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ORIGINAL ARTICLE

Sowing parameters influenced on proso millet quality and yielding capacity

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The aim of the research is to define optimal sowing parameters that ensure the highest yielding capacity and high quality of the proso millet seeds (*Panicum miliaceum* L.). To achieve a stated goal we established and analyzed multiple-factor interrelations of the formation of highly productive seed sowing of the proso millet by improving sowing methods and sowing rates as well as conditions improving sowing qualities and yielding capacity of seeds with the application of correlation pleiades. We founded that deviation from the recommended sowing rates in production results in the decline of yielding capacity level. We also suggested that the deficit of seed material caused the highest shortfalls in seed yields compared to its over-expenditure; moreover, the seed planted with wide row spacing had the best yielding capacity, while sowing with row spacing of 15 cm and sowing rate at 3.5 million seeds/ha provided the its highest yielding capacity.

Key words: Proso millet; seeds; sowing method; seeding rate; correlation pleiades

Introduction

The optimal method of sowing and seeding rate, density of plants, individual nutrition area, water, air, and light regimes determine the seeding material with high sowing and harvest conditions. Haulm stand density depends on the parameters of sowing, which also affects the complex relations in plant groups. Such inner relations are defined by solar energy and light, air carbon dioxide, nutrients, and soil water (Toure et al, 2018; Lechowski, 2007). These links are more stronger the smaller plant living spaces are. Currently, the most common methods of sowing of the proso millet are common gutter, row, and band sowing; narrow-row and cross sowing are used much less (Iqbal et al, 2013; Mesquita and Pinto 2000; Nelson, 1977).

Sowing rates of the proso millet greatly vary in the major areas of its cultivation (from 10 to 45 kg/ha or from 1.2 to 8.0 million viable seeds per hectare (Yakuta, 2013; Belogurova, 2001). Although there are no consensus on the optimal method of sowing and seeding rate of the proso millet seed among the farmers, they affirm that optimal density of the proso millet agricultural lands depends on zonal features, hydrothermal conditions of the vegetation period, the preceding crop, the prevailing weed species, function of sowings, and varietal differences (Poltoretskyi, 2017; Jahansouz et al, 2014). Therefore, the purpose of our research is to improve the technology of growing high-quality seed of the proso millet varieties, to optimize the sowing method and seeding rate in the Right-Bank Forest-Steppe of Ukraine with unstable water supply.

Methods

Field researches were conducted at the experimental field of education-scientific-production department of Uman National University of Horticulture, situated in Mankivka natural farming region of Middle-Dnieper-Bug county of Right-Bank Forest-Steppe province of Ukraine (Uman, Cherkassy region, Ukraine).

Two-factor field experiment on studying the effects of sowing method (factor A) and seeding rate (factor B) of parent plants on the sowing and yielding seed (in 2011–2014) was carried out according to the scheme shown in Table 1. We used the middle ripening variety of the proso millet "Omriyane" for sawing.

Yielding properties of parent plant seeds were tested by re-sowing for the next year (the first seed progeny), by gutter sowing method with sowing rate of 4.0 million viable seeds per ha (2012–2015).

The winter wheat have been grown in previous year. We used common technology of the proso millet growing. Experimental plot was 50 m². We made four subsequent repetitions of the variant. Harvesting was conducted by biphase method – mowing in rolls, followed by threshing in 4–6 days (combine 'Sampo'), weighing the grain and scaling it on a standard humidity and foreign matter. Yield was controlled by trial sheaves per 1 m² in all reps.

Research field soil was podzol black soil, heavy loamy, on loess with humus content of 3.5 %, with low content of alkali hydrolysable nitrogen (103 mg kg of soil – by Kornfield method). The soil was also characterized by average content of available phosphorus and high potassium content (respectively 88 and 132 mg kg as was determined by Chirikov method), high saturation level with bases (95%), medium acidic reaction of soil solution (pH_{KCl} – 6.2) and low hydrolytic acidity (2.26 resin kg of soil).

Calculation, analysis and monitoring were carried out by conventional methods (State, 2012; Eschenko et al., 2009).

The research area is characterized by unstable moisture. The comprehensive assessment of moisture and temperature conditions during research was done by the hydrothermal coefficient (HTC). Proso millet growing season in 2012 was characterized as medium dry season (HTC=0.6), while in 2011 and 2013, and 2014-2015 they were extremely humid (HTC=2.0) and sufficiently humid

(HTC=1.0–1.5), respectively. The hot weather was during almost all the time of the full maturity and only in 2011 we registered significant amount of precipitations caused a partial crops lodging and hinder harvest.
For comparison of vitality and viability indicators we proposed *the generalized indicator of seed quality,* which is the integrative percentage among a certain group of indicators (energy (*%*), rate (*days*) and simultaneity of seed germination (*plants day*), its growth power (*%*) and laboratory similarity (*%*) (Poltoreczkyj and Bilonozhko, 2014).
To build correlation pleiades, we determined the influence of growing conditions on the formation of sowing qualities and yield properties of the proso millet seed; we also calculated the relationship between F1 plants yield and agronomic characteristics of seeds from parent plants. The seed agronomic charcteristics were: **A** – germinating readiness (%); **B -** emergence rate (days); **C** – seedling vigor (seeds day^{-1}); **D** – germinative power (%); **E** – laboratory germination (%); **F** – integrative quality score (%); **G** – mass 1000 seeds (g); **H** – seed weight (g/L); **I** – uniformity of seeds (%); **J** – seed hull content (%); **K** – seed yield (t/ha); **L** – seed protein content (%); **M** – seed fat content (%); $\mathbf{Y_1}$ – parental yield (t/ha); $\mathbf{Y_2}$ – F1 yield (t/ha). We used only correlations with r > 0.5 for correlation pleiades drawing (Borovikov, 2003; Terentev, 1960).

Results and discussion

Analysis of yield data obtained from re-sowing of seeds indicates that the studied parameters of sowing caused significant heterogeneousness of its yield properties (see table 1).

Table 1. Effect of sowing parameters of the proso millet seeds on yielding properties in F1 seed generation, t/ha.

Seeding rate, seeds 10^6/ha (*factor B*)	**Seed sowing (2011–2014)**	**The F1 seed generation (2012–2015)**	**Average application rate**
Sowing method (*Factor A*) – Gutter sowing (15 cm)			
3.0	4.14	4.07	
3.5	4.66	4.87	3.90
4.0 (*control*)	4.89	3.40	
4.5	4.89	3.25	
Sowing method (*Factor A*) – wide-row planting (30 cm)			
3.0	3.50	4.32	
3.5	3.86	4.97	4.17
4.0 (*control*)	4.20	3.78	
4.5	4.09	3.61	
Sowing method (*Factor A*) – wide-row planting (45 cm)			
3.0	2.86	3.26	
3.5	3.31	5.11	4.16
4.0 (*control*)	3.69	4.53	
4.5	3.63	3.72	
$LSD_{05\,(A)}$	*0.11–0.14*	*0.10–0.15*	
$LSD_{05\,(B)}$	*0.16–0.19*	*0.11–0.18*	
$LSD_{05\,(total)}$	*0.25–0.29*	*0.19–0.30*	

Thus, on average for years of research, the formation of the higher yield level of sowings of first seed progeny provided the seed grown under both variants of wide-row planting – respectively 4.17 t/ha (30 cm) and 4.16 (45 cm), compared with 3.90 t/ha for common gutter sowing at 15 cm. In all the research years, the advantage was accurate and varied within 0.18–0.34 t/ha ($LSD_{05(A)}$ = 0.10–0.15 t/ha). Thus, similar to the high level of indicators of sowing quality (first place by the integrated indicator), the combination with wide-row planting at depth of 45 cm and the rate of sowing 2.0 million seeds ha^{-1} contributed to formation of the best yield properties – for years of researches, the productivity of sowings of first seed progeny in these areas was highest in the experiment (4.99–6.03 t/ha). The seed grown with row spacing of 30 cm and seeding rate of 2.5 million seeds/ha somewhat inferiors to it – yield was at the level of 4.23–5.82 t/ha or on 0.08–0.21 t/ha less. Within the width of row spacing, the quantitative seeding rates also significantly dominated over the other variants of features of placing seeds in a row – on average for years of researches, the shortage of seed harvest of first seed progeny amounted 0.58–1.85 (45 cm) and 0.65–1.36 t/ha (30 cm).
Comparative analysis of the yield data of the first seed posterity allows to set high efficiency of common gutter sowing during the growing of seed sowings. Thus, after the sowing of 3.5 million seeds/ha, seeds are formed that by its yield properties are not inferior to the best variant of wide-row planting of 30 cm depth (2.5 million seeds/ha) – on average yield amounted 4.87 t/ha, which was only by 0.10 t/ha less. Compared to the best variant of sowing parameters in the experiment (45 cm and 2.0 million seeds/ha), yield shortage was significant (0.24 t/ha). However, on the plots with a width of row spacing 15 cm and seeding rate of 3.5 million seeds/ha, the yield increase compared with the best variants of both types of wide-row planting amounted 0.80–1.35 t/ha (see Figure 1), and these sowing parameters can be used in the proso millet sowing technology.
Considering the weather conditions of the research year, seeds grown under moderate hydrothermal conditions were characterized by better yield properties. Thus, in 2014 (HTC=1.0) the average yield amounted 4.76 t/ha, which was higher by 0.77 and 1.28 t/ha respectively compared to over moistened conditions of 2011 (HTC=2.0) and more droughty conditions of 2012 (HTC=0.6) of parent plants vegetation.
Outlined from the dispersion of data processing, the weather conditions of a growing year has 41 % share among the factors that influenced the formation of the yield level of the first seed posterity. Depending on the studied parameters of sowing, the effect of optimal placement of seeds in a row of parent sowing was the most significant (factor B)– 2 %. Share of influence of sowing method (factor A), and the features of parameters of formation of individual nutrition area of parent proso millet plants (interaction AB) appeared almost equivalent – respectively 12 and 15 %.
We checked the modifications resulted from the influence of sowing parameters and climatic conditions on yielding capacity of seeds sowing of the proso millets during a year of growth (Table 2).

Table 2. The influence of sowing parameters on the quality of the proso millet seeds (2012–2015).

Seeding rate, seeds 10^6/ha (*Factor B*)	Germinating readiness, %	Emergence rate, days	Seedling vigor, seeds day^{-1}	Germinative power, %	Laboratory germination, %	Integrated seed quality score, %	Rating
Sowing method (*Factor A*) – Gutter sowing (15 cm depth)							
3.0	87.7	2.24	15.9	92.2	93.8	93.2	8
3.5	90.7	1.99	17.0	94.0	95.7	98.1	2
4.0 (control)	86.7	2.32	15.1	90.7	91.2	90.6	10
4.5	86.8	2.33	15.0	90.0	90.5	90.3	11
Sowing method (*Factor A*) – Wide-row planting (30 cm)							
3.0	85.5	2.36	16.1	88.7	90.5	90.7	9
3.5	89.3	2.12	17.3	94.5	96.0	97.1	3
4.0 (control)	88.8	2.25	16.5	92.5	94.3	94.2	6
4.5	87.7	2.21	16.1	90.8	92.7	93.2	7
Sowing method (*Factor A*) – Wide-row planting (45 cm)							
3.0	83.2	2.58	13.3	85.0	86.7	84.1	12
3.5	90.5	2.14	18.3	95.0	96.8	98.6	1
4.0 (control)	88.7	2.18	17.6	92.7	94.0	96.0	4
4.5	88.3	2.28	17.4	92.5	93.0	94.6	5

The combination of wide row spacing with inter-row spacing at 45 cm and sowing rate at 2.0 million of viable seeds/ha fostered the formation of the highest level of seedlings vigor (18.3 seeds/day), germination readiness (95.0), and laboratory germination (96.8). The same variant of sowing provided the highest value of integrated parameter of quality – 98.6 % (the first place).

The variants of sowing by common row method with the rate of 3.5 million seeds/ha and wide-row sowing at 30 cm and 2.5 million seeds/ha turned out to be less effective. The level of abovementioned parameters lowered and formed corresponding values of integrated parameter 98.1 (second place) and 97.1 % (the third place). With the increase in sowing rate from 2.0 to 3.0 million seeds/ha the quality of seed material deteriorated even under wide-row sowing (the 4th and 5th place), however, according to the laboratory germination (94.0 and 93.0 %) it remained in the elite category.

Excessive thinning of parent plant density (inter-row spacing is 45 cm and sowing rate is 1.5 m seeds/ha) as well as increasing of plant density (inter-row spacing is 15 cm and sowing rate 4.0–4.5 m seeds/ha were the least effective for the technology of seed sowing (it corresponds to the 12th, 11th, and 10th place). In addition, the seeds grown on these seedbeds did not correspond to the elite category according to the level of laboratory germination (less than 92 %). The maximum decrease (by 1.0 m seeds/ha) of a recommended quantity rate (the 9th place) had the similar negative effect on the formation of the quality of seed material (9th place) under wide row sowing with inter-row spacing of 30 cm. In our experiments, the wide row sowing with inter-row spacing at 45 cm (except the variant with minimum sowing rate) facilitated the formation of the highest quality of seed material with integrated quality parameter up 96.4 %. In other variants of inter-row spacing in seed sowing, this parameter decreased to 93.1–63.8 %.

Obtained results substantiate the recommendations as to the application of wide row sowing method for seed sowing of field crops. Thus, according to the laboratory parameters, the wide row sowing with inter-row spacing at 45 cm and 30 cm respectively and quantity sowing rates at 2.0 and 2.5 million similar seeds/ha provided high sowing quality of a grown seed. However, the application of a common row sowing method with inter-row spacing at 15 cm and sowing rate of 3.5 m seeds/ha turned out to be also effective. It is obvious that under above-mentioned sowing parameters for the parent plants of proso millet of Omriyane cultivar, the best conditions are created for the formation of the best sowing properties of seeds.

We draw the correlation pleiades (Figure 1), which shows that plant yielding capacity in F1 seed generation (**Y_2**) is closely related with two sets of properties: sowing characteristics (**A-F**) and yielding capacity of seed (**G-J**), formed under the influence of investigated sowing methods, sowing rates, and climatic conditions during the year of growth. Biological interpretation of the obtained correlations allowed to combine them in symmetrical links of branching with separate spheres of influence. Yielding capacity of the proso millet grain (**Y_2**) was determined via integrated quality evaluation (**F**) of seed (r = 0.98 ± 0.00) and analyzed laboratory parameter; it is directly correlated with seedling vigor (**A**), germinating readiness (**C**), germinative power (**D**), and laboratory germination (**E**), r = 0.72…0.91 ± 0.01; however, it was inversely depended on emergence rate (**B**), r = -0.75 ± 0.01.

Besides, all analyzed parameters of sowing quality of the proso millet seed material turned out to be interdependent and were in strong inter-relation. Evaluation of the character of these interactions allowed to build five-radius geometric figure with integrated seed quality score (**F**) in its center.

The level of this parameter strongly and directly depended on the seedling vigor (**A**) and germinating readiness (**C**), germinative power (**D**) and laboratory germination (**E**), correspondingly, r=0.94…0.98 ± 0.00; and it also inversely and strongly interacted with emergence rate (**B**), r=0.95 ± 0.00. Number of days necessary for emergence rate (**B**) was in a negative inverse correlation with the other parameters of the quality of seed material within these pleiades (r=0.80…0.95 ± 0.00).

The character of correlations among yielding capacity of grain, sowing properties of seed material and its technological, cereal standards turned out to be different. According to the results of the multiple correlation analysis it was possible to include into the created pleiades only the mass of 1000 seeds (**G**), seed weight (**H**), and hull content (**J**) from all analyzed technological parameters. All other parameters were excluded, because they did not meet the requirements of building these pleiades (r < 0.5).

Taking into account power of influence of physical and technological standards of seed on its sowing properties and yielding capacity in the next generation (the F1 seed generation) we managed to single out separate circles with their own spheres of influence.

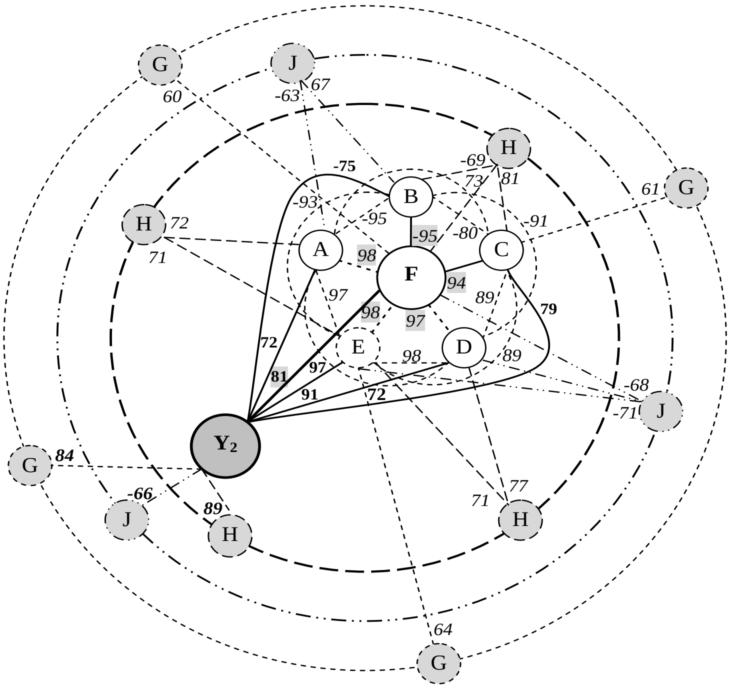

Figure 1. Correlation pleiades of sowing qualities and yield properties of the proso millet seeds formed under the influence of sowing parameters, the average for 2011–2015. Numbers are the values of correlation coefficient after the decimal point.

Direct correlation between mass of 1000 seeds (**G**) and laboratory parameters of quality (r=0.60…0.64 ± 0.04) turned out to be the least strong (outer circle): only with germinating readiness (**C**), its laboratory germination (**E**) and integrated quality parameter (F) correspondingly. The effect of hull content (**J**) was stronger (the middle circle) and of reversible character (r=-0.63…-0.71 ± 0.04). The greater amount of hulls indicated less full-weight of seed, deterioration of its seedling vigor (**A**) and germinating readiness (**C**), germinative power (**D**) and laboratory germination (**E**) and considerably slowed down (r=0.67 ± 0.02) the emergence rate (**B**).
Correlations of sowing properties of seed material and seed weight (**H**) were the strongest (the inner circle). Thus, the sphere of their correlation included positive correlations (r=0.71…0.81 ± 0.00) with all investigated parameters, except the emergence rate (**B**), where decline in grain-unit showed the deteriorating of its sowing standards (r=-0.69 ± 0.03).
In its turn, like sowing qualities of seed, according to the abovementioned parameters it is possible to forecast the yielding capacity of the proso millet in the next generation (the F1 seed generation). Thus, optimization of the density of seed cenosis will provide the formation of full weight seed material with potentially high yielding properties. Like sowing properties of seeds, above-mentioned physical and technological parameters can also indicate the level of yielding capacity of the proso millet in the next generation (the F1 seed generation) (Poltoretskyi, 2017; Grygoraschenko, 2010).
Thus, we established a strong positive correlation (r=0.84 and 0.89 ± 0.00) among mass of 1000 seeds (**G**), seed weight (**H**), F1 yield (**Y2**), and negative correlation with seed hull content (**J**), r=-0.66 ± 0.04. Obtained results show that under optimization of parameters of placing parent plants in seed sowing the better conditions are provided for the formation of full-weight seed material with potentially high yielding capacity in the next generation.

Conclusions

The deviation from the recommended in production seeding norms, in each of the studied methods of sowing, causes the reduction of yield level. The biggest shortfall of seed yield caused the shortage of seed material, compared to its overruns. Share of impact of seeding rate for years of research was at the level of 19–26 %;
A similar tendency, concerning the decrease of yield level, can be traced in the sowing method – with increase of row spacing from 15 to 45 cm, the level of this indicator in parent plants is also significantly reduced. Share of impact of sowing method for years of research was at the level of 57–65 %;
The best yield properties had the seed grown under both variants of wide-row planting – respectively 4.17 t/ha (30 cm) and 4.16 (45 cm), compared to 3.90 t/ha under common gutter sowing at 15 cm. However, taking into consideration the significantly higher productivity (on 0.80 – 1.35 t/ha) of plots of common gutter sowing method with seeding rate of 3.5 million seeds/ha, such sowing parameters can also be used in the proso millet sowing technology;
Among the factors that influenced the formation of the yield level of the first seed posterity, stood out the weather conditions of the growing year – 41 %. Depending on the studied parameters of sowing, the effect of optimal placement of seeds in a row of parent sowing was the most significant (factor B) – 32 %. Share of influence of sowing method (factor A), and the features of parameters of formation of individual nutrition area of parent proso millet plants (interaction AB) appeared almost equivalent – respectively 12 and 15 %.

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