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EFFECT OF SEEDING RATES ON GRAIN YIELD OF A FEMALE FORM IN WINTER RYE HYBRIDIZATION PLOTS

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Introduction. Sufficient amounts of hybrid seeds is a necessary prerequisite for the widespread use of hybrid rye in Ukraine. Although hybrid rye in Ukraine is still not produced in sufficient volumes of commercial activities, it is possible to start creating important prerequisites for successful reproduction of parental components followed by their hybridization [1, 2, 3].

Currently, hybrid seed production systems of other cross-pollinated crops, such as corn, sorghum and sunflower, using a sterile female component and a male component (fertility restorer) are well known. A lot of scientists participated in the development and improvement of methods and technologies for obtaining hybrid seeds of these crops [4, 5, 6].

Literature Review and Problem Articulation. Basing on their results, one can assume that the easiest way to obtain hybrid winter rye seeds is to copy hybridization plot designs either for corn or for sunflower. However, regular control of the fertility and sterility of parental components is a very important factor affecting the seed quality.

It is known that the plant density of female sunflower forms in hybridization plots is 5–7 plants/running meter; for corn, this parameter is 4–5 plants/running meter [7–9], while the number of rye plants is 25–40. At the same time, rye tillers well (on average 5–6 shoots per plant), so it is hardly possible to control the sterility or fertility of 200–240 spikes/running meter. Therefore, taking into account the biological features of the rye development, it does not make sense to sow parental components separately (in alternating bands).

For the last stage of seed production (production of hybrid seeds, i.e., the crossing of a CMS simple hybrid and a male component), isolating distances can be significantly smaller than those upon CMS lines reproduction, but larger than those when varieties - populations are grown.

It has been proven that it is possible to obtain hybrid winter rye seeds in hybridization plots by mechanical mixing seeds of female (sterile) and male (fertile) components. V.D. Kobylyanskiy [10] believed that it was possible to create mixtures with ratios 80–95% ♀ and 5-15% ♂. Growing a male component may be appropriate either in alternate bands in a ratio of 3:1 or 4:1, or using a mechanical mixture with a pollinator portion of approximately 4–8% [11–16].

The latter method significantly reduces the expenditure of seeds, but can decrease the seed productivity of the mixture because of the male component seeds, especially when a low-yielding synthetic variety is used, as such seeds cannot be completely or partially (by grain size and color) separated from the hybrid seeds [16].

We believe that the uniform distribution of male component plants in a hybridization plot is a mandatory condition for creating such mixtures. If the plant coenosis is formed in a proper way, the amount of fertile pollen will be sufficient for pollination of female plants [17–19].

To ensure the purity of hybrid seeds when using this method, one should carefully cull at the previous stages of reproduction of the female and male forms, with due account for the reproductive feature of this crop, and adhere to the spatial isolation requirements.

Upon propagation of one CMS line (3–5 generations), any contamination of this line with foreign pollen or with any mechanical mixture during sowing, harvesting or processing of seeds must be completely excluded. Even the smallest number of atypical plants (especially fertility restorers), which have cross-pollinated, will render the seeds unfit for further propagation and possibly even for elite seed production.

It is also necessary to avoid mechanical mixing between the CMS line and its fixer. Upon the reproduction of a synthetic male component, the seed production requirements for varieties - populations should be followed. However, the more inbred a synthetic is, the greater the probability of foreign pollination is, since foreign gametes have advantages in fertilization [20, 21].

Another limitation to mixing seeds of parental component is that the pollinator synthetic variety, which has a higher "vigor" and shows a wide genetic variability, should not suppress the plants of a female component in a row coenosis. Therefore, it is impossible to obtain seeds of three-line hybrids using this method [10, 22–32].

In literature, there are no sufficiently convincing data that would allow us to draw conclusions about the most acceptable method of obtaining hybrid winter rye seeds using CMS. H.H. Geiger [4] and V.D. Kobylyanskiy [33] demonstrated the effectiveness of mechanical mixtures of seeds of female and male components of a heterotic hybrid. A sufficiently high amount of hybrid seeds is achieved when the seeds of the female sterile line account for 90%, and the share of the seeds of the male form is 10% [34].

This method of obtaining hybrid seeds does not require separate sowing or harvesting and, finally, can be the most profitable. When high-yielding synthetic varieties or varieties - populations are used as male components of hybrids, some admixture of non-hybrid seeds of the parental variety to hybrid seeds will not have a significant effect on the yield of F_1 hybrids. The seeding rate of a female component is another factor that directly affects the seed productivity of winter rye plants in hybridization plots.

Publications give no clear scientifically-sound and economically feasible seeding rates for parental components of hybrids. Some authors suggest using a "half" seeding rate [35], which allows for a higher seed yield. However, we think that it is necessary to know this parameter exactly lest excessive amounts of seeds of female components of hybrids should be sown and lest the risks associated with reduced quantity and quality of hybrid seeds should be enhanced [36–38].

Rye is a crop that is unpretentious to growing conditions [39–41]. Owing to its biological features, it responds very well to better weather and improved farming techniques. Biologically, winter rye is more resistant to stressors during the growing period. In addition, modern rye varieties and hybrids, thanks to breeding and the use of different genetic systems, are able to have high potentials of quantitative traits. High winter hardiness of 8–9 points, drought resistance of 7–9 points, productive tillering capacity of 8–15 shoots, spike length of 9–12 cm – such major parameters are expected from a modern variety [23, 42–44].

The response of rye plants to favorable weather conditions is manifested as a change in their habitus. The plant height, the number of fertile shoots, the spike length, and the leaf surface increase; redistribution between the vegetative and generative parts of the plant occurs [45, 46]. In addition, the number of shoots per plant increases, but lateral shoots are significantly shorter than the main ones. This, in turn, affects anthesis, in particular shorter shoots flower 5–7 days later than the main shoot, which can negatively affect caryopsis setting and lead to unseeded spikelets. If the weather during anthesis does not favor crosspollination (increased rainfall or, on the contrary, air drought), there is a high probability of damage to plants (primarily lateral shoots) by *Claviceps purpurea*. Severely damaged seeds must not be sown for seed production purposes [47].

This has an especially negative effect on obtaining hybrid seeds in hybridization plots: the sterile female form should be only fertilized by pollen of the male component (variety or line), the anthesis duration of which is limited. Even if the anthesis timeframes of the parental components of a hybrid coincide, there may be circumstances when the pollen amount from the male component will not be sufficient to pollinate lateral (shorter) shoots.

It was proven that a great amount of grain did not always mean a large amount of grade seeds. Hence, the conditions during the rye plant vegetation affect the quantity and – most importantly – the quality of hybrid seeds [48]. Upon strong thickening, rye plants become taller, which can lead to lodging and, as a consequence, to decrease the amount and quality of seeds (germination, shriveling) [49, 50].

We demonstrated that at the initial stages of seed production, when winter rye varieties are sown with a row width of 30 cm, the gross seed collection decreased by 2–3%, but the yield of grade seeds increased by 10–15%. Thus, we put forward a working hypothesis that the sowing of female components of hybrids with a row width of 30 cm contributes to the formation of productive rye stems equalized in the height of the main and lateral shoots, thanks to which all the spikes will flower simultaneously with the restorer anthesis, which, in turn, will positively affect the quantity and, most importantly, the quality of seeds.

Patterns of the construction of plant populations in a macrocoenosis allow for a correct approach to the issue of variability amplitudes of quantitative traits. Each of the yield characteristics varies in the population only within certain limits.

In winter rye, all yield elements can be divided into two groups by variation degree: weakly and strongly variable. Group 1 includes the plant height, the number of spikelets per spike, thousand kernel weight, the spike density, and the number of kernels per spike. Group 2 includes the kernel number and weight from the main spike, productive tillering capacity, and the kernel weight per plant [49].

There is a directly fixed capacity for one or another level of variability.

The variability degree is determined by genotypic peculiarities of a trait, which determine its amplitude. With a sharp change in growing conditions, when the species is in extreme conditions and its very existence is threatened, the system ensures the stability of variations of traits in the population, and when the growing conditions are altered, values of the coefficient of variation change [51–55].

According to Kobylyanskiy's and Kasaieva's data, a model winter rye variety is supposed to have the following characteristics: yield capacity – 8.0 t/ha, number of productive stems per m^2– 400–450, plant height – 90–120 cm, number of kernels per spike – 70–80, thousand kernel weight – 35–40 g, weight of kernels per spike – 2–2.5 g [44, 56–58].

Purpose. To establish the regularities of the plant stand formation in the female form of modern hybrids depending on seeding rates in winter rye hybridization plots; to prove that an increase in the seeding rate does not lead to an increase in the seed yield and entails an increase in costs for the production of hybrid winter rye seeds; to calculate the economic losses resulted from increased seeding rates due to the purchase of seeds.

Material and Methods. The study was carried out in the experimental field of the Plant Production Institute named after V.Ya. Yuriev of NAAS in 2016–2018. In the study, the female form of modern commercial winter rye hybrids (Yurivets, Yupiter) was used; it was sown by solid or wide-row planting, with a seeding rate of 750,000–4,000,000 germinable seeds per hectare.

Results and Discussion. Basing on the experience with winter rye hybrids, we believe that the parameters of a model hybrid should be as follows: yield capacity – 9.0 t/ha, number of productive stems per m^2 – 550–600, plant height –90–120 cm, number of kernels per spike – 70–80, thousand kernel weight – 35–40 g, weight of kernels per spike – 2–2.5 g. Taking into account that the average heterosis in winter rye hybrids is 15%, the model parameters of female forms of winter rye hybrids should be the same as those of varieties.

Plant density and its influence on yield. The plant density affects the yield and primarily depends on seeding rates. We analyzed the plant density in the female form of winter rye hybrids depending on the seeding rate. The optimal plant density was calculated by Savytskyi's formula for determining seeding rates with due account for the optimal density of productive stems [59].

A.P. Orliuk, A.K. Kasaieva and other researchers showed that the field germinability of winter wheat seeds was 75–80%. During the growing period, another 35 - 40% of plants die under the influence of abiotic and biotic environmental factors. Thus, 35-40% of the sown plants will remain before harvesting [44, 60]. According to V.I. Khudoierko's and V.D. Kobylyanskiy's data, the percentage of winter rye plants that survived until harvesting is 60–65% [42, 61].

Our calculations are summarized in Table 1. We determined that, if rye seeds with the laboratory germinability of 92%, the average field germinability of 80% and the average multi-year plant death from diseases, drought and other factors of 20% are sown, the average estimated number of plants in the field would be only 60% of the number of seeds sown. Thus, only 60% of the plants will be harvested (Table 1).

Table 1

Predicted pre-harvest number of plants (PNP) in the female form, Koroleva BK, upon solid and wide-row planting and various seeding rates.

Seeding rate			Predicted pre-harvest number of plants, plants/m^2
Seeds/ha	Seeds/m^2	Kg/ha	
75,000	75	22.5	48.00
1,000,000	100	30	64.00
1,500,000	150	45	96.00
2,000,000	200	60	128.00
2,500,000	250	75	160.00
3,000,000	300	90	192.00
3,500,000	350	105	224.00
4,000,000	400	120	256.00

Having compared the PNP with the observed data, we established the effects of the investigated factors on the plant density.

Figure 1 shows the predicted and observed numbers of plants per m^2 at various seeding rates in 2016–2018 (solid planting).

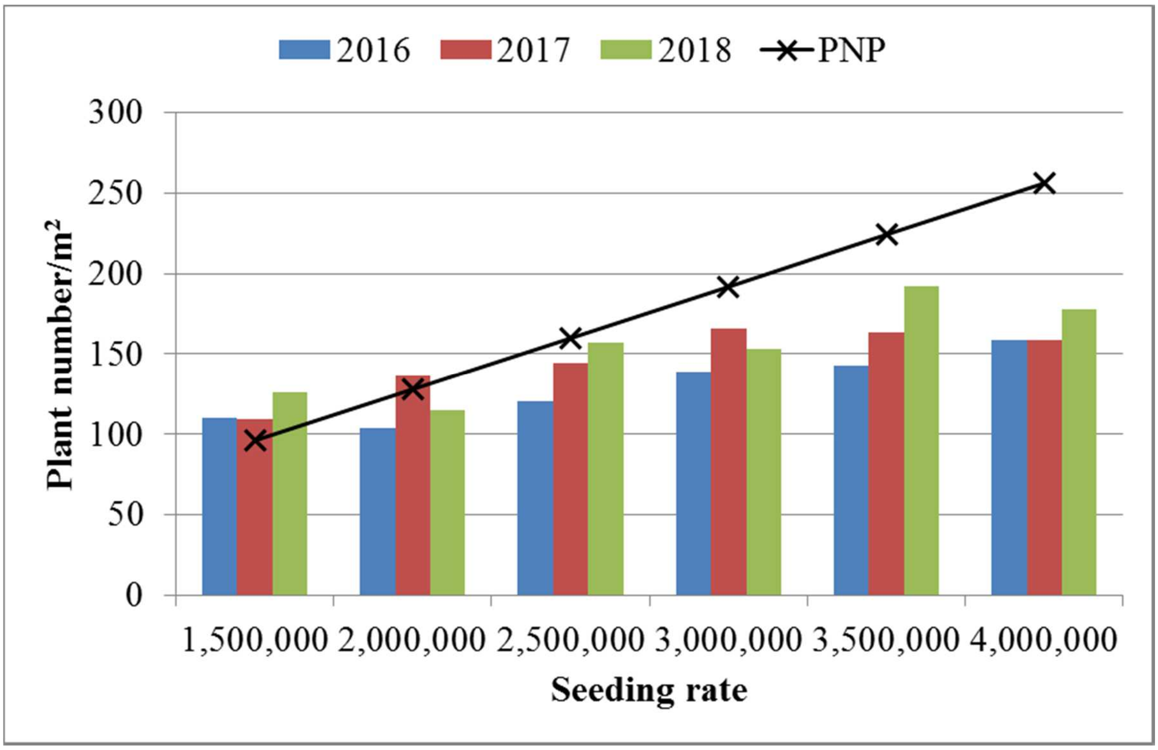

Figure 1 Predicted and observed numbers of plants in the female form, Koroleva BK, upon solid planting at various seeding rates.

We established that the predicted and observed numbers of rye plants were equal (or very similar) at the seeding rates of 1,500,000–2,500,000 germinable seeds per hectare in all the study years. That is, such seeding rates upon solid planting allow avoiding waste of extra seeds sown. The seeding rates of 3,000,000–4,000,000 germinable seeds per hectare did not ensure the estimated number of plants per unit area.

The percentage of realization of the plant number was determined depending on the investigated factors (Fig. 2)

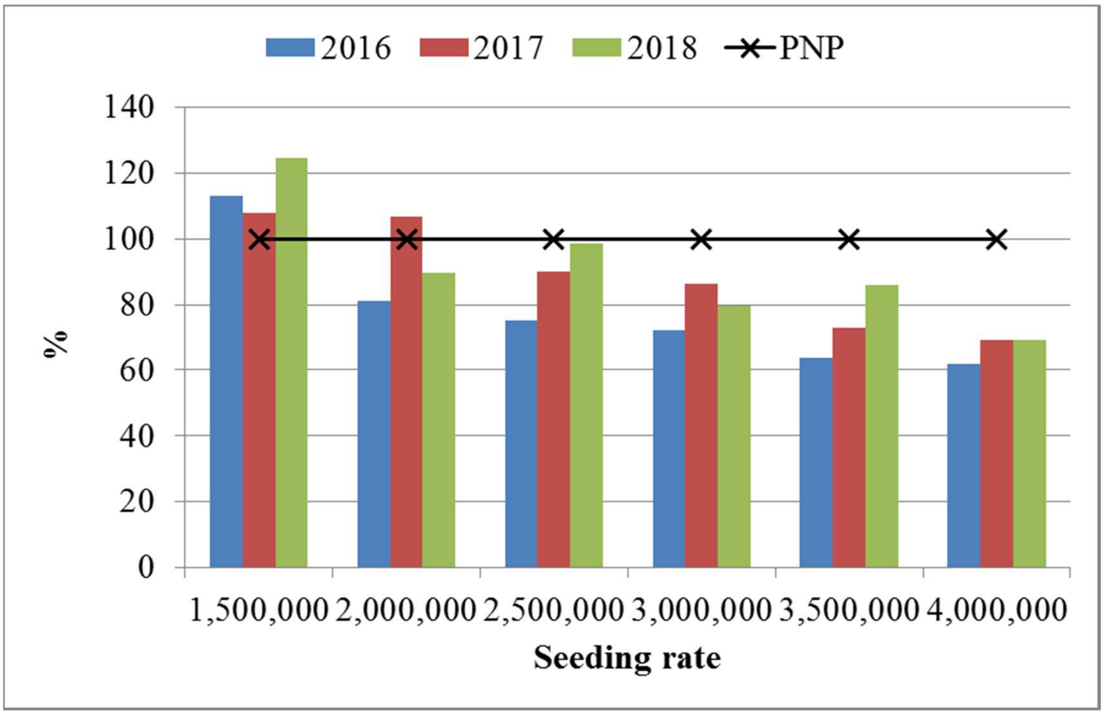

Figure 2 Percentage of realization of the potential plant density at various seeding rates (solid planting).

In all the study years, the observed plant density approached the PNP only at one seeding rate – 1,500,000 seeds/ha. At the seeding rates of 2,000,000 and 2,500,000 seeds/ha, the observed value was often 90 Zbirnyk Naukovykh Prats SHI-NTsNS 109% related to the PNP. Realization of the potential number of plants at the seeding rates of 3,000,000–4,000,000 seeds/ha was only 57–85% of the PNP.

Figure 3 shows the predicted and observed numbers of plants per m^2 at various seeding rates in 2016–2018 (wide-row planting).

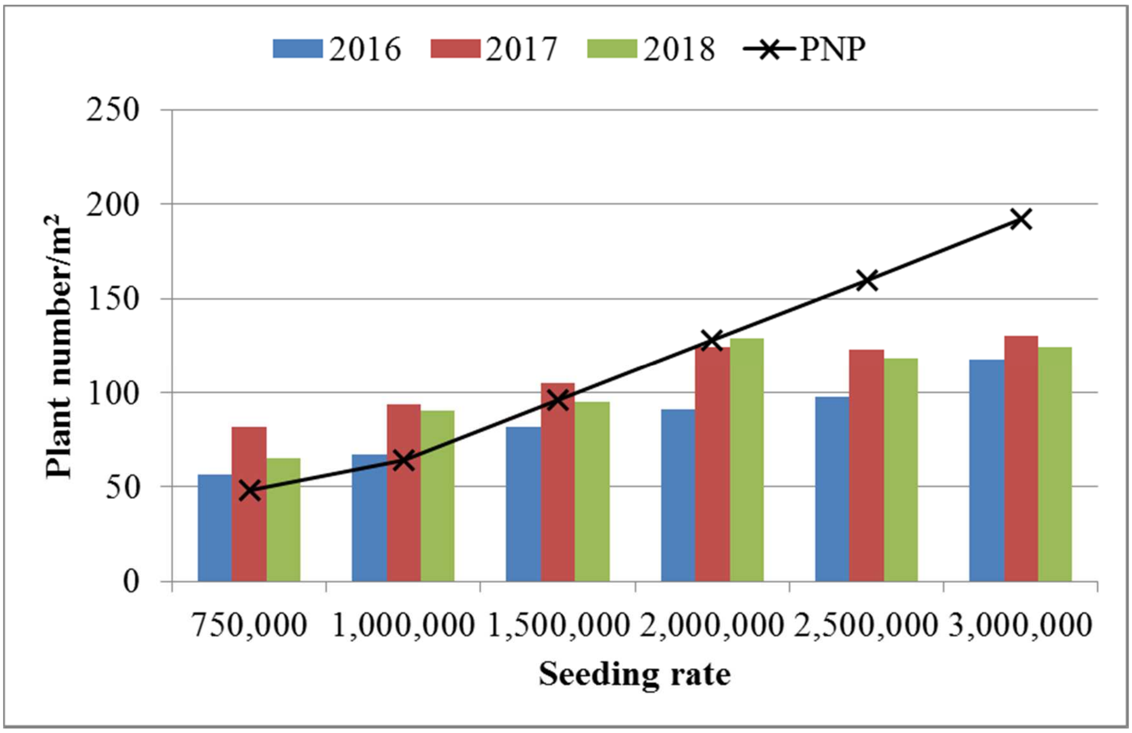

Figure 3 Predicted and observed numbers of plants in the female form, Koroleva BK, upon wide-row planting at various seeding rates.

It was found that, in all the study years at the seeding rates of 750,000–1,000,000 germinable seeds per hectare, the observed numbers of plants exceeded the PNP; at 1,500,000–2,000,000 seeds per hectare, the observed numbers were often similar to the PNP; and at 2,500,000–3,000,000 seeds per hectare, the observed numbers were significantly lower than the PNP.

Therefore, the femal form plant coenosis was better formed at low seeding rates; it was attributed to higher field germinability and survival of plants during the winter rye vegetation period.

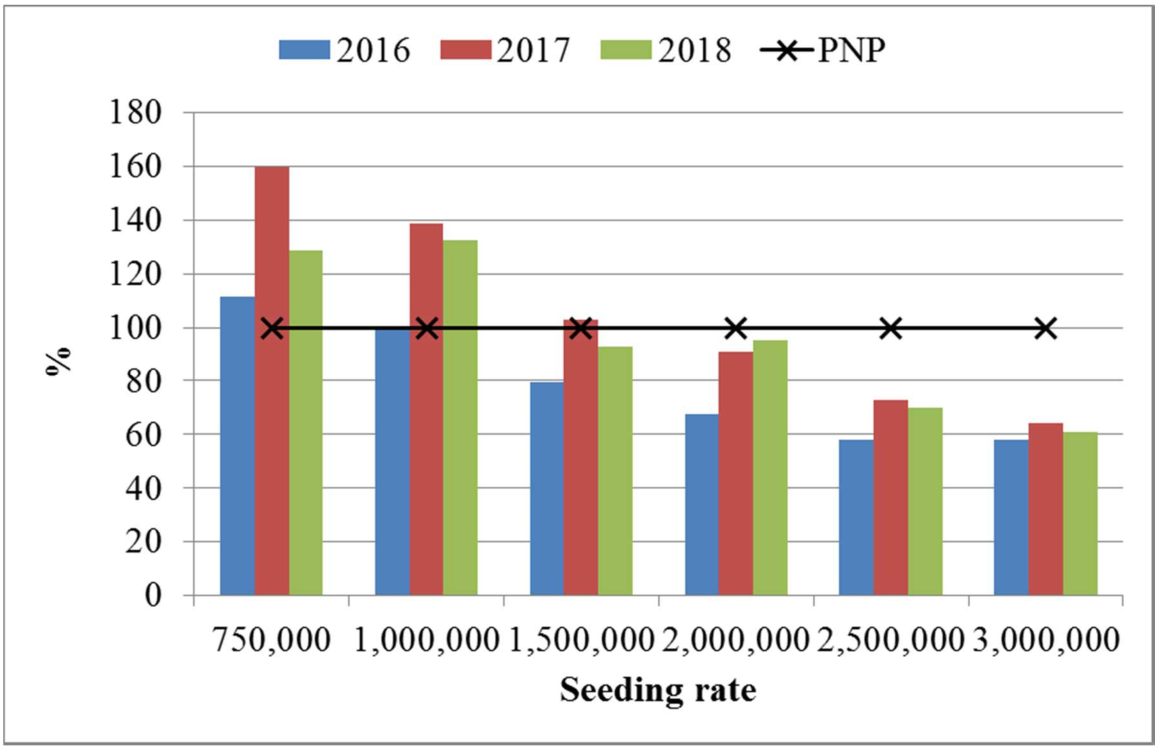

Figure 4 Percentage of realization of the potential plant density at various seeding rates (wide-row planting).

With a mechanical mixture, stable realization of the plant potential in relation to the PNP is possible at the seeding rates of 750,000 and 1,000,000 seeds/ha; it is unstable at 1,500,000 and 2,000,000 seeds/ha; on average, 70% of the plant density potential is realized at 2,500,000 and 3,000,000 seeds/ha (Fig. 4).

The main criterion for evaluating a new breeding innovation is its advantages over existing accessions and over check accessions. We believe that technologies of obtaining hybrid winter rye seeds in hybridization plots should entertain the technological peculiarities of rye growing and the characteristics of the heterosis effect in hybrids and their parents.

An important condition for the wide and rapid dissemination of an innovation is the identification of all its advantages and disadvantages. It is important for consumers to have complete information about the measures that they will be supposed to apply when using this innovation (mainly, these are the necessary costs and expected profit from implementation of the innovation).

Costs for seed directly depend on seeding rates. In Table 1, the amounts of seeds (kg) at the seeding rates under investigation are presented. The minimum sowing amount was 22.5 kg/ha (750,000 germinable seeds/ha), the maximum – 120 kg/ha (4,000,000 germinable seeds/ha). The price of seeds in the study years was ₴ 60,000/ton.

Thus, calculations showed that the profit was ₴ 93.15–449.55/ha at the seeding rates for the female form, Koroleva BK, of 750,000, 1,000,000, and 1,500,000 germinable seeds/ha in the hybridization plots. The seeding rates of 2,000,000, 2,500,000, 3,000,000, 3,500,000, and

4,000,000 germinable seeds/ha led to losses of ₴ 412.56–2386.08/ha because of purchase of extra seeds only (Fig. 5).

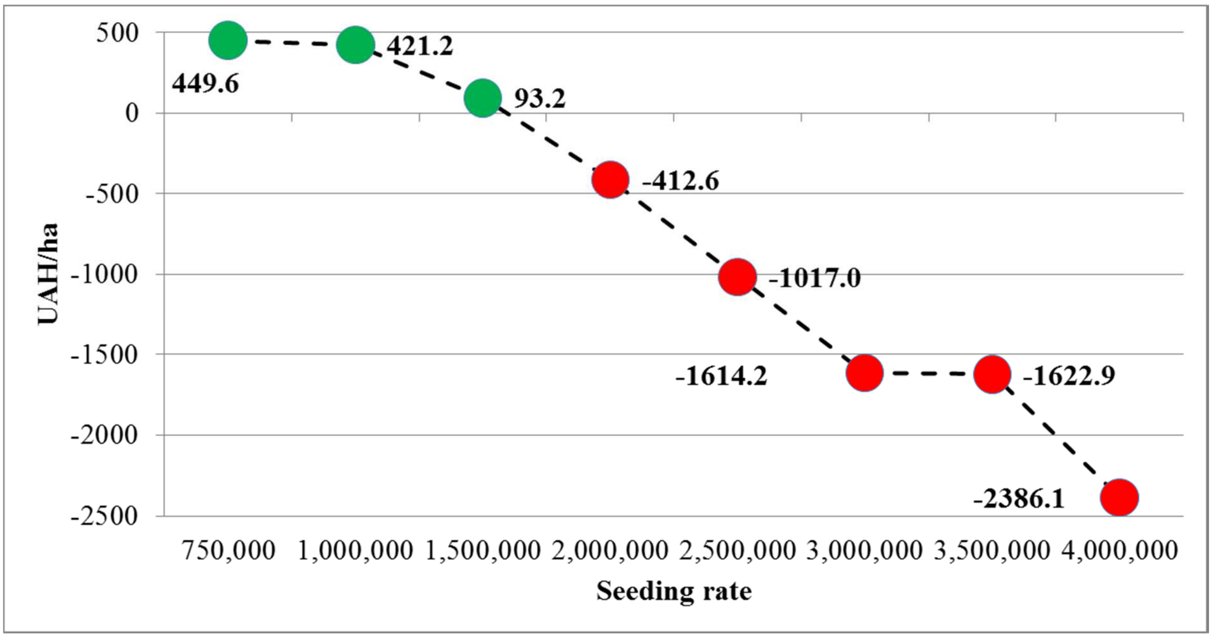

Figure 5 Profit/loss vs. seeding rate of the female form, Koroleva BK, in the hybridization plots, UAH (2016–2018).

Conclusions. It was proven that reduced seeding rates should be used to form a plant coenosis of the female component, Koroleva BK, and to obtain hybrid se[...] hybridization plots. At the rates of 750,00–1,500,000 germinable seeds/ha, the numb Costs sted plants exceeded or were close to the predicted number of plants (PNP). With the seeding rates of 2,500,000–4,000,000 ger Profit ha, the numbers of harvested plants decreased to 50–70%. The increased seeding ra[...]ficant economic losses, amounting to ₴ 412.56–2386.08 per hectare depending on the seeding rates.

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EFFECT OF SEEDING RATES ON GRAIN YIELD OF A FEMALE FORM IN WINTER RYE HYBRIDIZATION PLOTS

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Purpose. To establish the regularities of the plant stand formation in the female form of modern hybrids depending on seeding rates in winter rye hybridization plots; to prove that an increase in the seeding rate does not lead to an increase in the seed yield and entails an increase in costs for the production of hybrid winter rye seeds; to calculate the economic losses resulted from increased seeding rates due to the purchase of seeds.

Material and Methods. The study was carried out in the experimental field of the Plant Production Institute named after V.Ya. Yuriev of NAAS in 2016–2018. In the study, the female form of modern commercial winter rye hybrids (Yurivets, Yupiter) was used; it was sown by solid or wide-row planting, with a seeding rate of 750,000–4,000,000 germinable seeds per hectare.

Results and Discussion. The plant density affects the yield and primarily depends on seeding rates. We determined the level of realization of the plant density by plants of the female form of the winter rye hybrids depending on seeding rates. The optimal plant density was calculated by Savytskyi's formula for determining seeding rates with due account for the optimal density of productive stems [59]. We determined that, if rye seeds with the laboratory germinability of 92%, the average field germinability of 80% and the average multi-year plant death from diseases, drought and other factors of 20% are sown, the average estimated number of plants in the field would be only 60% of the number of seeds sown. Thus, only 60% of the plants will be harvested. Having compared the predicted pre-harvest number of plants (PNP) with the observed data, we established the effects of the investigated factors on the plant density. We established that the predicted and observed numbers of rye plants were equal (or very similar) at the seeding rates of 1,500,000–2,500,000 germinable seeds per hectare in all the study years. That is, such seeding rates upon solid planting allow avoiding waste of extra seeds sown. The seeding rates of 3,000,000–4,000,000 germinable seeds per hectare did not ensure the estimated number of plants per unit area. In all the study years, the observed plant density approached the PNP only at one seeding rate – 1,500,000 seeds/ha. At the seeding rates of 2,000,000 and 2,500,000 seeds/ha, the observed value was often 90-109% related to the PNP. Realization of the potential number of plants at the seeding rates of 3,000,000–4,000,000 seeds/ha was only 57–85% of the PNP. It was found that, in all the study years at the seeding rates of 750,000–1,000,000 germinable seeds per hectare, the observed numbers of plants exceeded the PNP; at 1,500,000–2,000,000 seeds per hectare, the observed numbers were often similar to the PNP; and at 2,500,000–3,000,000 seeds per hectare, the observed numbers were significantly lower than the PNP. With a mechanical mixture, stable realization of the plant potential in relation to the PNP is possible at the seeding rates of 750,000 and 1,000,000 seeds/ha; it is unstable at 1,500,000 and 2,000,000 seeds/ha; on average, 70% of the plant density potential is realized at 2,500,000 and 3,000,000 seeds/ha. Costs for seed directly depend on seeding rates. The amounts of seeds (kg) at the seeding rates under investigation are presented. The minimum sowing amount was 22.5 kg/ha (750,000 germinable seeds/ha), the maximum – 120 kg/ha (4,000,000 germinable seeds/ha). The price of seeds in the study years was ₴ 60,000/ton. Thus, calculations showed that the profit was ₴ 93.15–449.55/ha at the seeding rates for the female form, Koroleva BK, of 750,000, 1,000,000, and 1,500,000 germinable seeds/ha in the hybridization plots. The seeding rates of 2,000,000, 2,500,000, 3,000,000, 3,500,000, and 4,000,000 germinable seeds/ha led to losses of ₴ 412.56–2386.08/ha because of purchase of extra seeds only.

Conclusions. It was proven that reduced seeding rates should be used to form a plant coenosis of the female component, Koroleva BK, and to obtain hybrid seeds in the hybridization plots. At the rates of 750,00–1,500,000 germinable seeds/ha, the numbers of harvested plants exceeded or were close to the predicted number of plants (PNP). With the seeding rates of 2,500,000–4,000,000 germinable seeds/ha, the numbers of harvested plants decreased to 50–70%. The increased seeding rates led to significant economic losses, amounting to ₴ 412.56–2386.08 per hectare depending on the seeding rates.

Key words: *winter rye, seeding rate, plant density, female form of hybrids.*

ЗАКОНОМІРНІСТЬ ВПЛИВУ НОРМ ВИСІВУ НАСІННЯ НА УРОЖАЙНІСТЬ ЗЕРНА МАТЕРИНСЬКОЇ ФОРМИ НА ДІЛЯНКАХ ГІБРИДИЗАЦІЇ ЖИТА ОЗИМОГО

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Мета роботи – Встановити закономірності формування стеблостою рослин материнської форми сучасних гібридів від норм висіву насіння на ділянках гібридизації жита озимого. Довести, що збільшення норми висіву насіння не приводе до збільшення урожайності насіння і тягне за собою підвищення витрат на виробництво гібридного насіння жита озимого. Розрахувати економічні втрати на придбання насіння, при використанні збільшених норм висіву насіння.

Матеріал і методи. Дослідження проведено у 2016–2018 роках на дослідному полі Інституту рослинництва імені В.Я. Юр'єва НААН. Для досліджень використовували материнську форму сучасних комерційних гібридів жита озимого (Юр'їведь, Юпітер), яку висівали суцільним та широкорядним способом, з нормою висіву 0,75–4,0 млн. схожих зерен на га.

Обговорення результатів. Густота рослин впливає на урожайність та насамперед залежить від норми висіву насіння. Нами встановлено рівень реалізації рослинами материнської форми гібрида озимого жита густоти рослин в залежності від норми сівби. Розрахунки оптимальної густоти рослин на одиниці площі базувалися за формулою визначення норм висіву з урахуванням оптимальної густоти продуктивного стеблостою Савицького [59]. Ми визначили, що середня розрахункова кількість рослин, яка буде отримана в польових умовах, при посіві насіння жита з лабораторною схожістю 92% при середній польовій схожості 80% та середній багаторічній загибелі рослин від хвороб, посухи та інших факторів на рівні 20% буде складати лише 60% від кількості висіяного насіння. Таким чином, тільки 60 % рослин, буде зібрано. Порівнявши прогнозовану кількість рослин (ПКР), що будуть збиратися, з фактичними даними кількості рослин з 1 $м^2$, ми встановили залежність впливу факторів, які досліджувалися, на формування густоти рослин. Встановлено, що показники прогнозованої та фактичної кількості рослин жита співпадали (або наближалися) в усі роки досліджень при нормах висіву 1,5–2,5 млн. схожих зерен на га. Тобто використання таких норм висіву при суцільній сівбі дозволяє не витрачати зайвого насіння при сівбі. Норми висіву 3,0–4,0 млн. схожих зерен на га не забезпечували розрахункову кількість рослин на одиниці площі. За всіма роками досліджень фактичні показники густоти рослин наближалися до ПКР лише при одній нормі висіву 1,5 млн. При нормі висіву 2,0 та 2,5 млн. в більшості років показники дорівнювала 90–109% до ПКР. Реалізація потенційної кількості рослин при нормах висіву 3,0–4,0 млн. складала всього 57–85% від ПКР. Встановлено, що при нормах сівби 0,75–1,0 млн. схожих зерен на гектар в усі роки дослідження фактична кількість рослин перевищувала ПКР, при 1,5–2,0 млн. в більшості років наближалася до

ПКР, а при 2,5–3,0 млн. була суттєво нижчою. Стабільна реалізація потенціалу рослин за відношенням до ПКР при використанні стабільно можлива при нормах 0,75 та 1,0 млн., нестабільно можлива при 1,5 та 2,0 млн., а при 2,5 та 3,0 млн. реалізується в середньому на 70 %. Економічні розрахунки витрат на насіння напряму залежать від норми висіву. Наведено кількість насіння (кг) при досліджених нами норм висіву. Мінімальна посівна одиниця складає 22,5 кг/га (0,75 млн. схожих зерен на га), максимальна 120 кг/га (4,0 млн. схожих зерен на га). Ціна на насіння за роки досліджень становила 60 тис. грн. /т. Таким чином, базуючись на розрахунках нами встановлено, що використовуючи норми висіву насіння при використанні материнського компоннта Королева БК на ділянках гібридизації 0,75 млн., 1,0 млн., 1,5 млн. схожих зерен на га спостерігається прибуток від 93,15 до 449,55 грн./га. Використання норм висіву насіння 2,0 млн., 2,5 млн., 3,0 млн., 3,5 млн., 4,0 млн. схожих зерен на га приводе до втрат від 412,56 до 2386,08 грн. /га тільки на придбанні зайвого насіння.

Висновки. Доведено, що для формування ценозу рослин материнського компоненту Королева БК для отримання гібридного насіння на ділянках гібридизації, слід використовувати зменшені норми висіву насіння. При нормах 0,75–1,5 млн. схожих зерен на га кількість рослин, які збираються перевищують, або близькі до прогнозованої кількості рослин (ПКР). При застосуванні норм висіву насіння від 2,5 до 4,0 млн. схожих зерен на га кількість рослин, які збираються зменшується до 50–70%. Використання збільшених норм висіву насіння призводе до суттєвих економічних втрат, які складають від 412,56 до 2386,08 грн. на га залежно від норми висіву.

Ключові слова: *жито озиме, норма висіву, густота рослин, материнський компонент гібридів.*