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Relationships Between Seeding Densities and Selection Parameters in Bread Wheat (*Triticum aestivum* L.) Genotypes under Rainfed Conditions

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ABSTRACT

Agronomic approaches are important for high yield in changing environmental conditions such as climate and soil structure. Drought and heat stress due to climate change require the determination of tolerant genotypes using different seeding densities in bread wheat. The experiment was carried out in the Trakya Agricultural Research Institute experimental field in the 2015-2016 and 2016-2017 growing cycles. In the research, 8 bread wheat genotypes and three different seed densities of 400, 500 and 600 grains per square meter were used. The study was conducted in the randomized complete blocks design. Data on, the number of spikes and grains per spike, the number of spikes per square meter, grain yield, peduncle length and spike length, flag leaf area and normalized difference vegetation index were examined. In the study; year, genotype and year×genotype interaction were significant. The mean grain yield was 6197 kg ha^{-1}. Genotype G6 produced a higher grain yield with 7730 kg ha^{-1}. The results of the research showed that there was no significant difference between the seed densities for grain yield. However, it was observed that using 500 seeds per square meter had a higher grain yield (6280 kg ha^{-1}). The maximum peduncle length (31.04 cm) and spike length (8.94 cm) were determined in the application using 400 seeds per square meter. The use of 400 seeds per square meter produced the maximum spikelet number per spike (17.90). According to seeding density, the maximum number of spikelet's (535.6) and flag leaf area (24.51 cm^2) were obtained when 500 grains per square meter were used.

Keywords: Wheat genotypes, seeding density, yield, yield component, physiological parameters

Introduction

The number of plants or ears per unit area according to different environmental conditions and soil structure is the most significant factor determining the yield of bread wheat. Tillering potential and environmental conditions should be considered for wheat's planting density. Genotypes with low tillering potential show a higher effect on yield and spike weight due to the increase in seed density. The number of grains per ear reveals the lowest genotype effect and is strongly affected by the planting rate (Valerio et al., 2013). Plant rate in a square meter is one of the main factors determining the crop's ability to capture resources. Wheat production is important because it is under the control of the farmer in the planting system (Satorre, 1999). Optimum plant densities vary significantly between regions, climates, soil types, planting times and cultivars. Because varieties are genetically different in their yield components, varieties require to be examined over a broad range of seeding rates to establish optimum seeding rates (Wiersma, 2002). The planting date is highly affected by the optimum planting percentage, mainly controlled by climatic conditions and crop rotation requirements. Latitude and longitude, as well as the temperature of the production area, also affect the growing time (Gooding and Davies, 1997). It is important to use the most appropriate planting density to achieve the highest production efficiency. If an excessive seed rate is used, as the plant population will increase, there will be competition for water, nutrients and sunlight in the plant, and as a result, productivity and quality will decrease. If a lower seed rate is used, the yield will be lower as the plant number per unit area will decline (Attarde and Khuspe, 1989). However, this compensatory mechanism may vary depending on bread wheat genotypes (Dahlke et al., 1993; Lloveras et al., 2004). It is known that the optimum seed rate may increase with the influence of environmental factors (Arduini et al., 2006; Gooding et al., 2002). Nevertheless, increasing planting frequency does not always increase yield because as seed density increases, competition between plants also increases (Park et al., 2003). Appropriate planting rates help to ease the conflict between individuals and populations by establishing a reasonable population structure. It is also useful to coordinate the development of spike number, spike grain number and grain weight of winter wheat (Wang et al., 2011). The seeding densities influence the wheat population, which further influences the use of soil water and nutrients and ultimately affects wheat growth and yield formation (Kühling et al., 2017). Wheat yield rises with the increase in seeding densities under the low planting densities and rises at a certain threshold value, after which it might not increase and may even cause a decrease in grain yield (Bhatta et al., 2017).

Determining the optimum seed density in varieties is very essential for high-yield potential. Seed frequency to be used in sowing may vary according to dry and productive conditions. Different soil structures also such as sandy or loamy can also be effective in seed density. Soil moisture and temperature after planting are also important factors in tillering. The genetic factor is the most important factor in determining seed density, as it requires the use of lower seed density in varieties with high tillering ability. Depending on the vernalisation needs, some cultivars may have early and fast tillering, while in some cultivars it may be late. This is especially important in early drought and provides an advantage to early and fast-growing varieties. In the research, the impacts of various planting density treatments on grain yield and yield components in some wheat genotypes under rainfed conditions and the relationships between the parameters were examined.

Materials and Methods

The experiments were completed during the period of the 2015-2016 and 2016-2017 growing cycle's breeding field area in Edirne locations, in the northwest of Türkiye. The study site is located in the Trakya region lowland, the experiment site is 41° 38′ 55″ N, 26° 36′ 06″ E and the altitude is 40 m. In the research, 8 bread wheat genotypes (Saban, Köprü, Yüksel, BBVD7-2014, BBVD24-2014, BBVD3-2015, BBVD12-2016, BBVD17-2016) and 3 different seed density (400, 500 and 600 kernel per square meter) applications were examined under rainfed conditions. The study was a split plot randomized complete blocks design with four replications. In the experiment plot area was 6 m^2, with 6 rows and 0.17 cm spaced rows. The following field characters were evaluated; a number of spikes per square meter (SNM), the number of spikelet per spike (SNS) and the number of kernels per spike (KNS) were counted after harvesting for each genotype. Grain yield (kg ha^{-1}) was determined in a 6 m^{-2} plot area. Spike length (SL) and peduncle length (PL) were determined by scaling ten randomly selected plants in each subplot at physiological maturity for tested genotypes. At the heading stage (Z55) normalized difference vegetative index (NDVI) was measured defined by Reynolds et al., 2001, Reynolds et al., 2012 and Pask et al., 2012. During the heading period, the width and length of 10 flag leaves were measured and multiplied by 0.68 to determine the average flag leaf area (Fowler and Rasmusson, 1969). Normalized difference vegetative indices (NDVI) was scaled at the heading phase of the genotypes (Gutierrez-Rodriguez et al, 2004). The Zadoks Decimal Code (Z) defined plant growth stages (Zadoks et. al., 1974).

Statistical Analyses

Data were analysed statistically using L.S.D (Least Significant Difference at 5%) to test the significant difference between means (Gomez and Gomez, 1984; Steel and Torrie, 1980). Correlation coefficient analysis for the relationship between parameters was performed according to the Dewey and Lu (1959) method.

Climate Data

Total precipitation and temperature in the studied field area in the 2015-2016 and 2016-2017 cycles are given in Table 1. In the experimental area, monthly total precipitation in the 2015-2016 cycles was higher and in 2016-2017 lower than the long year. Total rainfall in November and December in both cycles was much lower than in a long year. Average temperature was very low in 2016-2017 and higher than the average in 2015-2016 cycles.

Results and Discussion

Plant density per unit area is an important factor affecting the many components in wheat genotypes. Plant ratio per unit area is one of the essential factors and it varies according to climatic conditions, soil type, planting time and genotype effect. The results of variance analysis indicate considerable variations ($p<0.01$) among genotypes (G), among years (Y) and their interaction (Y×G) for all parameters examined.

The interaction of seeding densities (treatment) was non-significant statistically in all data investigated except for the flag leaf area. In the flag leaf area there was a significant difference in treatment, Y×T and G×T interactions. The grain number per spike, which is one of the important factors determining yield, is affected by drought and temperature during grain filling, sowing frequency also has an important effect. The interaction of G×T and Y×G×T was statistically significant according to grain number per spike (Tables 2 and 3).

The appropriate seeding rate in wheat genotypes may differ based on climate effect, soil type and genetic structure. Grain yield in genotypes differed from the highest 7730 kg ha^{-1} in G6 to the lowest 4994 kg ha^{-1} in G1 (Table 5). In the experiment, the average yield was 6197 kg ha^{-1}. According to genotypes, the maximum yield was produced by genotypes G6 and G5. The data showed that spike length and peduncle length differed significantly by the seeding rate of the genotypes. Based on seeding rates, the longest peduncle (33.37 cm) was measured in genotype G7 followed by G4. Genotypes G7 and G4 exhibited the longest spike length with 9.52 cm and 9.50 cm, respectively. Different seeding densities significantly affected the spikelet number per spike, genotype G2 produced a maximum spikelet number in spike (19.28) closely followed by G7 with an 18.71 spikelet number (Table 4).

Kernel number per spike varied among genotypes. While the highest kernel number was determined in G4 (44.78) the lowest grains were established in G1 (33.91). The spike number in a square meter may vary depending on the sowing depth, plant ratio and genotype. In the study, the spike number in a square meter varied among genotypes, the minimum was 455.6 in genotype G7 and the highest was 592.9 in genotype G3. Flag leaf is an important plant organ that contributes to productivity through photosynthesis. The maximum flag leaf area was scaled in genotype G1 (26.20 cm^2) and followed by G7 (25.88 cm^2), while the minimum (17.68 cm^2) flag leaf area was recorded in genotype G3. The mean normalized difference vegetative index (NDVI) of wheat genotypes was 0.59; genotype G1 had a higher NDVI and G2 had the lowest NDVI (Table 4).

In the study, no significant difference was found in yield according to seed density. The use of only three different seed densities can be considered one of the factors. Nevertheless, the using of 500 seeds in a square meter yielded higher yield potential in genotypes. There were also no statistically differences among seeding rates for other parameters tested. Using only one lower and upper ratio of the recommended seed density caused the application to be insignificant. In the study, longer spike (8.94 cm) and peduncle length (31.04 cm) were obtained when 400 seeds were used per square meter. As expected in the study, a higher number of spikelets was determined at sparse seed density. The highest number of spikelet was 17.90 when 400 seeds per square meter were used (Table 5). Peduncle length, spike length, spikelet number per plant and kernel number per plant decreased along with the seeding rate. Normalised difference vegetative index increased with increasing seeding rate.

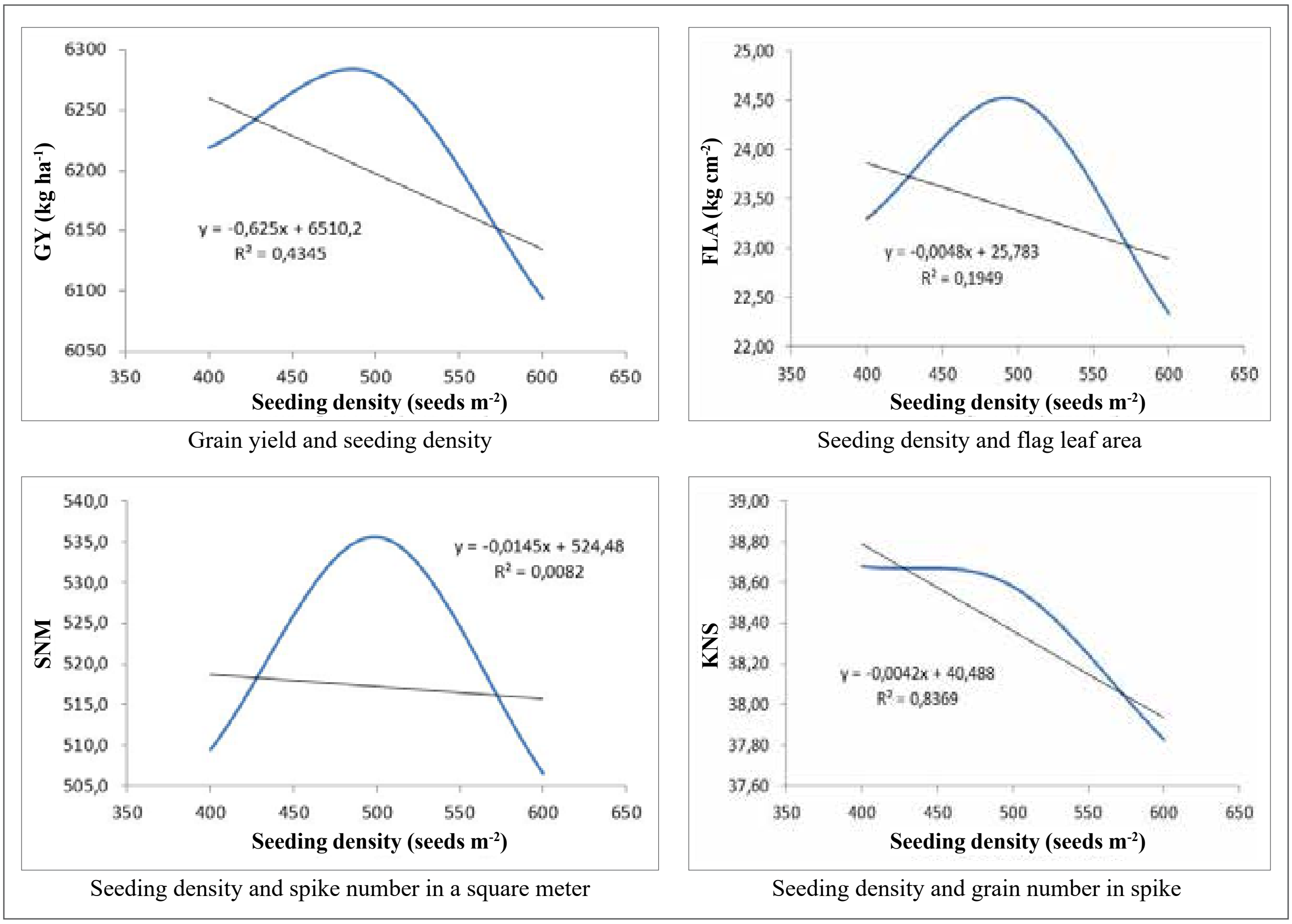
The number of grains per ear is among the essential yield components. The highest number of grains per spike was determined at 400 and 500-grain frequencies. The maximum spikelet number per square meter (535.6) was scored when 500 seeds were used per square meter. The results showed that seeding rate significantly influenced the flag leaf area of wheat genotypes. The largest flag leaf area (24.51 cm^2) was determined in the application using 500 seeds per square meter. In the experiments, NDVI increased with increasing seed frequency (Table 5). The fact that the application of seeding density is not important has shown that these studies should carry on under various environmental conditions and various seeding densities. It is possible to interpret that the expected result cannot be obtained in some parameters according to the seed frequency, the genotypes are similar and the research area has a similar environment. Therefore, similar studies should use different genotypes and be conducted in different environments.

Comparisons among the parameters examined in the study and different relationships were found (Table 6). In the study, all parameters except normalised difference vegetative index were found to have a positive relation with yield. A positive association was found between grain yield with the number of spikes in a square meter (p=0.809), the number of spikelet in a spike (p=0.592), the number of grains in a spike (p=0.907), the length of the peduncle (p=0.618) and flag leaf area ($r=0.966^{*}$). Positively relation was found to be with flag leaf area and spikelet number in spike, kernel number in spike (r=0.766), spikelet number per square meter (r=0.934) and peduncle length. Correlation coefficients for wheat genotypes showed that a negative association between normalised difference vegetative index and grain yield (p=-0.659), peduncle length ($r=-0.998^{**}$), spike length (r=-0.903), spikelet number per spike ($r=-0.996^{**}$), kernel number per spike (r=-0.915). The results showed that the largest flag leaf area significantly influenced the yield components such as kernel number per spike, spikelet number per spike and spike number per square meter of winter wheat.

In the study, pairwise relations between seeding rate and the parameters tested were examined. Peduncle length, spike length, spikelet number per plant and kernel number per plant decreased along with the seeding rate. Normalised difference vegetative index increased with increasing seeding rate (Figure 1).

Conclusions

Adjustment of seeding densities is one of the main crop management procedures that most impact grain yield components. In the study, genotypes, years and the interaction between them were statistically significant. The use of 500 seeds per square meter had a higher grain yield in genotypes. The highest yielding potential was performed by genotypes G6 and G5. The data showed that peduncle length and spike length differed significantly by the seeding rate of the genotypes. The longest peduncle length was observed in G7 followed by G4. Genotypes G7 and G4 exhibited the longest spike length. Seeding densities greatly influenced the spikelet number in spike and genotype G2 produced the maximum spikelet number. The spike number in a square meter differed based on genotypes and seeding densities used. Genotype G1 had the maximum flag leaf area. In the research, the longest peduncle and spike with the highest spikelet number per spike were determined in the application of 400 seeds in a square meter. The highest spikelet number per spike and flag leaf area was obtained using 500 kernels per square meter. It would be useful to conduct studies using different seed densities to determine the adaptation of bread wheat genotypes to changing environmental conditions. Drought and heat stress due to climate change increases its effect on grains produced under rainy conditions. Morphological, agro-physiological and biochemical responses occur in plants against drought and heat stress. In drought conditions, the number of plants per unit area that share water in the soil is the most important factor in drought tolerance. Therefore, it is necessary to determine tolerant genotypes using different planting densities in drought stress conditions.



Grain yield and seeding density

Seeding density and flag leaf area

Seeding density and spike number in a square meter

Seeding density and grain number in spike

Figure 1. Association with yield and yield component with curves for the regression analysis at different seeding density levels.

Table 1. Total rainfall and mean temperature in 2015-2016 and 2016-2017 cycles and long year.

Months	Long year		2015-2016		2016-2017	
	Rainfall (mm)	Mean temp. (°C)	Rainfall (mm)	Mean temp. (°C)	Rainfall (mm)	Mean temp. (°C)
October	52.9	14.1	52.6	15.6	44.4	14.3
November	72.4	8.5	26.2	13.5	3.2	0.7
December	61.7	4.2	0.3	5.5	3.2	0.7
January	48.1	2.8	114.8	2.8	67.8	-1.9
February	46.9	4.2	91.4	9.2	43.4	5.3
March	52.2	7.6	54.8	10.2	51.0	10.2
April	51.0	12.8	116.1	15.5	65.6	12.5
May	56.0	17.9	81.4	17.4	85.0	17.9
June	41.5	22.3	10.2	23.9	44.4	21.2
Total/Mean	482.7	10.5	547.8	12.6	408.0	8.9

Table 2. Analysis of variance for genotypes, year and its interaction for yield and yield component.

Source of variation	DF	GY		PL		SL		FLA	
		MS	F Ratio	MS	F Ratio	MS	F Ratio	MS	F Ratio
Year (Y)	1	87739.4**	29.41	422.45**	133.92	15.67**	39.70	293.96**	31.01
Genotype (G)	7	101187.1**	33.92	54.27**	17.20	5.81**	14.72	149.39**	15.76
Y×G	7	61894.4**	20.75	65.60**	20.79	4.76**	12.06	85.63**	9.03
Treatment (T)	2	4310.5	1.44	0.13	0.04	0.83	2.11	56.50**	5.96
Y×T	2	5087.1	1.71	7.14	2.26	0.05	0.13	42.05*	4.44
G×T	14	4212.8	1.41	2.9	0.92	0.27	0.67	7.09**	0.75
Y×G×T	14	3572.4	1.20	2.11	0.67	0.48	1.21	9.66	1.02
Error	92			3.15		0.39		9.48	
C. Total	143								

* and ** indicate significances, at $p<0.05$ and $p<0.01$, respectively. ns: non-significant. GY: Grain yield (kg ha^{-1}), PL: Peduncle length (cm), SL: Spike length (cm), FLA: Flag leaf area (cm^2)

Table 3. Analysis of variance for genotypes, year and its interaction for yield components.

Source of variation	DF	SNS		KNS		SNM		NDVI	
		MS	F Ratio	MS	F Ratio	MS	F Ratio	MS	F Ratio
Year (Y)	1	35.57**	10.64	704.06**	23.23	1136356.0**	141.17	0.1320**	18.54
Genotype (G)	7	14.45**	4.32	254.56**	8.40	29169.0**	3.62	0.0353**	4.95
Y×G	7	11.75**	3.52	175.73**	5.80	24190.4**	3.01	0.0176*	2.47
Treatment (T)	2	1.95	0.58	10.31	0.34	12238.8	1.52	0.0053	0.74
Y×T	2	2.27	0.68	14.34	0.47	4864.4	0.60	0.0316*	4.44
G×T	14	2.33	0.69	71.30**	2.35	4357.3	0.54	0.0029	0.41
Y×G×T	14	4.24	1.27	77.74**	2.56	8962.7	1.11	0.0051	0.72
Error	92	3.34		30.304		8049.7		0.0071	
C. Total	143								

*, ** Significance at respectively 5% and 1% level probability, ns: non-significant. SNS: Number of spikelet in square meter, KNS: Number of grain in spike, SNM: Number of spike in a square meter, NDVI: Normalized differences vegetative index.

Table 4. The average data of genotypes based on yield and agronomic parameters and standard deviation.

Genotype	GY	PL	SL	SNS	KNS	SNM	FLA	NDVI
G1	4994±209[d]	28.17±0.7[e]	8.56±0.2[cd]	17.09±1.2[c]	33.91±.2[d]	517.1±38[b]	26.20±1.2[a]	0.67±0.05[a]
G2	6291±103[bc]	31.78±0.3[bc]	8.31±0.1[de]	19.28±5.5[a]	38.55±1.0[bc]	520.9±31[b]	24.08±0.5[bc]	0.52±0.02[d]
G3	5945±441[c]	29.85±0.4[d]	8.40±0.2[de]	17.61±1.8[bc]	38.16±0.7[bc]	592.9±11[a]	17.68±1.2[e]	0.58±0.01[bc]
G4	6056±82[bc]	32.91±0.7[ab]	9.50±0.2[a]	17.89±3.1[bc]	44.78±0.6[a]	487.6±28[bc]	24.93±1.3[abc]	0.59±0.01[bc]
G5	6321±133[b]	30.73±0.7[cd]	9.20±0.1[ab]	16.94±2.0[c]	35.65±0.4[cd]	521.6±35[b]	23.43±1.1[c]	0.62±0.03[ab]
G6	7730±378[a]	31.36±1.0[c]	8.01±0.2[e]	16.76±2.1[c]	34.19±0.4[d]	542.0±24[ab]	20.60±1.4[d]	0.55±0.03[cd]
G7	6029±301[bc]	33.37±0.4[a]	9.52±0.5[a]	18.71±3.2[ab]	40.14±0.8[b]	455.6±31[c]	25.88±2.8[ab]	0.61±0.01[b]
G8	6218±236[bc]	29.69±0.7[d]	8.83±0.2[bc]	17.22±4.7[c]	41.53±0.3[ab]	500.2±32[bc]	24.27±1.2[abc]	0.59±0.01[bc]
Mean	6197	30.98	8.79	17.69	38.36	517.2	23.38	0.59
$LSD_{(0.05)}$	36.05	1.17	8.79	1.21	3.62	59.2	2.02	0.05
CV (%)	8.8	5.7	7.1	10.3	14.3	17.3	13.1	13.5

GY: Grain yield (kg ha^{-1}), PL: Peduncle length (cm), SL: Spike length (cm), SNS: Number of spikelet in square meter, KNS: Number of grain in spike, SNM: Number of spike in a square meter, FLA: Flag leaf area (cm^2), NDVI: Normalized differences vegetative index.

Table 5. Mean performance of genotypes yield and yield component based on treatment

Seed Rate	GY	PL	SL	SNS	KNS	SNM	FLA	NDVI
400	6219[a]	31.04[a]	8.94[a]	17.90[a]	38.68[a]	509.5[a]	23.30[ab]	0.58[a]
500	6280[a]	30.98[a]	8.73[a]	17.67[a]	38.58[a]	535.6[a]	24.51[a]	0.59[a]
600	6094[a]	30.93[a]	8.71[a]	17.50[a]	37.83[a]	506.6[a]	22.34[b]	0.60[a]
Mean	6197	30.98	8.79	17.69	38.36	517.2	23.38	0.59
$LSD_{(0.05)}$	22.05	0.71	0.24	1.04	2.22	36.25	1.23	0.03

GY: Grain yield (kg ha^{-1}), PL: Peduncle length (cm), SL: Spike length (cm), SNS: Number of spikelet in square meter, KNS: Number of grain in spike, SNM: Number of spike in a square meter, FLA: Flag leaf area (cm^2), NDVI: Normalized differences vegetative index.

Table 6. Correlation coefficients between grain yield and tested parameters for treatment

Parameter	GY	PL	SL	SNS	KNS	SNM	FLA
PL	0.618						
SL	0.271	0.924					
SNS	0.592	0.999**	0.936				
KNS	0.907	0.892	0.652	0.877			
SNM	0.809	0.039	-0.347	0.005	0.485		
FLA	0.966*	0.394	0.012	0.362	0.766	0.934	
NDVI	-0.659	-0.998**	-0.903	-0.996**	-0.915	-0.091	-0.441

Significant at **: $p<0.01$, *: $p<0.05$, GY: Grain yield (kg ha^{-1}), PL: Peduncle length (cm), SL: Spike length (cm), SNS: Number of spikelet in square meter, KNS: Number of grain in spike, SNM: Number of spike in a square meter, FLA: Flag leaf area (cm^2), NDVI: Normalized differences vegetative index.

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