http://www.moderntechno.de/index.php/meit/article/view/meit41-03-040
DOI: 10.30890/2567-5273.2025-41-03-040

UDC 631.52:633.853.494

DEPENDENCE OF THE DURATION OF THE VEGETATIVE PERIOD OF WINTER RAPE ON THE SOWING METHOD, SOWING RATE AND MINERAL NUTRITION

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Abstract. *The study presents the results of research on the effects of sowing method, seeding rate, and mineral nutrition level on the duration of the growing season of winter oilseed rape (Brassica napus L.) under the Forest-Steppe conditions of Ukraine. The aim was to determine the patterns of variation in the duration of interphase growth periods depending on the combination of technological factors. Experiments were conducted using the variety Antaria and the hybrid Exagon under two sowing methods (row and wide-row), four seeding rates (0.4–1.0 million seeds ha^{-1}), and three fertilizer treatment (control, $N_{120}P_{60}K_{90}$, and $N_{120}P_{60}K_{90}$ + Caramba). It was found that applying a full dose of mineral fertilizers combined with a growth regulator prolonged the growing season by 10–20 days compared with the control, ensuring more balanced plant development. Increasing the seeding rate shortened the growing season by 6–10 days due to intensified intra-population competition. The optimal combination for balanced growth and high productivity was a row sowing method (15 cm spacing), a seeding rate of 0.6–0.8 million seeds ha^{-1}, and the combined application of $N_{120}P_{60}K_{90}$ + Caramba. The findings confirm that regulating the duration of the growing season through the integration of technological factors is an effective tool for enhancing the adaptability and productivity of winter oilseed rape under conditions of climatic variability.*

Keywords: *winter oilseed rape, growing season, seeding rate, mineral nutrition, growth regulator, Caramba*

Introduction.

The duration of the growing season of winter oilseed rape (*Brassica napus L.*) is one of the key characteristics that determines crop yield, adaptability to climatic conditions, and efficiency of nutrient use. Recent studies have shown that sowing methods, seeding rates, and mineral nutrition systems significantly influence this parameter.

Under conditions of climatic variability, shortening of the autumn vegetative growth period and increased risk of spring stress make it particularly important to scientifically justify agronomic practices that regulate the duration of the growing season of winter oilseed rape. This approach not only ensures stable crop productivity but also improves mineral fertilizer use efficiency and enhances plant adaptability to environmental stressors.

One of the leading areas in the study of oilseed rape agri-biology is the investigation of the crop's response to sowing dates and methods. According to Voloshchuk O.P., Sluchak O.M., and Rasputenko A.O. [1], the sowing method and timing determine the intensity of growth processes, the duration of autumn vegetation, and the formation of productive stems. Polyakov O.I. [2] demonstrated that optimal sowing dates ensure proper rosette development and enhance winter hardiness. Studies by Jarecki W. and Bobrecka-Jamro D. [3] confirmed that a 10–14 -day delay in sowing reduces the growing season by 6–9 days, accompanied by a 10–15% decrease in yield. Modeling conducted by Xie Z., Kong J., Tang M., Luo Z., Li D., Liu R., Feng S., and Zhang C. [4] showed that changes in plant density and sowing dates significantly affect the duration of growth phases and final crop productivity.

Research by Korotkova I.V. and Drobitko A.M. [5] indicated that the sowing method determines the characteristics of plant entry into the winter period, while combined schemes (strip-row) promote better root system development and extend the growing season in spring.

An important component of winter oilseed rape cultivation technology is the optimization of seeding rate. According to Hoisiuk Yu.V. and Hoisiuk S.O. [6], reducing the seeding rate from 6.0 to 4.0 kg/ha allows better realization of the potential of each plant, increases leaf area, and prolongs the active photosynthesis phase. Similar conclusions were reported by Bezkorovayny V.M. and Moisiienko V.V. [7], noting that excessive plant density reduces leaf area index and accelerates seed maturation.

Yurchuk S.S. [8] established that optimal plant density combined with rational mineral nutrition enhances the photosynthetic potential of crops and prolongs the growing season by 5–7 days, indicating a close relationship between seeding rate, plant density, and the duration of ontogenetic phases of winter oilseed rape.

The mineral nutrition system of oilseed rape determines not only yield level but also the rate of phenological phase progression. Muntian S.V., Shatkovskyi A.P., Fedorchuk M.I., and Saidak R.V. [9] demonstrated that using nitrification inhibitors combined with moderate nitrogen doses ensures uniform plant development and increases the duration of the active growing season. Rahimi Tanh S., Woodcock T., Spink J., Forristal P., and Berry P. [10] found that improving nitrogen uptake efficiency from soil and fertilizers extends the autumn growing period, positively affecting winter survival.

Jarecki W., Korczyk-Szabó J., Macák M. [11], and Barłóg P., Grzebisz W. [12] noted that combining nitrogen and sulfur nutrition increases the duration of the growing season and seed yield by 12–15%, while timely nitrogen application in early growth phases prolongs active plant growth and enhances fertilizer use efficiency.

According to Vasylenko S.V. [13], combining primary nutrients (NPK) with micronutrients (B, Mg, S) optimizes photosynthetic processes, prolongs the active growing period, and improves seed quality.

Recent studies emphasize the need for a comprehensive approach to evaluating the effects of agronomic factors. Li Q., Luo T., Cheng T., Yang S., She H., Li J., Wang B., Kuai J., Wang J., Xu Z., and Zhou G. [14] demonstrated that combining adapted oilseed rape hybrids with optimized sowing and nutrition parameters ensures a stable growing season duration and high-quality yield under mechanized harvesting. Bełdycka-Bórawska A. [15] highlights the importance of coordinating technological and breeding decisions in the context of climate change, which contributes to stabilizing crop productivity.

Analysis of the literature indicates that the duration of the winter oilseed rape growing season is a complex function of technological factors, among which sowing method, plant density, and level of mineral nutrition play leading roles. Domestic and international studies confirm that optimizing these parameters not only extends the growing season by 8–15 days but also enhances plant adaptability to stressful weather conditions, improves crop structure, and seed quality. Therefore, further study of the interaction between agronomic factors and physiological growth processes is fundamental for improving adaptive precision farming technologies in winter oilseed rape cultivation.

The aim of the study was to determine the patterns of influence of sowing method, seeding rate, and mineral nutrition level on the duration of the growing season and specific interphase periods of winter oilseed rape development under Forest-Steppe conditions of Ukraine.

Research objectives include assessing the effects of sowing methods, seeding rates, and mineral nutrition levels on the duration of key interphase periods of winter oilseed rape development; evaluating the response of the cultivar Antaria and hybrid Exagon to combinations of technological factors; and determining optimal growing conditions to ensure rational growing season duration and high crop productivity.

Materials and methods. The study of the effects of sowing method, seeding rate, and mineral nutrition level on the growing season duration of winter oilseed rape was conducted at the fields of the Institute of Forage and Agriculture of Podillia, NAAS, in the Forest-Steppe zone with dark gray typical soils. Two sowing methods and four seeding rates (0.4–1.0 million viable seeds per hectare) were tested under three fertilizer treatments: control, $N_{120}P_{60}K_{90}$, and $N_{120}P_{60}K_{90}$ + Caramba (1.0 L ha^{-1}). The experiments were conducted on the cultivar Antaria and the hybrid Exagon.

Main text.

The duration of the growing season of winter rapeseed (Brassica napus L.) is determined by the combined effects of agrotechnical, climatic, and soil factors, among which the sowing method, seeding rate, and level of mineral nutrition play a key role in regulating the crop's growth and development. These factors directly affect the rate of vegetative mass accumulation, leaf rosette formation in autumn, progression through the dormancy phase, and the dynamics of spring regrowth [2], [4].

Optimizing the sowing method, seeding rate, and mineral nutrition not only increases yield but also enables the regulation of the growing season duration, ensuring balanced progression through phenological phases and enhancing the crop's adaptive potential under changing climatic conditions.

Overall, the integrated regulation of sowing and nutrition parameters is an effective tool for managing the growth rhythms of winter rapeseed, providing an optimal combination of productivity and ecological stability of agroecosystems.

The duration of interphase periods during rapeseed growth is an important indicator that determines the pace of growth, development, and yield formation. It depends on a complex of factors, including sowing method, seeding rate, level of mineral nutrition, and growth regulation, which influence the speed of phenological phase progression. In the context of climate variability, optimizing crop structure and nutrition regimes is particularly important for ensuring stable plant development and rational use of resources.

Research results showed that the duration of the rapeseed growing season significantly varies depending on the combination of nutrition and growth regulation factors. Application of the full dose of mineral fertilizers ($N_{120}P_{60}K_{90}$) extended the growing season by an average of 10–15 days compared to the control, while their combined use with the growth retardant «Caramba» extended it by 10–20 days. This effect is due to improved accumulation of assimilates in autumn, enhanced winter hardiness, and prolonged spring growth.

For both cultivars, the growing season was prolonged with the application of the full dose of mineral fertilizers ($N_{120}P_{60}K_{90}$). In the Antaria variety, the growing period increased from 278 days (control) to 290 days, and with combined fertilizer and retardant application, it reached 305–307 days. A similar trend was observed in the Exagon hybrid, from 270 to 302–304 days. This is explained by the fact that balanced mineral nutrition promotes more intensive autumn growth and slows the transition to the generative phase, allowing plants to accumulate more assimilates.

The application of the growth regulator, either alone or in combination with fertilizers, stabilized the duration of interphase periods and promoted more harmonious plant development. The longest growing seasons (up to 307 days in Antaria and 304 days in Exagon) were observed in the « $N_{120}P_{60}K_{90}$ + Caramba» treatments. This indicates that the retardant not only limited excessive stem elongation but also extended the active phase of generative organ formation, positively affecting pod and seed formation.

Increasing the seeding rate from 0.4 to 1.0 million viable seeds per hectare slightly shortened the growing season. For instance, in the Antaria cultivar under control conditions, the difference amounted to 6 days (278 → 272), while in the fertilized treatments it reached up to 9 days (290 → 281). This reduction is attributed to heightened competition among plants for light and moisture, which accelerates the progression of individual developmental phases.

The greatest variations in duration were observed in the bud–beginning of flowering and pod formation–ripening phases, indicating the sensitivity of these stages to agrotechnical conditions. Full fertilization combined with the growth retardant extended these phases by an average of 3–5 days, which may be associated with more active photosynthesis and prolonged accumulation of assimilates in generative organs.

Comparative analysis shows that the Exagon hybrid had a shorter total growing season (on average by 10–12 days) compared to the Antaria variety, corresponding to its genetic predisposition to early maturity. However, under intensive nutrition and growth regulation, the difference between cultivars was minimized, indicating the adaptability of both genotypes to wide-row sowing.

Thus, the results confirm that combining an optimized seeding rate (0.6–0.8 million seeds/ha), balanced mineral nutrition ($N_{120}P_{60}K_{90}$), and the application of the growth retardant «Caramba» ensures the most balanced growth rate, prolonging the winter rapeseed growing season by 8–12 days compared to the control, which contributes to the formation of more productive plants.

Therefore, regulating the duration of the growing season through management of nutrition, seeding rate, and growth-regulating agents is an important tool in adaptive winter rapeseed cultivation technology, particularly under climate variability and spring-summer water deficit.

The duration of interphase periods is a crucial characteristic that determines growth rate, development rhythm, and the adaptive potential of winter rapeseed to environmental conditions. Under conventional row sowing (row spacing 15 cm), crop structure is characterized by higher plant density, affecting competitive interactions, photosynthetic intensity, and generative organ formation. Accordingly, changes in seeding rate, mineral nutrition, and growth regulator application impact the duration of individual ontogenetic phases and the overall growing season.

On average, for both cultivar and hybrid, the total growing season under conventional row sowing ranged from 276–311 days, which is shorter than under wide-row sowing (278–307 days), indicating that denser stands accelerate the progression of certain phonological phases, especially generative development, due to increased competition for light, space, and nutrients.

Application of mineral fertilizers ($N_{120}P_{60}K_{90}$) consistently extended the growing season by 12–15 days compared to the control. For example, in Antaria at a seeding rate of 0.6 million/ha, the period increased from 280 to 293 days, and in Exagon from 277 to 295 days. Fertilizer application intensified photosynthetic activity during the rosette and budding phases, ensuring biomass accumulation and favorable conditions for pod formation.

The combination of $N_{120}P_{60}K_{90}$ + Caramba provided the longest growing season (306–311 days) for both cultivars. Compared to the control, this represents an extension of over 10–20 days, explained by the biochemical effect of the retardant, which reduces growth intensity in autumn, promoting plant hardening, increasing winter hardiness, and prolonging active spring growth. This treatment also had longer bud (up to 10 days) and pod formation phases (up to 15 days), positively affecting productivity.

The variant with Caramba alone resulted in a slight extension of the growing season (by 5–7 days compared to the control), but its effect was significantly lower than in combination with *NPK*. This indicates that the growth regulator is most effective under balanced nutrition, when plants have sufficient assimilates to support prolonged development.

Increasing the seeding rate from 0.4 to 1.0 million seeds/ha led to a 6–10 day reduction in the growing season. In denser stands, individual plant development accelerated due to competition, reducing the duration of bud and pod formation phases. The optimal seeding rate for both cultivars was 0.6–0.8 million/ha, achieving a balanced combination of phase duration and productivity.

The Antaria cultivar exhibited a slightly longer growing season (on average 286–311 days), whereas the Exagon hybrid was characterized by a shorter period (275–308 days), reflecting its genetic tendency toward early maturity. However, under intensive fertilization and growth regulation, the difference between the cultivars decreased to

3–5 days, indicating a high adaptive potential of hybrid forms to changing cultivation conditions.

Analysis of individual interphase periods revealed that the greatest variations were observed during the bud formation–beginning of flowering (7–10 days) and pod formation–ripening (8–15 days) phases. The prolongation of these phases in treatments with fertilizers and growth retardants indicates balanced development of the generative system, potentially enhancing seed productivity.

The study results suggest that under standard row sowing, the optimal conditions for full development of winter rapeseed include a seeding rate of 0.6–0.8 million seeds per hectare, application of a complete mineral fertilizer ($N_{120}P_{60}K_{90}$), and the use of the growth regulator Caramba. This combination contributes to an extension of the growing season by an average of 10–20 days, improves the pace of spring regrowth, and ensures harmonious formation of generative organs.

The findings indicate that the sowing method is one of the key agrotechnical factors determining the pace and duration of the winter rapeseed growing season. Comparison of results from wide-row (45 cm) and standard row (15 cm) sowing allowed identification of certain patterns in crop development dynamics under different seeding rates, fertilization levels, and the application of the growth regulator Caramba.

Based on long-term average data, the growing season duration for wide-row sowing ranged from 274 to 307 days, while for standard row sowing it ranged from 276 to 311 days. Thus, the difference between sowing methods was minimal (1–4 days within the experimental error). However, row sowing was characterized by greater stability of phase duration regardless of seeding rate, due to a more uniform distribution of plants and reduced microclimatic fluctuations between rows.

During the bud formation–beginning of flowering and pod formation–ripening phases, winter rapeseed under standard row sowing exhibited slightly longer development (by 1–3 days), associated with a slower transition to the generative stage due to higher plant density. Conversely, in wide-row sowing, these phases progressed more rapidly, albeit at the cost of reduced individual plant mass.

In both sowing methods, increasing the seeding rate from 0.4 to 1.0 million seeds per hectare resulted in a shortening of the growing season by 6–10 days, with the effect being more pronounced in wide-row sowing. This is due to stronger competition among plants at earlier developmental stages in wider rows, which accelerates the completion of active growth phases.

All treatments with the full mineral fertilizer $N_{120}P_{60}K_{90}$ resulted in an extension of the growing season by an average of 12–15 days, regardless of the sowing method. However, in wide-row sowing, this effect was more pronounced during the spring regrowth and bud formation phases, whereas in row sowing it was more evident during pod formation and ripening, reflecting differences in the pace of physiological processes: vegetative mass develops more intensively in sparser stands, while in denser stands it is redistributed more rapidly to generative organs.

The application of the growth regulator in combination with mineral fertilization ($N_{120}P_{60}K_{90}$ + Caramba) extended the growing season by 25–30 days in all sowing variants, with a more pronounced effect in row sowing. This is explained by the fact that in denser stands, the effect of the retardant is enhanced due to reduced apical dominance and increased development of lateral shoots, prolonging the flowering and pod formation phases.

The Antaria cultivar had a longer growing season under both sowing methods (up to 311 days), whereas the Exagon hybrid exhibited a shorter cycle (up to 308 days). However, in wide-row sowing, the differences between cultivars were reduced, indicating greater plasticity of hybrids in response to environmental changes.

In summary, it can be concluded that:

− Wide-row sowing (45 cm) promotes the development of more robust plants with longer vegetative phases but a shorter generative part of the cycle;

− Standard row sowing (15 cm) ensures a more uniform progression of phenological phases, a stable development rhythm, and an extended generative period, which is beneficial for seed productivity;

− The optimal combination under the study conditions is row sowing (15 cm), a seeding rate of 0.6–0.8 million seeds per hectare, and combined application of $N_{120}P_{60}K_{90}$ + Caramba, providing the most complete plant development and a growing season exceeding 305 days.

Thus, the choice of sowing method is a critical element of adaptive winter rapeseed cultivation technology. Under current conditions of climatic change, row sowing with optimized plant density and regulated nutrition is more appropriate for ensuring stable yields, as it combines high productivity with agroecological stability of the crop stand.

Conclusions.

The patterns of the influence of sowing method, seeding rate, and mineral nutrition level on the duration of the growing season of winter rapeseed across different genotypes were examined.

The results demonstrate that reducing row spacing to 15 cm and applying full mineral fertilization ($N_{120}P_{60}K_{90}$) in combination with the growth regulator Caramba contributed to the extension of the active growing season, better plant development, and increased adaptive potential.

It was established that the Antaria variety and the Exagon hybrid responded differently to changes in agrotechnical factors; however, in both cases, the optimal combination of seeding density and nutrition level ensured a longer growing period and potentially higher productivity.

The obtained data can be used to improve winter rapeseed cultivation technologies, taking into account the biological characteristics of the variety and the specific regional conditions.

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