International Science Journal of Engineering & Agriculture
2026; 5(2): 81-91
https://isg-journal.com/isjea
doi: 10.46299/j.isjea.20260502.08
ISSN: 2720-6319

Productivity formation of winter rapeseed as affected by nitrogen fertilization level in the western forest-steppe of Ukraine

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Abstract: The article presents the results of field and laboratory studies on the peculiarities of vertical and seasonal migration of mineral forms of nitrogen $(NO)_3^{-}$-N and NH_4^{+}-N) in the soil profile for growing winter rape (*Brassica napus* L.) hybrids of DSV selection (Temptation, Dominator, Duke) in the conditions of the Western Forest Steppe of Ukraine. The study was conducted in the farm «Victoria-92» of Ternopil district on typical medium loam chernozem with the use of various forms of nitrogen fertilizers (ammonium nitrate, urea, ammonium sulfate) with single and fractional application in doses of 60–175 kg N/ha. The relevance of the work is due to the intensive use of nitrogen fertilizers in the cultivation technologies of modern rapeseed hybrids and the associated environmental risks — by nitrate leaching and denitrification, which leads to soil fertility degradation and environmental pollution. The purpose of the research was to establish the patterns of migration of mineral forms of nitrogen depending on the phases of crop development and to evaluate the effectiveness of various forms of nitrogen fertilizers. Samples were taken from layers 0–20, 20–40 and 40–60 cm in the key phases of organogenesis of DSV (Temptation) breeding hybrids. No $content_3^{-}$-N and NH_4^{+}-N was determined by standard agrochemical methods. The total nitrogen dose was 175 kg/ha (ammonium nitrate — 250 kg/ha, ammonium sulfate — 100 kg/ha, urea — 150 kg/ha), applied once at the end of February – at the beginning of March. It was established that the maximum concentration of nitrate nitrogen is formed in the layer of 0–20 cm in the spring during the period of intensive plant growth, while in the late phases of vegetation, with sufficient moisture, it migrates to deeper horizons (20–60 cm), which increases the risk of leaching. The ammonium form is characterized by less mobility and is mainly accumulated in the upper layer of the soil. It has been proven that fractional application of nitrogen fertilizers ensures more uniform saturation of the soil with mineral nitrogen, increases the coefficient of its use by plants and reduces losses. The highest yield was obtained by using the ammonium-sulfate form of nitrogen. The obtained results justify the expediency of optimizing the norms, forms and terms of applying nitrogen fertilizers in order to increase the productivity of rapeseed and minimize the environmental risks of ground and undergroundwater pollution with nitrates. DSV (in particular Temptation) selection hybrids demonstrated high efficiency of mineral nitrogen absorption, which contributed to reducing its losses under optimized fertilization rates.

Keywords: winter rapeseed, nitrogen, nitrate form, ammonium form, nitrogen fertilization, Western Forest Steppe.

1. Introduction

Winter rapeseed (Brassica napus L.) is one of the key oil crops of modern agriculture in Ukraine. It plays an important role in building the export potential of the agricultural sector, providing a significant share of vegetable oil and biofuel production. For rapeseed ranks third among oil crops after sunflower and soybeans in terms of area sown and production, forming the basis of the raw material base country's oil and fat industry [1]. The biological features of the crop allow it to be grown effectively even in zones with limited agricultural conditions. The potential productivity of modern winter rape hybrids is 5.0–6.0 t/ha, and the oil content of the seeds reaches 45–50 %. In addition, rape successfully fills the niche of scarce precursors in crop rotations [1; 2]. The purpose of the research was to establish the regularities of vertical and seasonal migration of mineral forms of nitrogen (nitrate and ammonium) in the soil profile for the cultivation of modern winter rapeseed hybrid Temptation (DSV selection) in the conditions of the «Victoria-92» farm of Ternopil district of Ternopil region and to assess the impact of various forms and terms of application of nitrogen fertilizers on vegetative development and on the productivity of the crop as a whole.

2. Object of research

The object of research was the processes of transformation and vertical migration of mineral forms of nitrogen in the soil for growing the hybrid of winter rapeseed Temptation using intensive technology in the conditions of the «Victoria-92» farm of Ternopil district of Ternopil region (Western Forest Steppe of Ukraine). The subject of research was quantitative indicators of the content of nitrate and ammonium nitrogen in different layers of the soil profile, their dynamics during the growing season and dependence on the applied forms and norms of nitrogen fertilizers. The research was carried out on typical medium loam chernozems with a deep humus horizon. Basic agrochemical soil indicators: humus content 3.5–4.2 %, soil solution reaction close to neutral (pH aq 6.5–7.1, pH KCl 5.8–6.4), hydrolytic acidity 1.5–2.0 mg-eq/100 g, sum of absorbed bases 25–30 mg-eq/100 g. The climate of the territory — is moderately continental, the average annual rainfall is 520–560 mm, the hydrothermal coefficient (HTC) according to Selyaninov is 1.1–1.3.

3. literature review

The strong taproot system promotes the movement of nutrients from deeper soil layers to surface layers, which improves their availability for subsequent crops with surface root systems [2]. At the same time, high yield and quality of seeds largely depend on the supply of plants with elements of mineral nutrition, primarily nitrogen. The culture requires fertile, well-structured soils with high moisture capacity and soil solution response within pH 6.5–7.5 [3]. Due to the intensive absorption of nitrogen by a powerful root system, rapeseed reduces its residual content in the soil after its precursors, which to some extent reduces the risk of nitrate leaching and pollution of underground and surface water [4; 5].

Rapeseed is very sensitive to the level and timing of fertilizer application, so balanced mineral nutrition is a determining factor in the normal development of plants and the realization of potential productivity [4; 5]. From soil reserves, the crop absorbs 15–25% of the necessary nutrients, the rest should be compensated by applying organic and mineral fertilizers. The norms of the latter are calculated taking into account the removal of elements with the planned harvest, agrochemical indicators of the soil, coefficients of nutrient use. The recommended doses for winter rape in the forest-steppe zone are $N_{120-130}$ P_{80-90} $K_{120-150}$ kg/ha of active substance [5; 6].

Intensive but unsystematic cultivation of rapeseed, like other «heavy» crops (sunflower, corn, rapeseed), leads to rapid soil depletion. Without annual application of at least 150 kg of nitrogen, 60 kg of phosphorus and 120–130 kg of potassium per hectare, land fertility decreases significantly after 15–20 years. At the same time, improved yields due to fertilizers and pesticides are often accompanied by soil and groundwater pollution, which adversely affects the environment [6].

In this context, the study of the dynamics and migration of various forms of nitrogen in the soil profile for the cultivation of modern winter rapeseed hybrids of DSV selection (in particular, Temptation) in the conditions of the «Victoria-92» farm of Ternopil district is especially relevant.

The Temptation hybrid belongs to a new generation with genetic resistance to the turnips yellowing virus (TuYV), high field tolerance to major diseases (verticillosis, cylindrosporiosis, phomosis), excellent winter resistance, rapid autumn development without taking out the growth point, medium rates of recovery of vegetation in spring (which reduces the risk of damage by frost), medium-early long flowering, rapid pouring of seeds and synchronous ripening of pods and straw. Due to these characteristics, the hybrid exhibits consistently high yields and oiliness in various soil and climatic conditions in Europe, including Ukraine [sources DSV and Eridon].

The study of nitrogen migration processes is based on the work of domestic and foreign scientists in the field of agrochemistry, soil science and agricultural ecology. Ukrainian researchers (Institute of Soil Science and Agrochemistry named after. O. N. Sokolovsky, Lviv and Podilsky Agrarian Universities) established that winter rapeseed belongs to crops with a high need for nitrogen, which leads to the intensive use of nitrogen fertilizers and the activation of vertical migration of nitrate nitrogen outside the arable layer in the conditions of the Western Forest Steppe [6]. This is explained by the high solubility of nitrates, a significant amount of precipitation and the light/medium granulometric composition of the soils of Ternopil Oblast. In wet years, up to 30–40% of the applied nitrogen can move into deeper profile horizons.

Nitrogen affects all key physiological processes of plants: formation of the assimilation apparatus, photosynthetic activity, laying of reproductive organs [6; 7]. Providing sufficient nitrogen in the early stages is critical for the development of a powerful root systems and storage of spare substances in the root neck, which determines winter hardiness [7]. Lack of nitrogen in the initial phases reduces yield by 30–40%, while excess causes overgrowth, lodging and increased sensitivity to diseases [8; 9].

Separate studies show that the developed root system of rapeseed is able to absorb nitrates from a depth of 40–60 cm, partially reducing nitrogen losses. However, excessive doses, especially those introduced in early spring, exceed the absorption capacity of plants and increase nitrate leaching [10, 11].

The relevance of the work is due to the need to improve the efficiency of nitrogen fertilizer use, optimize the nutritional background and minimize the environmental risks associated with nitrate pollution of groundwater. Insufficient study of the patterns of nitrogen migration under conditions of intensive cultivation of modern rapeseed hybrids in the Western Forest Steppe requires comprehensive research to develop ecologically safe fertilization systems taking into account soil, climatic and biological factors.

4. Research methods

The research was carried out by the field method according to the generally accepted scheme of agrochemical experiments with three times repetition, by the method of randomized plots. The area of the elementary plot is — 72 m² (7.2 × 10 m), the accounting plot is — 40 m² (5 × 8 m).

Phenological observations and visual assessment of plant condition were performed according to phases of winter rape organogenesis (BBCH-scale).

The scheme of the experiment included von $R_{60}K_{90}$ and such options of nitrogen fertilizer:

– control (without nitrogen);

– N_{90} once (application in spring);

– N_{120} fractionally (N_{60} autumn + N_{60} in spring);

– N_{175} once in the spring (comparative version with an increased dose).

Forms of nitrogen fertilizers: ammonium nitrate, urea, ammonium sulfate.

Soil samples were taken with a drill in layers of 0–20, 20–40 and 40–60 cm in the key phases of culture development:

– autumn period (phase 4–6 leaves, BBCH 12–14);

– spring growing season recovery (BBCH 30–39);

– budding phase (BBCH 60–69).

Samples were dried to air dry state, milled and screened through a 1 mm hole screen. Nitrate content (NO_3^--N) and ammonium ($(NH)_4^+$- N) nitrogen was determined by generally accepted agrochemical techniques (photometric method with salicylic acid for nitrates, Nesler method or indophenolic for ammonium). Results were expressed in mg/kg dry soil.

Mathematical data processing was carried out by variational statistics methods using software (Statistica, Excel) —, mean values, standard errors, reliability of differences were determined according to the Student's criterion ($p \leq 0.05$).

5. Research results

As a result of field and laboratory studies, regularities of seasonal dynamics and vertical distribution of mineral forms of nitrogen (NO) were established$_3^-$-N and NH_4^+-N) in the soil profile for growing a hybrid of winter rapeseed Temptation (DSV selection) in the conditions of a farm «Victoria-92» of Ternopil district of Ternopil region (Western Forest Steppe of Ukraine).

The experiment was established by the method of randomized areas, the repetition is — three times.

1. The area of the elementary plot is — 72 m² (7.2 × 10 m), the accounting plot is — 40 m² (5 × 8 m).
2. Background — $R_{60}K_{90}$ (introduced under main cultivation). Nitrogen fertilization options:
3. Control (nitrogen free);
4. Background + N_{90} (N_{60} in autumn, in pre-sowing cultivation + N_{30} spring in the stemming phase) — ammonium nitrate $(NH)_4NO_3$);
5. Background + N_{90} (N_{60} + N_{30}) — urea ($(NH_2)_2CO$);
6. Background + N_{90} (N_{60} + N_{30}) — ammonium sulfate ($(NH_4)_2SO_4$).

To assess the effects of nitrogen fertilizer forms on plant growth, development and productivity, the following accounts were carried out [12; 13]:

1. Phenological observations — by stages of organogenesis and phases of development (BBCH-scale); the beginning of phase — presence in ≥10 % of plants, full phase — in ≥75 %.
2. Standing density — four times per growing season on permanent sites (3 per plot diagonally, size 1/6 m², row spacing 15 cm, row length 111 cm); calculation of plant preservation during the growing season.
3. Plant height — measured by a measuring ruler in each phase of development, sampling — 50 plants diagonally by accounting area.

The duration of the growing season of winter rapeseed is characterized by the dates of the onset of key phenological phases: seedlings, rosette formation, restoration of spring vegetation, stemming, budding, flowering, pod formation, seed ripening.

The maximum nitrate content in the 60 cm soil layer (6.7–26.7 mg/kg) was observed at the beginning of the — vegetation in the seedling phase of winter rape. The smallest values were noted in the variants with the application of only ammonia saliter, while the largest — for the application of nitrogen fertilizer in a dose of 120 kg d.r./ha.

As plants grew and developed, soil nitrate content naturally decreased in all variants and reached a minimum in the full seed ripeness phase (2.7–11.9 mg/kg).

The intensity of the reduction in nitrate content depended to a large extent on fertilizer doses (Table. 3.2). Between seedlings and budding in a layer of 0–60 cm:

- on non-feeding variants, the decrease was 39.6–47.5%;
- on variants with — feed only 28.0–33.0%.

During the period from budding to complete seed ripeness, higher rates of nitrate reduction were observed in nitrogen-fed variants, which is probably due to the intensive nitrogen absorption of plants when forming high productivity.

One of the main factors affecting the duration of interphase periods is the level and form of nitrogen nutrition. Studies have shown that the use of nitrogen fertilizers prolongs rapeseed vegetation by an average of 5–8 days compared to controls (without nitrogen), which is associated with more intense vegetative growth and delayed transition to the generative phase (Fig. 1).

Different forms of nitrogen affect this indicator differently:

– ammonium nitrate (ammonium-nitrate form) provides a quick starting effect, but the elongation of the vegetation is less pronounced;

– urea (amide form) is characterized by the gradual release of nitrogen after hydrolysis, which contributes to a uniform but moderate prolongation of vegetation;

– ammonium sulfate (ammonium form + sulfur) exhibits the most pronounced prolonged effect, which leads to the greatest prolongation of the growing season (7–8 days longer than at the control).

This is explained by the features of transformation and assimilation of nitrogen forms: the nitrate form quickly enters with mass flow and transpiration, ammonium — is regulated by diffusion and fixation on colloids, and sulfur in ammonium sulfate enhances protein synthesis and plant growth, contributing to longer vegetative development.

Extending the vegetation by applying ammonium and amide forms of nitrogen allows plants to more effectively use the period of active assimilation, accumulate more dry matter and form a more powerful harvest, but requires monitoring the risk of lodging and disease damage in conditions of excessive nitrogen nutrition.

Nitrogen plays a key role in the vital activity of winter rapeseed plants (Brassica napus L.), performing not only a structural function as the main component of proteins, nucleic acids and other nitrogen-containing compounds, but also a regulatory — due to the effect on the synthesis of phytohormones (in particular, cytokinins). The nitrate form of nitrogen stimulates the synthesis of cytokinins in the roots, which contributes to the prolongation of the vegetative phase and more intensive development of the above-ground mass [14; 15].

With a high and uniform supply of nitrogen, rapeseed plants remain in the vegetative stage longer, which is manifested in the delay in the formation of generative organs, increased formation of side shoots and peduncles. The results of our research this effect is confirmed: the application of nitrogen fertilizers extended the total duration of the growing season of winter rapeseed by 5–8 days compared to the control. At the same time, different forms of nitrogen affected this indicator in different ways:

– the ammonia-nitrate form (ammonium nitrate) provided a fast starting effect, but the prolongation of the vegetation was less pronounced due to high mobility and rapid absorption of nitrates;

– the amide form (urea) acted gradually after hydrolysis to ammonium and subsequent nitrification, which contributed to a moderate and uniform prolongation of the vegetation;

– the ammonium form (particularly ammonium sulfate) had the most prolonged action due to slower transformation and fixation of ammonium on soil colloids, which provided longer vegetative growth.

The total nitrogen requirement of crops is calculated taking into account the type of crop, potential yield, product quality requirements, residual nitrogen in the soil, level of mineralization and mobilization of organic nitrogen, precursors, climatic conditions, etc. The effectiveness of nitrogen fertilizers depends on the correct choice of form, terms, methods of application and dosage. Rational use allows not only to save fertilizers, but also to optimize physiological processes, minimize environmental risks and achieve consistently high yield and product quality.

The results of our research fully confirm these patterns. Ammonium sulfate, due to the combination of the ammonium form of nitrogen and sulfur (S 24 %), is characterized by a pronounced prolonged effect on the physiological and growth processes of winter rapeseed plants compared to the ammonium-nitrate (ammonium nitrate) and amide (urea) forms. This is what ensured longer vegetation, better development of the root system and higher productivity of the Temptation hybrid. In particular, the preference for ammonium sulfate in studying plant height was confirmed (Table 1).

Table 1. Height of rape plants of the winter hybrid Temptation (DSV selection) depending on fertilization, cm (average for 2024-2025)

Phenological phase	Option fertilization	Height plants, sm
Socket (before entering in winter)	Fon – R_{60} K_{90} (control)	9,0 ± 1.5
	Fon + N_{90} (N_{60} + N_{30}) ammonia saltpetre ($N.H._4 NO_3$)	14.7 ± 1.8
	Fon + N_{90} (N_{60} + N_{30}) urea ($(N.H._2)_2CO$)	14.5 ± 1.6
	Fon + N_{90} (N_{60} + N_{30}) sulphate ammonium ($(N.H._4)_2SO_4$)	14.9 ± 2.1
Stalking	Fon – R_{60} K_{90} (control)	84.2 ± 2.3
	Fon + N_{90} (N_{60} + N_{30}) ammonia saltpetre ($N.H._4 NO_3$)	90.1 ± 2.8
	Fon + N_{90} (N_{60} + N_{30}) urea ($(N.H._2)_2CO$)	93.5 ± 3.2
	Fon + N_{90} (N_{60} + N_{30}) sulphate ammonium ($(N.H._4)_2SO_4$)	98.9 ± 2.7
Flowering	Fon – R_{60} K_{90} (control)	132.9 ± 2.6
	Fon + N_{90} (N_{60} + N_{30}) ammonia saltpetre ($N.H._4 NO_3$)	142.8 ± 2.9
	Fon + N_{90} (N_{60} + N_{30}) urea ($(N.H._2)_2CO$)	143.2 ± 2.7
	Fon + N_{90} (N_{60} + N_{30}) sulphate ammonium ($(N.H._4)_2SO_4$)	146.0 ± 2.5
Maturation (green ripeness)	Fon – R_{60} K_{90} (control)	129.9 ± 2.3
	Fon + N_{90} (N_{60} + N_{30}) ammonia saltpetre ($N.H._4 NO_3$)	142.4 ± 1.9
	Fon + N_{90} (N_{60} + N_{30}) urea ($(N.H._2)_2CO$)	142.9 ± 1.6
	Fon + N_{90} (N_{60} + N_{30}) sulphate ammonium ($(N.H._4)_2SO_4$)	147.9 ± 1.8

The conducted studies established a clear relationship between the form of nitrogen fertilizer and the formation of the height of winter rapeseed plants. Growth processes largely depend on weather conditions: ammonification begins already at a soil temperature above +3 °C, nitrification — above +9 °C. The optimal humidity for these processes is — 50–80 % of the total moisture capacity.

In the stemming phase, the height of the plants by the variants was 84.2–98.9 cm. Spring feeding with various forms of nitrogen contributed to a significant increase in height. The maximum increase (13.1–18.0 cm compared to the control) ensured the application of ammonium sulfate, which is explained by the better absorption of nitrogen and the positive effect of sulfur on the growth and development of rapeseed.

The highest height of the plant was reached in the phase of the beginning of ripening. Option with the introduction of ammonium sulfate (N_{60} + N_{30} in spring) allowed the formation of an average height of 147.9 cm (in two years of research), 18 cm more than in the control, 5.5 cm more than in ammonium nitrate and 1.9 cm more than in urea.

Among fertilization options, the least positive effect on plant growth and development was observed with the application of nitrogen in amide form (urea). This is explained by the slow transformation of urea in the soil: first, hydrolysis to ammonium occurs, and then — nitrification to nitrates. These processes occur gradually, so nitrogen enters plants evenly, but with a noticeable delay compared to other forms. This feature makes urea effective for long-term, stable nutrition throughout the growing season, but less pronounced in the rapid initial growth of biomass.

The highest increase was recorded precisely for the application of ammonium sulfate, which is due to the prolonged action of the ammonium form and the synergistic effect of sulfur.

A similar trend was observed when forming the area of the assimilation (leaf) sowing surface — of one of the key indicators of photosynthetic potential and future productivity. In the phase of two true leaves (BBCH 12–14), no significant dependence of the leaf surface area on the shape and dose of nitrogen was found —, the difference between the variants was statistically insignificant. This is because in the early stages of development, plants still make considerable use of nutrient reserves from seeds and soil reserves.

In the stemming phase (BBCH 30–39), the situation changes radically (Table. 2). The largest area of the leaf surface was formed according to the Von + N option$_{90}$ (N_{60} + N_{30} in spring) in ammonium sulfate forms — 35.41 thousand m²/ha. This is 33.14 thousand m²/ha (or almost twice) more than at the control.

Table 2. Assimilation surface area of winter hybrid rape plants Temptation (DSV selection) depending on fertilization (average 2024-2025)

Phenological phase	Option fertilization	Leaf surface area sowing, thousand. m^2/ha
Socket (before entering in winter)	Fon – R_{60} K_{90} (control)	4.52 ± 0.69
	Fon + N_{90} (N_{60} + N_{30}) ammonia saltpetre ($N.H._4 NO_3$)	5.69 ± 1.24
	Fon + N_{90} (N_{60} + N_{30}) urea ($(N.H._2)_2CO$)	6.28 ± 2.11
	Fon + N_{90} (N_{60} + N_{30}) sulphate ammonium ($(N.H._4)_2SO_4$)	6.96 ± 2.03
Stalking	Fon – R_{60} K_{90} (control)	20.82 ± 2.63
	Fon + N_{90} (N_{60} + N_{30}) ammonia saltpetre ($N.H._4 NO_3$)	28.30 ± 2.96
	Fon + N_{90} (N_{60} + N_{30}) urea ($(N.H._2)_2CO$)	31,18 ± 3.52
	Fon + N_{90} (N_{60} + N_{30}) sulphate ammonium ($(N.H._4)_2SO_4$)	33.14 ± 2.96

Continuation of Table 2

Flowering	Fon – R_{60} K_{90} (control)	42.45 ± 2.64
	Fon + N_{90} (N_{60} + N_{30}) ammonia saltpetre ($N.H._4NO_3$)	52.08 ± 4.57
	Fon + N_{90} (N_{60} + N_{30}) urea ($(N.H._2)_2CO$)	56.61 ± 5.24
	Fon + N_{90} (N_{60} + N_{30}) sulphate ammonium ($(N.H._4)_2SO_4$)	62.23 ± 4.78
Maturation (green ripeness)	Background – R_{60} K_{90} (control)	11.48 ± 2.04
	Fon + N_{90} (N_{60} + N_{30}) ammonia saltpetre ($N.H._4NO_3$)	17.88 ± 2.36
	Fon + N_{90} (N_{60} + N_{30}) urea ($(N.H._2)_2CO$)	19.55 ± 3.02
	Fon + N_{90} (N_{60} + N_{30}) sulphate ammonium ($(N.H._4)_2SO_4$)	21.49 ± 2.52

In the flowering phase (BBCH 60–69), the application of ammonium nitrate (ammonium-nitrate form) in spring feeding provided the largest increase in leaf surface area compared to the control —, the average increase over the years of research was +9.63 thousand m^2/ha. This is explained by the rapid influx of nitrate nitrogen, which intensively stimulates the elongation of internodes and the growth of leaf mass precisely during the period of maximum photosynthetic activity.

During the seed ripening phase (BBCH 80–89), the area of the assimilation surface naturally decreased in all variants due to natural aging and death of the lower leaves, yellowing and redistribution of assimilates into generative organs. The smallest decrease in leaf surface area compared to the budding phase was observed with the application of sulfate ammonium, which indicates better maintenance of functional activity of leaves in the late phases of vegetation.

Therefore, based on the results of the research, a clear hierarchy of the effectiveness of various forms of nitrogen was established regarding the formation of the leaf surface area of winter rapeseed sowing during the entire growing season (weighted average value of the increase before control):

– ammonium sulfate form (ammonium sulfate) — +37.5 % (highest value);

– amide form (urea) — +29–33 % (intermediate value);

– ammonium nitrate form (ammonium nitrate) — +21–22.5 % (lowest increase among the studied forms).

The preference for ammonium sulfate is due to the combined action of the prolonged available ammonium nitrogen and sulfur, which is a structural element of many amino acids, enzymes and chlorophyll, which contributes to longer preservation and build-up of the assimilation apparatus.

The content and dynamics of dry matter accumulation by plants were determined by the main stages of organogenesis (BBCH scale) by sampling biomass, drying to constant weight and weighing. The conducted studies showed that the use of nitrogen fertilizers in all forms had a pronounced positive effect on the intensity of accumulation of dry matter (Fig. 1).

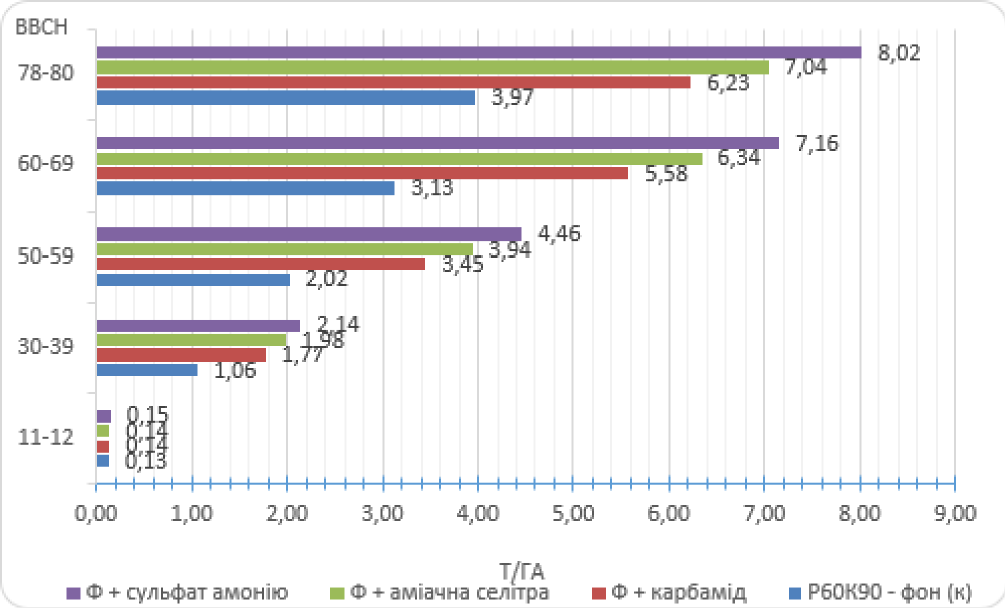

Figure 1. Accumulation of dry matter by crops of winter rapeseed depending on the use of different forms of nitrogen fertilizers, t/ha (average for 2024-2025)

The highest rates and overall level of accumulation of dry matter were recorded in the variant with the introduction of ammonium sulfate.

This is due to:

– prolonged nitrogen availability throughout the growing season;

– by the synergistic action of sulphur, which enhances the synthesis of proteins, enzymes and chlorophyll, promotes more intensive photosynthesis and better carbohydrate accumulation;

– stimulating the development of a powerful root system that improves the absorption of water and nutrients.

In order to justify the obtained yield levels and determine the range of variation of productive characteristics, a detailed analysis of the structure of the winter rapeseed crop depending on the form of nitrogen fertilization was carried out (Table. 3).

Table 3. Temptation winter hybrid rapeseed crop structure indicators (DSV selection) depending on the use of different forms of nitrogen fertilizers, average for 2024–2025 rr.

Option fertilization	Quantity, pc.		Mass 1000 seeds, g
	pods on the plant	seeds in a pod	
Fon – R_{60} K_{90} (control)	62.5	18.4	4.88
Fon + N_{90} (N_{60} + N_{30}) ammonia saltpetre ($N.H._4NO_3$)	68.3	22.8	4.95
Fon + N_{90} (N_{60} + N_{30}) urea ($(N.H._2)_2CO$)	71.2	23.5	5.01
Fon + N_{90} (N_{60} + N_{30}) sulphate ammonium ($(N.H._4)_2SO_4$)	72.4	23.9	5.09
NIR $_{05}$	0.38	0.37	0.007

The largest increase in pods per plant was recorded with the application of ammonium form nitrogen as ammonium sulphate — +9.9 pcs. (or +15.8% to the control).

Conclusions Research conducted in the conditions of the «Victoria-92» farm of Ternopil district of Ternopil region (Western Forest Steppe of Ukraine) on the improvement of elements of the technology of growing winter rapeseed hybrid Temptation (DSV selection) under various forms of nitrogen fertilization allows us to draw the following main conclusions:

1. The obtained results indicate that the intensity of vertical migration of nitrate nitrogen is determined by a combination of the following factors: the form and dose of fertilizer, application terms, phases of crop development, weather conditions. Optimization of these factors ensures a reduction in nitrogen losses due to leaching and increases the coefficient of its use by winter rapeseed plants.

2.The highest indicator of plant height was reached in the phase of the beginning of seed ripening. The application of ammonium sulfate in spring to the stemming phase ensured the formation of an average plant height of 147.9 cm, which was 18.0 cm above control, 5.5 cm — variant with ammonium nitrate and 1.9 cm — variant with urea. This indicates the most pronounced stimulation of growth processes by the ammonium-sulfate form of nitrogen.

3.The application of ammonium sulfate form of nitrogen (ammonium sulfate) provided the maximum increase in leaf surface area during all key phenological phases — average +37.5 % before control. In second place in terms of efficiency is the amide form (urea) with an increase of 29—33 %, in third place is the ammonium-nitrate form (ammonium nitrate) with an increase of 21–22.5 %. The preference for ammonium sulfate is due to the synergistic action of nitrogen and sulfur, which promotes more intense photosynthesis, longer leaf function, and better accumulation of assimilates.

4.The highest yield was shown by the variant with the application of ammonium sulphate — for an average of 3.31 t/ha over the two years of the studies, which was 1.51 t/ha (+83.9 %) above the control. This confirms the complex superiority of the ammonium-sulfate form of nitrogen over the ammonia-nitrate and amide form both in terms of vegetative development and in terms of crop productivity as a whole.

This approach makes it possible to maximize the potential of modern rapeseed hybrids, increase the nitrogen utilization rate, reduce environmental risks (nitrate leaching, groundwater pollution) and ensure an economically justified increase in yield and product quality.

Prospects for further research In order to obtain a stable yield of winter rapeseed at the level of high technological quality in the conditions of the Western Forest Steppe, the following nitrogen fertilization system should be investigated in the future:

– background — $R_{60}K_{90}$ under main cultivation;

– nitrogen — N_{90} fractional: N_{60} in pre-sowing cultivation in autumn + N_{30} in the stemming phase (BBCH 30–39) in spring;

– optimal form of nitrogen — ammonium sulfate ($(NH_4)_2SO_4$).

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