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EFFICIENCY OF SLOW-ACTING FERTILIZER IN THE INTEGRATED CULTIVATION OF CHINESE CABBAGE

EFEKTYWNOŚĆ NAWOZU WOLNODZIAŁAJĄCEGO W INTEGROWANEJ UPRAWIE KAPUSTY PEKIŃSKIEJ

Abstract: The study aimed to assess the suitability of slow-acting fertilizer in cultivation of Chinese cabbage in the integrated production system. The assumed objective was realized on the basis of a strict field experiment set up on the soil with granulometric composition of medium loam. The test plant was Chinese cabbage (*Brassica rapa* L.), 'Parkin F1' cv. The experiment was set up on 17.08.2011 and the plants were harvested on 08.10.2011. The experimental factor was diversified fertilization. The cultivation and protection of the plants were conducted on the basis of methodology of Chinese cabbage integrated production approved by the Main Inspector for Plant Protection and Seed Science. Traditional fertilizers (triple superphosphate, potassium salt and ammonium nitrate) and NPKCaMg (18-05-10-4-2) multi-component fertilizer with nutrient slow-release were applied. The experiment comprised 8 fertilization variants and the control treatment. Doses of phosphorus and potassium, meeting the plants requirements at assumed yield amount, were applied in all fertilization variants. Nitrogen fertilization on subsequent objects differed both with the form and quantity of applied element. On the basis of the results obtained in conducted experiments, the indices showing nitrogen fertilization efficiency were computed: agronomic efficiency, partial factor productivity, physiological efficiency, nitrogen recovery efficiency and removal efficiency.

Fertilization significantly modified the quantity of obtained yield. On the control, without mineral fertilization, the crop yield was 44.22 $Mg \cdot ha^{-1}$. The largest yield, 120.7 $Mg \cdot ha^{-1}$, was obtained on the object with an admixture of 400 kg of slow-acting fertilizer, 89 kg of triple superphosphate and 177 kg of potassium salt. The best optimal values of fertilization efficiency were obtained in the objects where 400 and 500 $kg \cdot ha^{-1}$ of slow-acting fertilizer and full doses of phosphorus and potassium were applied. Computed indices of fertilization efficiency indicate that optimization of fertilization using slow-acting fertilizer, particularly in conditions of intensive cultivation, may improve fertilization efficiency several-fold in comparison with integrated production methods using traditional fertilizers. Results of conducted experiments show that optimization of fertilization in conditions of intensive production may enhance fertilizer nitrogen uptake by 50 % at maintained high crop yields, which greatly improves economic effectiveness of production and reduces the amount of biogens dispersed in the environment.

Keywords: Chinese cabbage, integrated production, slow-acting fertilizer, fertilization efficiency

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Introduction

Integrated production (IP) is the food quality system which bases on sustainable use of the environmental resources, energy and means of production to generate good quality yields at maintained profitability of production. The idea of integrated production emphasizes the environmental and health aspects in agricultural production. The environmental benefits, which may be reached through implementation of integrated production are associated with reducing the amount of xenobiotics supplied to the environment through a rational plant protection based in the first place on agrotechnical and biological methods. According to IP assumptions, the use of pesticides should be preceded by a thorough monitoring of the cultivated plants but also attempts should be made to use in the first place agrotechnical and biological methods for plant protection [1]. In the situation when the full knowledge in the field of pest biology and conditions of pathogen expansion in specified plantations using biological methods is applied, the results comparable with the systems using traditional plant protection may be obtained [1, 2]. Both the quantity of pesticides used and the date of their application are important, as well as the selection of an appropriate assortment of plant protection means. Optimization of plant protection may result in a diminishing of eco-toxicological effect of agriculture on the environment and consumers, as pointed to by many researchers dealing with this problem [4–6]. However, implementing plant protection in compliance with IP principles is problematic due to insufficient knowledge of producers about biological and environmental aspects of agronomic production and a lack of universally used technologies of production [7]. A necessity to employ a highly qualified staff responsible for plant protection, high labour outlays and greater risk of plantation destruction by agrophages, discourage producers from introducing integrated production [8]. Another problem preventing an efficient realization of integrated production is the system of sustainable nutrient management. Fertilization plays an important role in crop production because it shapes the quantity and quality of yield, affects physical, biological and physicochemical soil properties, influences quality of surface and groundwater and the air quality. From the producer's point of view, fertilization and plant protection are crucial factors in price formation. Too high or too low doses of components but also wrong technologies of fertilization (techniques and dates of fertilizer application) negatively affect the environment, the quantity and quality of yield [9]. Increase in the efficiency of plant irrigation is also an important aspect of integrated plant production [10]. Application of irrigation, despite greater energy and environmental outlays connected with the exploitation of water resources, often produces positive results through improving fertilization efficiency and use of soil productive potential. Improvement of the efficiency of fertilization and irrigation has been currently one of the priorities of agricultural sciences [11]. In the extensive agriculture, owing to simple techniques, crop yielding may be increased even by several dozen percent at low outlays of labour and means of production [12]. Improving fertilization efficiency in modern agriculture is much more difficult due to efficient methods of production already in use. However, improvement of fertilizer components utilization by several percent is profitable in the global scale [13, 14], therefore contemporary agriculture must be equipped with the technologies making use of the recent scientific achievements [15]. Implementing integrated production, despite the benefits resulting from the idea behind it, is risky at the present stage of knowledge and experiments because of a danger of destroying crops by pests or diseases or a hazard of plant malnourishment, mainly with nitrogen. These hazards result from inadequate knowledge and mistakes, which may be made during production process. Limited use of pesticides requires their more precise application, which is connected with a necessity of choosing the optimal date of their application and implementing phytosanitary crop rotations, which are usually troublesome from the producer's point of view. Effective application of pesticides may be associated with a necessary ongoing counselling in this respect, which raises the costs of production. The only effective way of implementing the principles of integrated agriculture is convincing farmers about a possible improvement of production owing to the application of methods in compliance with the principles of sustainable agriculture [16]. Implementing quality systems in a primary production is connected with necessary costs which must be borne by the society, therefore the strategic objective should be convincing consumers about the necessity of bearing costs of environment-friendly technologies implementation. Carlsson et al [17] point to the non-economic aspects of rationalization of agronomic production.

For many producers moral and social aspects are important. Farmers implementing integrated production systems achieve a higher social status on local markets and win greater confidence of consumers. Educational activities undertaken by non-governmental organization caused that integrated production is the food quality system winning increasingly greater confidence among consumers, whereas IP quality mark is more desired. In compliance with The Directive of the European Parliament and the Council of 21 October, 2009 no. 2009/128/WE [1], farmers are obliged to implement plant protection according to the principles of integrated production from 1.01.2014.

Agricultural production is to various degree affected by the soil properties, water availability in individual periods of vegetation and the weather conditions [18, 19]. A proper approach to agricultural production should be based on making decision about fertilization, plant protection or agrotechnology basing on the results of plantation monitoring. Formulating and unification of the principles of integrated production is difficult because of changeability of soil conditions depending on the region of production and climatic conditions in respective years. Because the efficiency of widely understood agrotechnology to a great extent depends on the temperature and water availability, cultivation technologies should be developed based on a thorough analysis of the atmospheric and soil conditions, which on the same time do not require a costly equipment or specialist knowledge.

The aim of presented investigations was determining the usability of a slow-acting fertilizer for the optimisation of Chinese cabbage production efficiency under conditions of integrated production. Efficiency of nitrogen fertilization was assessed on the basis of the following indices of fertilization efficiency: agronomic efficiency, physiological efficiency, partial factor productivity, efficiency of nitrogen recovery and efficiency of nitrogen removal [20]. The indices showing fertilization efficiency provide plenty of information about the environmental and productive aspects of nitrogen fertilization.

Material and methods

The field experiment was set up using randomised block method, on the soil with granulometric composition of medium loam; its properties were shown in Table 1.

Table 1

Selected properties of soil used for the experiments [mg · kg^{-1}]

pH in H_2O	pH in KCl	N_{tot}	C_{org}	N_{min}	P	K	Mg	Ca
		[g · kg^{-1}]		[mg · kg^{-1}]				
7.01	6.65	3.14	46.5	366	147.8	459.5	199.4	1350

The test plant was Chinese cabbage (*Brassica rapa* L.), 'Parkin F1' cv. The forecrop for the Chinese cabbage was early potato. Organic fertilization with 35 Mg FYM · ha^{-1} was applied under the forecrop in autumn 2010. A full dose of mineral fertilization was applied under potatoes. The experiment was set up on 17.08.2011. The experimental factor was diversified fertilization. The experiment comprised the control and 8 fertilizer treatments in four replications, according to the design presented in Table 2.

Table 2

Experiment design

Object number	Fertilizer quantity				Component dose		
	Slow acting fertilizer NPKCaMg (18-05-10-4-2)	Ammonium nitrate	Triple superphosphate	Potassium salt	N	P_2O_5	K_2O
	[kg · ha^{-1}]				[kg · ha^{-1}]		
Control	0	—	—	—	—	—	—
1	200	—	108	213	36	60	150
2	400	—	89	177	72	60	150
3	500	—	76	158	90	60	150
4	600	—	65	140	108	60	150
5	800	—	43	103	144	60	150
6	—	150	130	250	50	60	150
7	—	225	130	250	100	60	150
8	—	300	130	250	150	60	150

A slow-acting multi component fertilizer NPKCaMg (18-05-10-4-2), ammonium nitrate, triple superphosphate and 60 % potassium salt were used for the experiment. The slow-acting fertilizer was applied in points under each plant during planting of seedlings prepared in cell VEFL trays. Phosphorus and potassium fertilizers were wholly used pre-sowing, whereas ammonium nitrate was applied at two terms: 60 % of nitrogen dose before and 40 % after the plants planting. The date of top dressing was selected on the basis of observations of meteorological conditions and plant condition monitoring. The plants were cultivated at the row spacing of 50 × 28 cm. Chinese cabbage was harvested on 08.10.2011.

Plants were cultivated and protected in compliance with the Methodology of integrated production of Chinese cabbage by art. 5, item 2 of the Act on plant protection of 18 December 2003, uniform text [21] approved by the Main Inspector for Plant Health and Seeds [22].

Production and technical documentation was kept for each fertilization variant, in compliance with the regulations of the appropriate legislation [23]. The plants were watered to the optimum moisture content in order to eliminate the effect of water stress on the experiment result.

Prior to the experiment outset, analyses of physiochemical and chemical properties were conducted for the soil on which the experiment was located. Soil pH, granulometric composition, organic matter content, mineral nitrogen and Kjeldahl's nitrogen content, available forms of P, K, Mg, Ca and Na contents and microelement content were assessed in the soil.

Results and discussion

In the integrated cultivation of brassica vegetables all doses of organic and mineral fertilizers are determined on the basis of fertilizer needs resulting from the expected crop yield, the kind of soil, its abundance in nutrients and position in a crop rotation. Particular attention is paid to the use of organic fertilizers as the basic source of soil humus and nutrients for plants. At a low level of organic fertilization there may be problems with a necessary application of larger doses of mineral fertilizers, which poses a hazard of a occasionally higher supply of components for plants and higher soil salinization. It results in a greater amount of fertilizer components dispersed in the environment and their utilization by plants to a lower degree. The optimum content of nutrients for Chinese cabbage is 160–200 mg of mineral N, 90–105 mgP, 240–270 mgK and 80–100 mgMg per 1 kg of soil. Chinese cabbage requirements, *ie* the amount of components taken up with 10 Mg yield are: 20 kg nitrogen (N), 10 kg phosphorus (P_2O_5), 35 kg potassium (K_2O) and 3 kg magnesium (MgO) [22]. Plant nutrient requirements were computed for the assumed yield of 100 $Mg \cdot ha^{-1}$, as: 160 kgN, 36 kgP, 270 kgK and 21 $kgMg \cdot ha^{-1}$. Fertilizer needs were calculated on the basis of the content of available element forms in soil and nutrient needs of plants, with regards to the history of the field, following the methodology of Chinese cabbage integrated production system [22]. The fertilizer needs were determined on the level of 100 kgN, 60 kgP_2O_5 and 150 $kgK_2O \cdot ha^{-1}$. While designing the fertilization system a negative balance of the main fertilizer components was assumed due to a high content of their available forms in soil (Table 1). The fertilizers used for the experiment meet the standards stated in the Directive of the European Parliament and the Council of 24 November 1997 [24].

The doses of phosphorus and potassium applied in all variants of the conducted experiment corresponded to the fertilizer needs calculated according to the methodology of integrated production, while individual objects differed with the form of applied fertilization. In case of nitrogen fertilization the variable factor was the form and dose of this element.

The yield of Chinese cabbage aboveground parts obtained on the control was on the level of 44.22 Mg · ha^{-1} (Fig. 1).

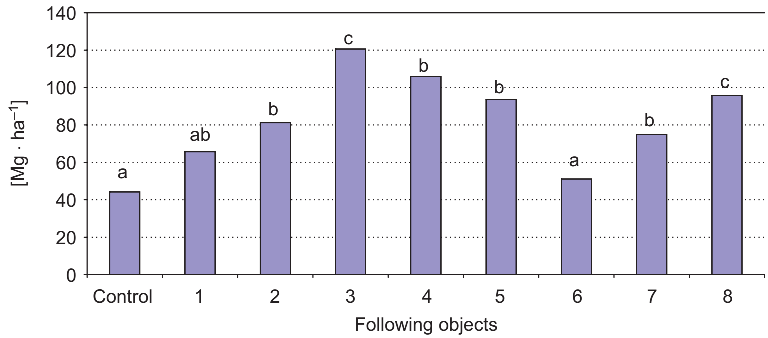

Fig. 1. The yield of Chinese cabbage aboveground parts in the successive objects of experiment

Fertilization with 200 kg of slow-acting fertilizer per 1 hectare and application of a full dose of phosphorus and potassium led to an increase in yield by over 20 Mg · ha^{-1}. The biggest yield of 120.7 Mg · ha^{-1} was obtained in the 3rd fertilization variant in which 500 kg of slow-acting fertilizer was applied with a complementary phosphorus and potassium treatment. Further increasing the amount of slow-acting fertilizer (objects 4 and 5) caused a decline in the crop yield. The effect of decline in yields might have been connected with worsening of growth conditions caused by a large quantity of fertilizer applied immediately under the root. It results in increased salinization of the soil solution in the root zone, which always affects negatively plant growth [25]. Nitrogen fertilization with ammonium nitrate (objects 6–8) influenced the crop yield of Chinese cabbage to a lesser extent, however statistically significant differences were observed between the objects fertilized with growing nitrogen doses applied as ammonium nitrate.

The way of fertilizer application is crucially important for achieving the assumed productive objectives [12]. The use of nitrogen in contemporary farming systems is insufficient and methods of fertilizer efficiency improvement should be implemented, both through the use of more specialist fertilizers and fertilizing technologies [26, 27]. Efficiency of nitrogen recovery in the individual fertilization variants ranged from 13.29 to 130 % (Fig. 2).

In the variant with three first levels of fertilization the highest efficiency of nitrogen recovery was observed. The reason was high soil abundance in available nitrogen

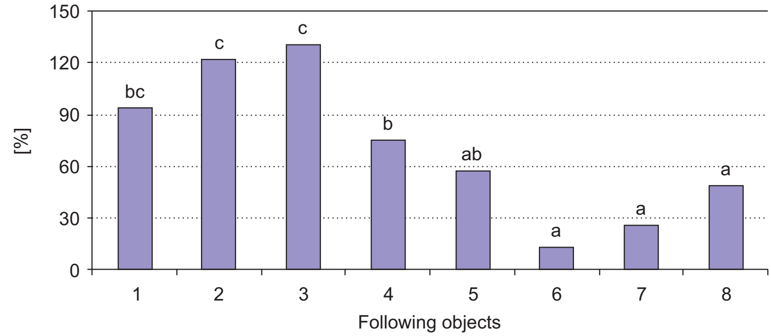

Fig. 2. The values of recovery efficiency in the successive variants of fertilization

compounds. The highest value of this parameter was noted in the 3rd experimental variant in which the slow-acting fertilizer was applied in the amount of 400 kg · ha^{-1} and supplementary fertilization with phosphorus and potassium. Treatment with ammonium nitrate did not have any marked effect on the efficiency of nitrogen recovery. In ammonium nitrate treatments (objects 6–8) value of this parameter was the lowest, ranging from 13.29 to 49.26 %.

Recovery efficiency is an index of the uptake of nitrogen supplied to the soil ecosystem with fertilizers. Generally, the higher value of this index, the more efficient fertilization. While interpreting the value of recovery coefficient one should consider also the crop yield. At very low fertilization level, value of nitrogen recovery coefficient may be high, even above 100 %, yet the obtained yield will be small, not corresponding with productive potential of the site. In such case production per area unit will not be effective. Under regular conditions this parameter value ranges from 30 to 50 %. At low level of fertilization and high nitrogen contents in soil it may be from 50 to 80 % [20]. Cassman et al [28] report that the efficiency of nitrogen removal on farms producing wheat, rice and corn in Asia and the US ranged from 18–49 %, depending on farming system. The authors point to a significant effect of the source of nitrogen applied in mineral fertilizers. The soil on which the experiment was set up revealed a high content of mineral nitrogen, therefore high value of recovery coefficient is advantageous from the environmental point of view.

Partial factor productivity determines the yield obtained following the application of 1 kg of nitrogen as fertilizer. In Author's own investigations the factor expressed in the yield of fresh mass ranged from 650 to 1825 kg · kg^{-1} of applied N (Fig. 3). Partial factor productivity in conversion to dry weight of yield was from 22.91 to 66.63 kg · kg^{-1} N.

The highest value of this parameter (80.83 kg · kg^{-1} N) was registered in the object which received the smallest dose of slow-acting fertilizer, 200 kg (object 1). Dua et al [29] reported the value of this parameter for potato production in India in 1968–2000 ranging from 111 to 428 kg · kg^{-1} N, however at the beginning of the investigations period it was about 30 % lower in comparison with the results from the 90-ties of the

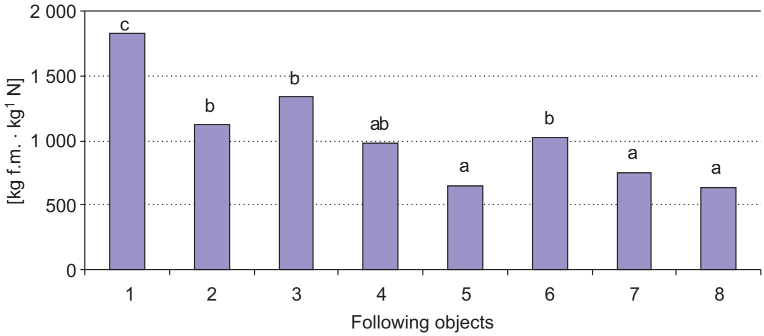

Fig. 3. The values of partial factor productivity in the successive variants of fertilization

20th century. The same authors point to a negative correlation between the value of partial factor productivity and fertilization amount.

Cassman et al [28] indicate a significant relationship between the quantity of applied fertilizer and the value of partial factor productivity. In farming systems using small doses of fertilizers, value of this coefficient is generally high, which does not evidence a high efficiency. On the basis of the analysis of 2000 farms the authors state that in 1965–2000 partial factor productivity calculated for corn in the US increased by about 15 %, but at the same time, average yield of this crop per hectare increased by over 100 %. Assessment of agronomic efficiency based on the analysis of partial factor productivity should be always connected with the obtained yield. Partial factor productivity is the most important index, because it considers the efficiency of nutrient utilization, which translates into profitability of production [30]. The most frequent values of this parameter in traditional farming systems in conversion to dry mass range from 40 to 80 kg $\cdot$ kg^{-1} N [20]. Values exceeding 60 kg d.m. $\cdot$ kg^{-1} N are noted in well managed systems, at low nitrogen concentrations in soil.

Agronomic efficiency is an index describing increase in the crop yield after the application of 1 kg of nitrogen fertilizer. Its value best shows the efficiency of farming systems. With development of agriculture, the value of this parameter increases [31]. The value of agronomic efficiency for cereal production in developing countries, in conversion to yield dry mass, ranges from 10 to 30 kg $\cdot$ kg^{-1} of fertilizer [32]. In the Author's own investigations, value of agronomic efficiency in the individual variants of the experiment, expressed in Chinese cabbage dry weight, ranged from 6.16 to 35.92 kg $\cdot$ kg^{-1} of fertilizer (Fig. 4). Significantly lower value of this parameter was registered in the object receiving traditional fertilization in the amount of 50 kg N as ammonium nitrate and full doses of phosphorus and potassium (object 6).

The highest value of this parameter was obtained in variant 3, where 500 kg $\cdot$ ha^{-1} of slow-acting fertilizer was applied. In general, in the objects receiving this fertilizer, except its highest dose, significantly higher values of agronomic efficiency were noted in comparison with traditional treatment with ammonium nitrate. Point application of slow-acting fertilizer caused a considerable increase in the yield of experimental crops. When corresponding doses were applied as ammonium nitrate, much lower yields were

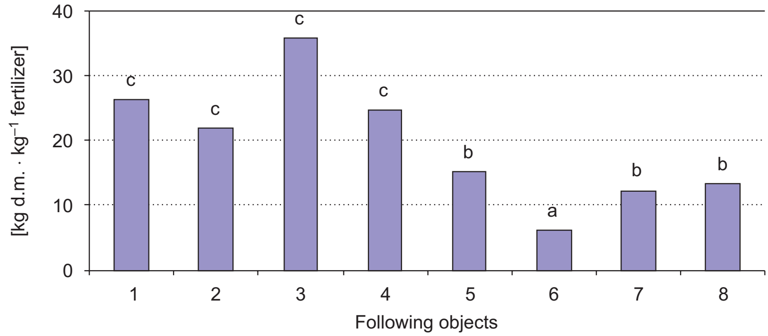

Fig. 4. The values of agronomic efficiency in the successive variants of fertilization

produced. These results indicate a better efficiency of fertilization using the slow-acting fertilizer under conditions of crop cultivation in the soils with very high nutrient content.

A fuller view of fertilization efficiency will be available after several years of fertilization using this type of fertilizers. Applied point fertilization caused a better utilization of nitrogen from the soil resources, which is an important factor improving economic effectiveness of production and reducing a negative environmental impact of production [33]. Helander and Delin [34] state that the content of nitrogen available forms in soil after plant harvesting should not exceed 30 kg $\cdot$ ha^{-1}. If available nitrogen concentration in soil after crop harvesting is below 30 kg $\cdot$ ha^{-1}, there is hardly any hazard of this element leaching into the soil profile or to the surface waters. Small amount of nitrogen in soil after crop harvesting evidences a proper use of this element applied in fertilizers.

Physiological efficiency shows the increase in agronomic production per 1 kg of nutrient absorbed by plants in result of applied fertilization. Its value in the highest degree depends on plant genotype and environmental conditions, but also on the strategy of fertilization management. Therefore, it is usually used for an assessment of farming systems efficiency [28]. Its low values indicate occurrence of a stressor for plants (nutrient deficit, drought, thermal stress, occurrence of a disease or pests). Physiological efficiency in the subsequent experimental variants ranged from 16.43 to 36.79 kg d.m. $\cdot$ kg^{-1} of nitrogen taken up by plants from the applied fertilizers (Fig. 5).

Significantly the highest value of physiological efficiency was obtained in the 7th variant of the experiment in which traditional fertilization was applied with a medium dose of nitrogen as ammonium nitrate. A decrease in this coefficient value was observed after the application of 50 kgN as ammonium nitrate. The environmental conditions were the same in all experimental variants, therefore the registered differences result from different fertilization in the respective objects. The lowest physiological efficiency was observed in the object where 400 kg of slow-acting fertilizer was applied together with the full dose of phosphorus and potassium. The most usual values of this parameter are 40–60 kg d.m. $\cdot$ kg^{-1} of applied N. In well managed

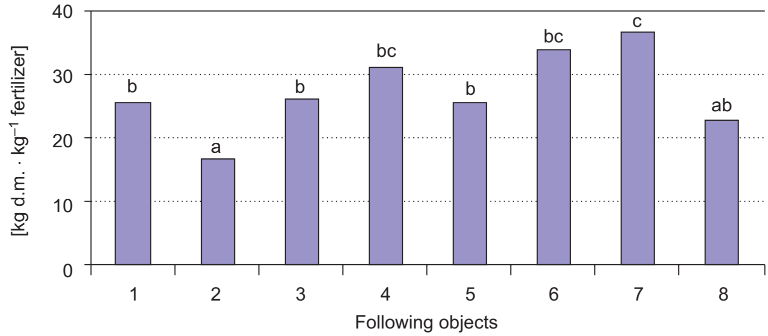

Fig. 5. The values of physiological efficiency in the successive variants of fertilization

systems under good conditions of plant growth and development, value of this parameter exceeds 50 kg d.m. · kg^{-1} N [ISA 2007].

Removal efficiency is an important indicator determining a potential environmental impact of agriculture. It informs which part of the component applied in fertilization is removed from the ecosystem with yield. At removal coefficient equaling 1, the quantity of nitrogen absorbed with yield is equal to its amount applied in mineral fertilizers. It is particularly important in case of nitrogen fertilization because it is the element poorly bound to soil sorption complex, particularly after the transformation into nitrate form. Mineral nitrogen which was not incorporated into the biomass during vegetation season is to a great extent dispersed in the environment, which negatively affects all of its elements but does not constitute this element reserve for the subsequent year. A very high nitrogen removal efficiency is encountered in the systems showing this element deficit. Low values of this index are characteristic for the cultivation in which plant growth limiting factors appeared, such as nutrient deficiency, drought, thermal stress, diseases or pests. The most frequently noted values of this parameter fluctuate from 0.3 to 0.9, whereas the values from 0.55 to 0.65 kg · kg^{-1} are regarded as optimal [20]. In the presented experiment the values of removal efficiency ranged narrowly between 0.93 and 2.77 kg · kg^{-1} (Fig. 6).

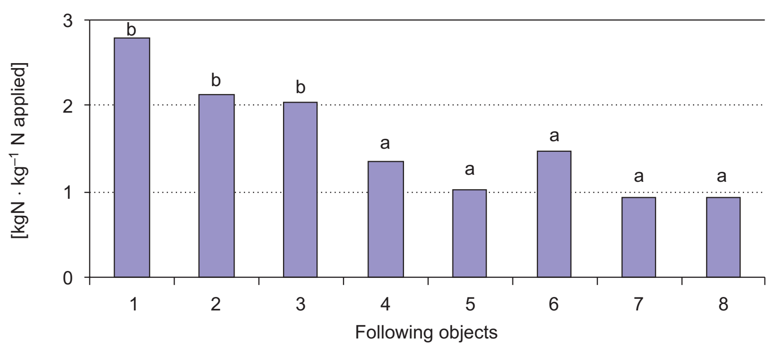

Fig. 6. The values of removal efficiency in the successive variants of fertilization [kg · kg^{-1} N]

The highest value of removal efficiency was registered in object 1, where 200 kg · ha^{-1} of the slow-acting fertilizer was applied. In objects 2 and 3 the values of this parameter were similar. A significantly lower nitrogen removal efficiency was noted in the other fertilizer variants. Values of nitrogen removal efficiency registered in all objects are very high and evidence a negative nitrogen balance. However, on the basis of the plant organoleptic and chemical analysis as well as their crop yield, no deficiency of this element was found. Very high nitrogen content in soil on which the experiment was conducted, was the cause of reduced nitrogen fertilization. It led to this element utilization by plants from the soil reserves and depletion of its reserves in soil and dispersion in the environment.

All quality systems in the primary agronomic production are implemented in the first place in vegetable and fruit growing because of a considerable impact of these branches of production on the environment, as well as bigger than in case of agronomic plants, hazard of obtaining product with elevated content of xenobiotics [35]. Fruit and vegetables are destined for immediate consumption to a greater extent than the other plants, therefore implementing quality systems in their production processes has a marketing importance. Rationalization in agriculture requires numerous experiments and observations to find solutions and developing a technology, which will make possible realization of integrated production.

Conclusions

1. The effect of applied fertilization on the obtained crop yield of Chinese cabbage was observed under conditions of the conducted experiment.

2. The most advantageous agronomic efficiency and nitrogen recovery efficiency were obtained in the combination of 500 kg · ha^{-1} of slow-acting fertilizer with supplementary traditional PK fertilizers. Generally higher values of these indices, in comparison with fertilization using exclusively traditional fertilizers, were observed after the application of a slow-acting fertilizer and traditional PK ones.

3. The highest nitrogen physiological efficiency was noted when traditional treatment with ammonium nitrate (100 kgN · ha^{-1}) was applied.

4. Application of fertilization technology based on the proportion of a slow-acting multi component fertilizer may improve efficiency of agronomic production.

References

[1] Dyrektywa Parlamentu Europejskiego i Rady z dnia 21 października 2009 r. 2009/128/WE ustanawiająca ramy wspólnotowego działania na rzecz zrównoważonego stosowania pestycydów.

[2] Perdikis D, Fantinou A, Lykouressis D. Enhancing pest control in annual crops by conservation of predatory Heteroptera. Biol Control. 2011; 59(1):13-21. DOI: 10.1016/j.biocontrol.2011.03.014.

[3] Tuomisto HL, Hodge ID, Riordan P, Macdonald DW. Exploring a safe operating approach to weighting in life cycle impact assessment e a case study of organic, conventional and integrated farming systems. J Cleaner Product. 2012;37:147-153. DOI: 10.1016/j.jclepro.2012.06.025.

[4] Jurasie R, Sanjuán N. Life cycle toxicity assessment of pesticides used in integrated and organic production of oranges in the Comunidad Valenciana, Spain. Chemosphere. 2011;82(7):956-962. DOI: 10.1016/j.chemosphere.2010.10.081.

[5] Danis TG, Karagiozoglou DT, Tsakiris IN, Alegakis AK, Tsatsakis AM. Evaluation of pesticides residues in Greek peaches during 2002–2007 after the implementation of integrated crop management. Food Chem. 2011;126(1):97-103. DOI: 10.1016/j.foodchem.2010.10.083.

[6] Shahpoury P., Hageman KJ, Matthaei CD, Francis S, Magbanua FS. Chlorinated pesticides in stream sediments from organic, integrated and conventional farms. Environ Pollut. 2013;181:219-225. DOI: 10.1016/j.envpol.2013.06.035.

[7] Morris C, Winter M. Integrated farming systems: the third way for European agriculture? Land Use Policy. 1999;16:193-205. DOI: 10.1016/S0264-8377(99)00020-4.

[8] Deike S, Pallutt B, Christen O. Investigations on the energy efficiency of organic and integrated farming with specific emphasis on pesticide use intensity. Europ J Agron. 2008;28:461-470. DOI: 10.1016/j.eja.2007.11.009.

[9] Pypers P, Sanginga J-M, Kasereka B, Walangululu M, Vanlauwe B. Increased productivity through integrated soil fertility management in cassava-legume intercropping systems in the highlands of Sud-Kivu, DR Congo. Field Crops Res. 2011;120(1):76-85. DOI: 10.1016/j.fcr.2010.09.004.

[10] Srivastava RC, Singhandhupe RB, Mohanty RK. Integrated farming approach for runoff recycling systems in humid plateau areas of eastern India. Agricult Water Manage. 2004;64:197-212. DOI: 10.1016/S0378-3774(03)00208-7.

[11] Bailey AP, Basford WD, Penlington N, Park JR, Keatinge JDH, Rehman T. A comparison of energy use in conventional and integrated arable farming systems in the UK. Agr Ecosyst Environ. 2003;97(1-3):241-253. DOI: 10.1016/S0167-8809(03)00115-4.

[12] Mucheru-Muna M, Pypers P, Mugendi D, Kung'u J, Mugwe J, Merckx R, Vanlauwe B. A staggered maize–legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. Field Crop Res. 2010;115:132-139. DOI: 10.1016/j.fcr.2009.10.013.

[13] Oenema O, Witzke HP, Klimont Z, Lesschen JP, Velthof GL. Integrated assessment of promising measures to decrease nitrogen losses from agriculture in EU-27. Agricult, Ecosyst Environ. 2009;133(3-4):280-288. DOI: 10.1016/j.agee.2009.04.025.

[14] He J, Wang J, He D, Dong J, Wang Y. The design and implementation of an integrated optimal fertilization decision support system. Math Comp Modell. 2011;54(3-4):1167-1174. DOI: 10.1016/j.mcm.2010.11.050.

[15] Li D. Preface to mathematical and computer modeling in agriculture. Mathematical and computer modelling. Folia Pomer Univ Technol Stetin. 2011;54(3-4):859-860.

[16] Mzoughi N. Farmers adoption of integrated crop protection and organic farming: Do moral and social concerns matter? Ecolog Econom. 2011;70:1536-1545. DOI: 10.1016/j.ecolecon.2011.03.016.

[17] Carlsson F, Khanh Nam P, Linde-Rahr M, Martinsson P. Are Vietnamese farmers concerned with their relative position in society? J Develop Stud. 2007;43(7):1177-1188. DOI: 10.1080/00220380701526303.

[18] Nendel C. Evaluation of Best Management Practices for N fertilization in regional field vegetable production with a small-scale simulation model. Europ J Agron. 2009;30(2):110-118. DOI: 10.1016/j.eja.2008.08.003.

[19] Sun Y, Ma J, Sun Y, Xu H, Yang Z, Liu S, Jia X, Zheng H. The effects of different water and nitrogen managements on yield and nitrogen use efficiency in hybrid rice of China. Field Crops Res. 2012;127(27):85-98.

[20] IFA. 2007. Sustainable management of the nitrogen cycle in agriculture and mitigation of reactive nitrogen side effects. Paris: International Fertilizer Industry Association; 2007;53 p.

[21] Ustawa z dnia 18 grudnia 2003 r. o ochronie roślin. DzU 2004, Nr 11, poz 94.

[22] Metodyka integrowanej produkcji kapusty pekińskiej. 2011. Zatwierdzona na podstawie art. 5, ust 3, pkt 2 Ustawy z dnia 18 grudnia 2003 r. o ochronie roślin (tekst jednolity DzU 2008 Nr 133, poz 849 ze zm) przez Głównego Inspektora Ochrony Roślin i Nasiennictwa, 33 p.

[23] Rozporządzenie Ministra Rolnictwa i Rozwoju Wsi w z dnia 8 kwietnia 2013 roku zmieniające Rozporządzenie w sprawie Integrowanej Produkcji. DzU 2013, poz 452.

[24] Dyrektywa Parlamentu Europejskiego i Rady z dnia 24 listopada 1997 roku. 76/116/EWG zmieniająca dyrektywy 76/116/EWG, 80/876/EWG, 89/284/EWG oraz 89/530/EWG w sprawie zbliżenia ustawodawstw Państw Członkowskich odnoszących się do nawozów.

[25] Ashraf M, Harris PJC. Potential biochemical indicators of salinity tolerance in plants. Plant Sci. 2004;166:3-16. DOI: 10.1016/j.plantsci.2003.10.024.

[26] Trenkel ME. Slow- and controlled release and stabilized fertilizers: An option for enhancing nutrient use efficiency in agriculture. Paris: International Fertilizer Industry Association; 2010;160 p.
[27] Sosnowski J. Wpływ użyźniacza glebowego na efektywność nawożenia azotem mieszanek Fesulolium Brauni z koniczyną łakową i lucerna mieszańcową. Folia Pomer Univ Technol Stetin. Agric, Aliment, Pisc, Zootech. 2012;295(22):43-52.
[28] Cassman KG, Dobermann AR, Walters DT. Agroecosystems, nitrogen-use efficiency, and nitrogen. J Human Environ. 2002;31(2): 132-140. DOI: http://dx.DOI.org/10.1579/0044-7447-31.2.132.
[29] Dua VK, Govindakrishnan PM, Lal SS, Khurana SMP. Partial Factor Productivity of Nitrogen in Potato. Better Crops. 2007;91(4):26-27.
[30] Aulakh MS, Manchanda JS, Garg AK, Kumar S, Dercon G, Nguyen M-L. Crop production and nutrient use efficiency of conservation agriculture for soybean-wheat rotation in the Indo-Gangetic Plains of Northwestern India. Soil Tillage Res. 2012;120:50-60. DOI: 10.1016/j.still.2011.11.001.
[31] Cui Z-L, Zhang FS, Chen X-P, Miao Y-X, Li J-L, Shi L-W, Xu J-F, Ye Y-L, Liu C-S, Yang Z-P, Zhang Q, Huang S-M, Bao D-J. On-farm estimation of indigenous nutrient supply for site-specific nitrogen management in the North China plain. Nutr Cycl Agroecosyst. 2008;81:37-47. DOI: 10.1007/s10705-007-9149-8.
[32] Dobermann A. Nutrient use efficiency, measurement and management. IFA International Workshop on Fertilizer Best Management Practices, 7–9 March 2007, Brussels, Belgium, International Fertilizer Industry Association.
[33] Chuan L, He P, Pampolino MF, Johnston AM, Jin J, Xu X, Zhao S, Qiu S, Zhou W. Establishing a scientific basis for fertilizer recommendations for wheat in China: Yield response and agronomic efficiency. Field Crops Res. 2013;140:1-8. DOI:10.1016/j.fcr.2012.09.020.
[34] Helander CA, Delin K. Evaluation of farming systems according to valuation indices developed within a European network on integrated and ecological arable farming systems. Europ J Agron. 2004;21:53-67. DOI: 10.1016/S1161-0301(03)00089-3.
[35] Musshoff O, Hirschauer N. Adoption of organic farming in Germany and Austria: an integrative dynamic investment perspective. Agricult Econom. 2008;39:135-145. DOI: 10.1111/j.1574-0862.2008.00321.x.

EFEKTYWNOŚĆ NAWOZU WOLNODZIAŁAJĄCEGO W INTEGROWANEJ UPRAWIE KAPUSTY PEKIŃSKIEJ

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Abstrakt: Celem pracy było określenie przydatności nawozu wolnodziałającego wykorzystywanego w uprawie kapusty pekińskiej w systemie integrowanej produkcji. Realizację założonego celu osiągnięto w oparciu o wyniki ścisłego doświadczenia polowego, założonego na glebie o składzie granulometrycznym gliny średniej. Rośliną testową była kapusta pekińska (*Brassica rapa* L.) odmiany 'Parkin F1'. Doświadczenie założono 17.08.2011 r. Rośliny zebrano 08.10.2011 r. Czynnikiem doświadczenia było zróżnicowane nawożenie. Uprawę oraz ochronę roślin prowadzono w oparciu o metodykę integrowanej produkcji kapusty pekińskiej zatwierdzonej przez Głównego Inspektora Ochrony Roślin i Nasiennictwa. W doświadczeniu zastosowano nawozy konwencjonalne (superfosfat potrójny, sól potasowa oraz saletra amonowa) oraz nawóz wieloskładnikowy NPKCaMg (18-05-10-4-2) o spowolnionym uwalnianiu składników pokarmowych. Doświadczenie obejmowało 8 wariantów nawożenia i obiekt kontrolny. We wszystkich wariantach nawożenia zastosowano dawki fosforu i potasu odpowiadające zapotrzebowaniu roślin przy założonej wielkości plonów. Nawożenie azotem w kolejnych obiektach różniło się zarówno formą, jak i ilością zastosowanego składnika. Na podstawie wyników przeprowadzonych doświadczeń obliczono wskaźniki obrazujące efektywność nawożenia azotem: efektywność agronomiczną, współczynnik produktywności, efektywność fizjologiczną, efektywność odzysku oraz efektywność usunięcia azotu.

Nawożenie w istotny sposób modyfikowało wielkość uzyskanego plonu. Plon roślin w obiekcie kontrolnym, bez nawożenia mineralnego, wynosił 44,22 Mg · ha^{-1}. Największy plon, wynoszący 120,7 Mg · ha^{-1} uzyskano w obiekcie z dodatkiem 400 kg nawozu wolnodziałającego, 89 kg superfosfatu potrójnego oraz 177 kg soli potasowej. Najbardziej optymalne wartości wskaźników efektywności nawożenia uzyskano w obiektach, w których zastosowano nawóz wolnodziałający w ilości 400 i 500 kg · ha^{-1} oraz pełne dawki fosforu i potasu. Obliczone wskaźniki efektywności nawożenia wskazują, że optymalizacja nawożenia z udziałem nawozu wolnodziałającego, szczególnie w warunkach intensywnej uprawy, może kilkakrotnie poprawić efektywność nawożenia w stosunku do integrowanych metod produkcji z wykorzystaniem nawozów konwencjonalnych. Wyniki przeprowadzonych badań wskazują, że optymalizacja nawożenia w warunkach intensywnej produkcji może zwiększyć pobieranie azotu zastosowanego w nawozach mineralnych o 50 % przy utrzymaniu wysokich plonów roślin, co znacznie poprawia efektywność ekonomiczną produkcji i zmniejsza ilość biogenów rozpraszanych w środowisku.

Słowa kluczowe: kapusta pekińska, integrowana produkcja, nawóz wolnodziałający, efektywność nawożenia