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Use of anhydrous ammonia in improving the nitrogen utilization efficiency in winter wheat plantings

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Aim. To study the specificities of the effect of anhydrous ammonia on the indices of soil fertility, yield and quality of winter wheat grain compared to granular nitrogen fertilizers in order to elaborate intensive production technologies. **Methods.** The content of mineral nitrogen in the soil was determined according to DSTU 4729-2007, the content of movable phosphorus and potassium forms − by Chirikov's method (DSTU 4115-2002). The abundance of the main ecological and trophic groups was registered after sowing the soil suspension on dense nutrient media. The concentration of total nitrogen, phosphorus, and potassium in plant samples was determined according to the measurement procedure 31-497058-019-2005. The quality indices of grain, i.e. protein and crude fiber content as well as general glassiness were determined using Inframatic 8600 NIR analyzer, Perten Instruments AB (Sweden). **Results.** The specificities of the effect of anhydrous ammonia on the indices of soil fertility, the use of nutrients from fertilizers and soil, the yield and quality of winter wheat grain were demonstrated. **Conclusions.** The advantages of anhydrous ammonia application prior to sowing compared to the use of ammonia nitrate, traditional for Ukrainian agriculture after the growing season, were established.

Keywords: anhydrous ammonia, ammonia nitrate, fertilizer elements, winter wheat, grain quality, yield.

INTRODUCTION

Recent years have witnessed ever growing anxiety of the world community about the global food safety which could be improved, firstly, via the crop production intensification and the implementation of technologies, ensuring the increase in the efficiency of resource management along with the minimization of the environmental effect [1].

Grain crops, which occupy half the arable area in the world, are attributed the central place in solving the food problem. They are remarkable "nitrogenphiles" as they use a considerable amount of nitrogen for their yield formation. In Ukraine traditional means of plant fertilizers are solid substances: ammonia nitrate, carbamide, ammonium sulfate, usually introduced in the dispersion. However, the utilization efficiency of nitrogen from the fertilizers by the crops in the world in general, and in Ukraine in particular, is rather low, not exceeding 33% [2]. Therefore, the improvement of utilization efficiency for nitrogen fertilizers is an important trend in increasing the yield and quality of grain products.

The known technological ways of diminishing nonproductive losses of nitrogen from fertilizers include the pelleting of granules with inert materials (sulfur, wax), the encapsulation with polymer coating (for instance, with aminoformaldehyde resin), the introduction of nitrogen to compounds with relatively low solubility or addition to the chelates [3–5]. The coating of

fertilizer granules with a thin film of low permeability allows prolonging the lifetime of fertilizers in soil considerably, decreasing their ability to become compressed and start absorbing water as well as solving the issue of fertilizer transportation in bulk.

At the same time one of the most promising solutions for the improvement of the system of fertilizing the winter wheat plantings with nitrogen is extending the areas of using the liquid nitrogen fertilizers, in particular, anhydrous ammonia. This will allow increasing the utilization efficiency of nitrogen from the soil and preventing the non-target losses of the mentioned element [6−8]. It is known that ammonium, into which ammonia transforms during the introduction into the soil, is fixed by soil collodions and is not washed out together with the infiltration moisture. It is assumed that the introduction of ammonia prior to sowing should provide for the sufficiency of the nitrogen amount for plants during the whole vegetation period.

Long-term experience of using anhydrous ammonium in the USA and Canada testifies to practical equipotency of its effect on the yield of agricultural crops compared to the granular nitrogen fertilizers [9, 10]. Its utilization is possible for all the agricultural crops, but the preference is given to winter wheat, sugar beet, corn and spring cereals. Unfortunately, there were scarce agrochemical studies of the specificities of this fertilizer impact in the ground and climatic conditions of Ukraine, and in practice it is usually used for corn, predominantly [11].

Thus, the aim of our study was to determine the specificities of the effect of anhydrous ammonium on the indices of soil fertility, yield and grain quality of winter wheat compared to the traditional granular nitrogen fertilizers.

MATERIALS AND METHODS

The study was conducted on the winter wheat plantings, Bohdan cultivar, during 2012–2013 vegetation period at the premises of the demonstrative and experimental field of Lokhvytsia division of PrivJSC Rise-Maksymko (Poltava Region), at podzolic medium-loam black soil. The plant-predecessor was grain maize. The scheme of experiment comprised primary cultivation of soil (two-disk plowing, 12 cm deep, and tillage, 20 cm deep) and the introduction of nitrogen fertilizers for the cultivation prior to sowing (anhydrous ammonia in the dose of N_{100} in 18 cm deep lines at 56 cm stepouts prior to sowing and ammonia nitrate in the dose of N_{100} dispersed after the vegetation period). Diammophos in the dose of 150 kg per ha was used as the degree of ground fertilization for the whole area of the experimental field. The area of the latter amounted to 120 square meters, the location was systematized into five repeats.

Soil samples were taken at the beginning and the end of the vegetation period in order to determine the effect of the anhydrous ammonia application on the fertility indices of the podzolic black soil. The content of mineral nitrogen in the soil was determined according to DSTU 4729-2007, the content of movable phosphorus and potassium forms − by Chirikov's method (DSTU 4115-2002).

The abundance of the main ecological trophic groups was registered after sowing the soil suspension on dense nutrient media.

The plant samples were studied for the content of total nitrogen, phosphorus and potassium in one batch (measurement procedure 31-497058-019-2005); the grain – for the content of protein, crude fiber and general glassiness, using Inframatic NIR analyzer 8600, Perten Instruments AB (Sweden).

RESULTS AND DISCUSSION

The prospects of nitrogen application in the form of anhydrous ammonia in the agriculture of the future seem to be evident. This technology is especially reasonable for large planting areas due to the possibility of complete mechanization of transportation and the introduction of fertilizers into the soil, which allows decreasing the expenses by 20−30 % compared to the utilization of their solid granular forms. Local disposition of nitrogen fertilizers below the soil surface promotes longer nitrogen retention and its more exhaustive consumption by plants. The decrease in the total amount of precipitation in spring and summer period, observed in all the regions of Ukraine in recent years, leads to the decrease in the efficiency of the surface fertilizers of winter wheat plantings. Thus, one-time introduction of anhydrous ammonia at a certain depth for the primary tillage may result in considerable increase in the efficiency of nitrogen utilization by winter wheat due to its better local availability and increased humidity of this soil layer.

The researchers from the USA and Canada who studied the effect of anhydrous ammonia on soil properties revealed negative changes in soil microbiocenosis, the acceleration of organic substance mineralization, the washing-out of nutrients from the soil layer, containing roots, and pH changes [9, 10]. According to our data

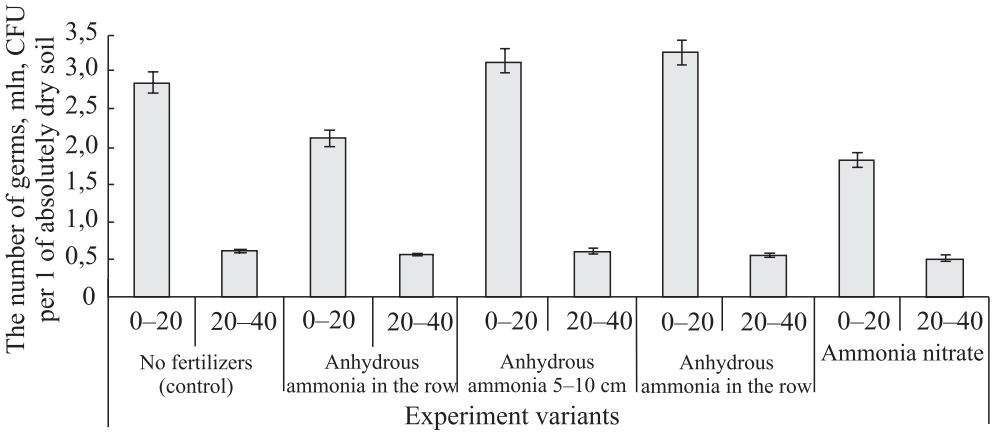

Fig. 1. The number of heterotrophic microorganisms after the end of the vegetation period of winter wheat in the tilth top soil (0–20 cm) and subsurface soil (20–40 cm)

the introduction of this fertilizer actually causes the changes in the microbiological activity and the nutrient regime, but in moderate doses it only promotes better realization of the efficient soil fertility.

Firstly, contrary to the introduction of ammonia nitrate in dispersion, the center of mineral nitrogen, which is in the ammonium form, gets developed in the zone of anhydrous ammonia introduction (during the restoration of spring vegetation the NH_4:NO_3 ratio is 1.7:1 whereas after the introduction of ammonia nitrate it is only 1:1.4). As a result, the introduction of anhydrous ammonia ensures higher content of mineral nitrogen in the tilth top soil until the end of winter wheat vegetation (Table 1) and its washing out from the soil profile in a lesser degree compared to the variant with ammonia nitrate [10].

It was established that there is no long-term negative after-effect of the introduced anhydrous ammonia on the activity of the main ecological and trophic groups of microorganisms. After the vegetation restoration in the top 20-cm layer, 8.7–13.2 million of colony-forming units (CFU) were detected in 1 g for the introduction of both investigated forms of nitrogen fertilizers, which is much higher compared to the variant with the non-fertilized ground (4.4 million/g). Due to the effect of NH_4 on the organic substance of soil there are better nutritional conditions for heterotrophic organisms which lead to the increase in their number even after the end of the vegetation period (Fig. 1).

In addition to the direct fertilizing effect, some authors [12, 13] note the increase in the content of soluble forms of phosphorus and potassium in the zone of ammonium introduction, but there are opposite opinions in the literature as well [14]. The results of our investigations demonstrate that after the introduction of anhydrous ammonia the amount of available phosphorus

Table 1. The content of nutrient elements in the tilth top podzolic black soil depending on the introduction of different forms of nitrogen fertilizers and primary tillage of soil

Experiment variant		Content of nutrient elements, mg/kg of soil					
		P_2O_5		K_2O		$NO_3 + NH_4$	
		Vegetation					
		Start	End	Start	End	Start	End
Control – tillage with no fertilizers		230.0	237.0	141.0	136.0	6.3	7.0
Two-disk plowing	Anhydrous ammonia	285.5	251.0	166.6	155.0	13.0	8.2
	Ammonia nitrate	279.0	261.9	151.5	148.0	44.2	6.5
Tillage	Anhydrous ammonia	284.0	249.8	154.5	140.0	15.5	11.0
	Ammonia nitrate	296.0	235.9	136.6	152.0	42.7	7.6
LSD_{05}		7.0	6.9	11.0	9.5	4.2	1.9

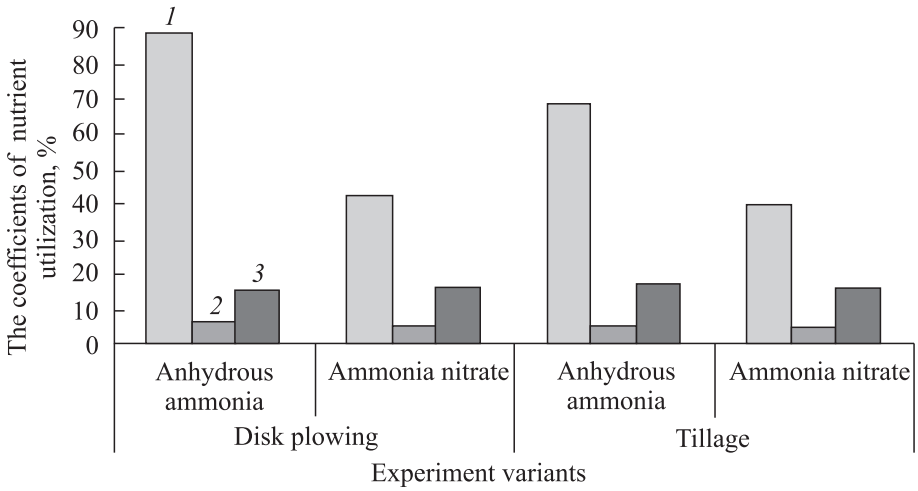

Fig. 2. The utilization of nutrient elements from fertilizers and soil depending on the form of nitrogen fertilizers: *1* – nitrogen from fertilizers; *2* – utilization of phosphorus from soil; *3* – utilization of potassium from soil

and potassium is actually increasing at the beginning of the vegetation period of winter wheat, but later this effect is not statistically reliable (Table 1). A possible reason for this fact may be soil acidification (pH from 5.2 to 5.0–4.8) and the increase in the concentration of water-soluble organic carbon.

The abovementioned specificities of the effect of anhydrous ammonia on soil have positive impact on phosphorus and potassium nutrition of winter wheat. The comparison of the application of ammonia nitrate and the variants with anhydrous ammonia demonstrated 1.3-fold higher coefficients of phosphorus and potassium utilization from the soil for the latter (Fig. 2).

The estimation of the coefficients of nitrogen utilization from fertilizers also testify to considerable advantage of the beneficial effect of nitrogen in the composition of liquid ammonia – it is 89.2–68.7 % depending on the primary tillage of soil; as for ammonia nitrate, the level of utilization of nitrogen therefrom by winter wheat plants does not exceed 40 %.

The results of winter wheat grain productivity demonstrate practical equipotency of both investigated forms of fertilizers on condition of disk tillage as the primary method and the preference to anhydrous ammonia on condition of tillage (Table 2).

After the introduction of 100 kg/ha of nitrogen in the form of liquid ammonia the yield excess and the cost recovery of 1 kg of the active substance was 1.5−1.9 times higher compared to ammonia nitrate. The application of nitrogen fertilizers increases grain

Table 2. The effect of different forms of nitrogen fertilizers and the primary method of soil cultivation on the yield and quality of winter wheat grain

Experiment variant		Yield, tons/ha	Control excess		Cost recovery of 1 kg of active substance with grain, kg	Grain quality index, %		
			tons/ha	%		Protein	Fiber	Glassines
Control – tillage with no fertilizers		4.38	–	–	–	14.2	30.2	38.1
Two-disk plowing	Anhydrous ammonia	5.18	0.80	18.3	8.0	15.8	33.7	42.1
	Ammonia nitrate	4.91	0.53	12.1	5.3	15.3	32.7	39.9
Tillage	Anhydrous ammonia	5.34	0.96	21.9	9.6	15.2	32.4	40.4
	Ammonia nitrate	4.88	0.50	11.4	5.0	15.6	33.3	39.8
LSD_{05}		0.45	–	–	–	–	–	–

Table 3. The effect of the primary introduction of different forms of nitrogen fertilizers on the removal of nutrients by winter wheat, kg/ha

Experiment variant		Removal by grain			Removal by chaff			Total removal		
		N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Control – tillage with no fertilizers		105	31	17	46	10	56	151	41	73
Two-disk plowing	Anhydrous ammonia	172	38	21	68	16	98	240	54	119
	Ammonia nitrate	135	32	19	58	13	81	193	45	100
Tillage	Anhydrous ammonia	147	39	22	73	15	102	220	54	124
	Ammonia nitrate	130	37	20	61	13	88	191	50	108

quality of winter wheat − its protein content increases by 1.0−1.6%. In addition, anhydrous ammonia promotes the increase in the general glassiness of grain. Similar results for fertilizing winter wheat with anhydrous ammonia were also obtained on the low-humic black soil in the Stavropol Territory, the Russian Federation [15].

In case of variants with anhydrous ammonia the increase in the productivity also demonstrated higher removal of nutrients compared to the control, amounting to 1.6 for nitrogen, 1.3 – for phosphorus, and 1.7 – for potassium, on average (Table 3).

Therefore, regardless of the stimulating effect of anhydrous ammonia pertaining to the utilization of phosphorus and potassium from the soil, it is insufficient to confine oneself only to this fertilizer or to introduce 100 kg/ha of ammonium nitrate phosphate fertilizer, which is typical for many farms. The application of high amounts of nitrogen introduction should presuppose the corresponding level of phosphorus and potassium nutrition of plants.

In addition, it should be noted that systematic application of residual acid-forming anhydrous ammonia leads to further acidification of soil, which may ultimately cause the decrease in crop productivity [7, 16]. This fact testifies to the relevance of using scientifically grounded approaches to determining optimal nitrogen doses, taking into consideration both economic efficiency and soil conservation and ecological requirements which is also proven by long-term experience of other countries [8, 9].

Conclusions. A promising approach of improving the system of nitrogen fertilizing for winter wheat plantings in Ukrainian conditions is the application of anhydrous ammonia during or prior to tillage at the depth of 14−18 cm, which allows increasing the efficiency of nitrogen utilization from the fertilizer and decreasing its non-target loss from the soil.

The application of anhydrous ammonia ensures increase in winter wheat productivity and in its quality indices compared to ammonia nitrate, traditional for Ukrainian agriculture, and is efficient in increasing the cost recovery for mineral nitrogen with the yield considerably.

Безводный аммиак в повышении эффективности использования азота посевами озимой пшеницы

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Цель. Для создания интенсивных технологий производства зерна озимой пшеницы исследовать особенности влияния безводного аммиака на показатели плодородия почвы, урожайность и качество зерна пшеницы озимой по сравнению с традиционными гранулированными азотными удобрениями. **Методы.** Содержание минерального азота в почве выявляли по ДСТУ 4729-2007, формы фосфора и калия – по Чирикову (ДСТУ 4115-2002). Количество основных эколого-трофных групп микроорганизмов определяли, высевая почвенную суспензию на плотную питательную среду. Содержание общих форм азота, фосфора и калия в образцах растений находили по МВВ 31-497058-019-2005. Качественные показатели зерна – содержание белка, сырой клейковины и общую

стекловидность − определяли на ИК-анализаторе Inframatic 8600 фирмы «Perten Instruments AB» (Швеция). **Результаты.** Продемонстрированы особенности влияния безводного аммиака на показатели плодородия почвы, использования элементов питания из удобрений и почвы, урожайность и качество зерна озимой пшеницы. **Выводы.** Установлены преимущества внесения безводного аммиака перед посевом по сравнению с применением традиционной для украинских сельхозпроизводителей аммиачной селитры после вегетации.

Ключевые слова: безводный аммиак, аммиачная селитра, элементы питания, озимая пшеница, качество зерна, урожайность.

Безводний аміак у підвищенні ефективності використання азоту посівами озимої пшениці

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Мета. Для створення інтенсивних технологій виробництва зерна озимої пшениці дослідити особливості впливу безводного аміаку на показники родючості ґрунту, врожайність та якість зерна пшениці озимої порівняно з гранульованими традиційними азотними добривами. **Методи.** Вміст мінерального азоту в ґрунті визначали за ДСТУ 4729-2007, вміст рухливих форм фосфору і калію − за Чиріковим (ДСТУ 4115-2002). Чисельність основних еколого-трофічних груп мікроорганізмів реєстрували, висіваючи ґрунтову суспензію на щільні поживні середовища. Концентрацію загальних форм азоту, фосфору і калію у рослинних зразках знаходили за МВВ 31-497058-019-2005. Якісні показники зерна – вміст білка, сирої клейковини та загальну скловидність визначали на ІЧ-аналізаторі Inframatic 8600 фірми «Perten Instruments AB» (Швеція). **Результати.** Продемонстровано особливості впливу безводного аміаку на показники родючості ґрунту, використання елементів живлення з добрив та ґрунту, врожайність і якість зерна озимої пшениці. **Висновки.** Встановлено переваги внесення безводного аміаку перед посівом порівняно із застосуванням традиційної для українських сільгоспвиробників аміачної селітри по вегетації.

Ключові слова: безводний аміак, аміачна селітра, елементи живлення, озима пшениця, якість зерна, врожайність.

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