora brassicae*), the most dangerous disease of this species. A high success rate of calcium cyanamide in control of clubroot, on a comparable level to fluazinam (Altima 500 SC), was proven by Klasse (1996) and Robak and Gidelska (2009). The application of this fertilizer is associated with a low risk of nitrate leaching and stimulation of the natural diversity and population size of soil microbes (Dixon 1984)

Taking into account the results of our studies and many data from the literature, it can be concluded that calcium cyanamide is a beneficial source of nitrogen for plants, friendly to the environment owing to reduced losses of this nutrient from soil, and a successful weed and soil born disease control substance in cabbage cultivation.

CONCLUSIONS

1. White head cabbage grown for early harvest in the spring showed high response to nitrogen fertilization, which – when applied at the dose of 150 kg N ha^{-1} – assured a high level of marketable yield, irrespectively of the form and method of its application.

2. Split application of ammonium nitrate or Entec 26 appeared to did not improve the yield volume or the nutritional value of cabbage above the level achieved by a single N dose supplied prior to planting.

3. On heavy clay soil with an adequate moisture level throughout the growing season, Entec 26, a nitrogen fertilizer containing a DMPP nitrification inhibitor, was as valuable source of nitrogen as commonly used ammonium nitrate.

4. Calcium cyanamide produced the highest marketable yield of cabbage with a significantly lower content of nitrates. The best advantage of this N source is its high efficiency in reducing weed infestation, which eliminates the need to use chemical or mechanical methods of weed control.

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