DOI: 10.34101/ACTAAGRAR/1/12144

Leaf reflectance characteristics and yield of spring oat varieties as influenced by varietal divergences and nutritional supply

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SUMMARY

Inadequacy of nutrients in the soil and sufficient inaccessibility to nutrients is caused by factors that affect production and productivity of spring oat varieties. Exogenous application of nutrient and real time nutrient assessment can therefore reverse these associated negative consequences. A field experiment was conducted to evaluate the response of spring oat varieties to sulphur and silicon based fertilisation. Eight spring oat varieties, four level of nutrient application was arranged in a split-plot design with three replications. The obtained results showed that foliar application of sulphur improves the grain yield of most nutrients responsive varieties by about 34.7%. However, application of silicon had shown a diminishing return association to grain yield of variety GK Kormorán, GK Pillangó, Lota, Panni. LAI, thousands grain weight, SPAD, NDVI was significantly ($p < 0.05$) influenced by genetic difference of the tested varieties, developmental plasticity, and nutrient application. Significantly higher grain yield was obtained from the variety Mv Pehely than the other tested varieties. Therefore, it could be inferred that a combined use of nutrient responsive spring oat varieties and sulphur containing fertilisers could be important agronomic practice to improve grain yield and to develop climate resilient oat varieties.

Keywords: *silicon; sulphur, drought; physio-morphological traits*

INTRODUCTION

Oats grain are widely used both as human food and animal feed (Tosh and Miller., 2016). In recent years, oat grain became a preferred raw material due to its high nutritional profile which could prevent several diseases such as cancer, obesity, diabetes, microbial and cardiovascular diseases (Chen et al., 2007; Tang et al., 2022). However, this aim is hampered by a number of biotic and abiotic factors including drought-induced stress. Drought stress can lead in more agricultural loses such as flowering, growth and yield of crops than the combination of all pathogens due to changes in plant physiology (Gupta et al., 2020; Xie et al., 2021).

Silicon has crucial role as a nutrient to alleviate drought stress and to improve the soil structure, fertiliser and water use efficiency (Kovács et al., 2022; Ming et al., 2012). According to Sorrato et al. (2012) the application of silicon as a fertiliser in crop production can enhance the grain yield by about 34% of winter oat and 26.9% of wheat, respectively. Silicon fertiliser can improve the leaf area, shoots height, thousands seed weight, number of grains and spikes which leads to increase the grain yield (Hanafy et al., 2008). Furthermore the silicon application could increase the plant height and NDVI values of cotton (Santos et al., 2020). Applying silicon in maize in drought circumstances has shown great results to enhance the plant height and grain yield (Amin et al., 2018). Furthermore the current studies in oats evaluated that silicon could enhance the transpiration, chlorophyl content, leaf area, water use efficiency and grain yield (Kutasy et al., 2022).

The application of sulphur as a fertiliser can increase the crop yield and the nutritional value (Aula et al., 2019). The essential elements for instance sulphur plays a crucial role in drought stress prevention, NPK uptake ability, synthesis of chlorophyll, antioxidants and protein and the amino acid formation (cysteine and methionine). Furthermore, sulphur has a positive impact on physio-biochemical processes, plant development and grain yield in crops (Shah et al., 2022).

Although grain yield is a polygenic trait influenced by multiple genes, there are a number of numerical evidence stated the role of physiological and morphological traits in predicting the synergies between total biomass of the crops and resource partitioning traits in breeding and agronomy studies (John et al., 2011; Reynolds et al., 2009). It has been frequently reported that NDVI and SPAD are potential precision agricultural tools which determine nutrient status of crops, predict the grain yield, and evaluate phenotypic variability, especially under the current climate change scenarios (Kizilgeci et al., 2021; Qi et al., 2020). A significant positive association between NDVI, grain yield and plant height has been observed in different crops (Milan et al., 2018).

MATERIALS AND METHODS

Description of the study area

A field experiment was conducted at the research station of the university of Debrecen during 2022. The meteorological data recorded showed that, in the past three decades, the climatic changes has effected every part of the year in Debrecen (*Figure 1*). During the year 2021/22 (August to July) the average temperature was 11.4 °C compared to 30 year total average (1991/2020) 10.6 °C. Furthermore the total precipitation rate for 2021/22 was 312.8 mm for 43% lower compared to the last three decades. Among all the months the drought has been appeared mostly during the June where the precipitation rate has been decreased for 83% compared

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to 30 years average. The experimental area has chernozem soil with good nitrogen supply and extremely high phosphorus and potassium content. The soil characters regarding pH, sulphur and soluble silicon content of the experimental site is indicated in *Table 1*. The sulphur and soluble silicon availability in top soil of the site was good (*Table 1*).

Figure 1: **Average monthly temperature and precipitation during 2021/22 compared to the 30 year average (1991–2020) years in Debrecen**

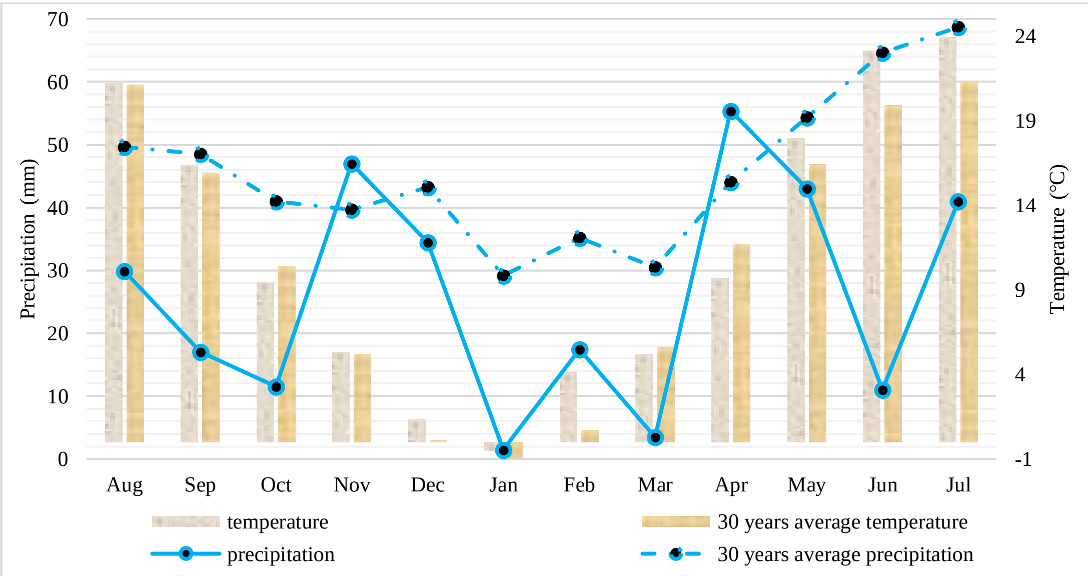

Table 1: **Soil chemical properties of the experimental sites, Debrecen 2022.**

	L (0–20cm)	L (20–40cm)	L (40–60cm)
pH (KCl)	6.93	7.46	7.51
S (mg kg^{-1})	14.1	7.31	3.69
Soluble Si (mg kg^{-1})	35.8	28.0	23.0

Abbreviation: L (Layers); KCl: (potassium-chloride soluble)

Experimental design and treatments

A field experiment was conducted during spring season of 2022 at students experimental garden of the University of Debrecen. The treatments consisting of four nutrients applications (i.e. Control, Silicon, Sulphur, and S+ Si) and eight oat varieties (i.e. GK Kormorán, GK Pillangó, Lota, Panni, Mv Kengyel, Mv Ménes, Mv Pehely, Mv Szellő) were arranged in a split plot design with four replication. The main plots were assigned to the nutrient application and the sub plots were to the oat varieties. The nutrients were foliarly applied at three developmental stages such as three leaves unfolded, flag leaf and early milk stages in 5th, 25th May and 8th of June, respectively. All the varieties were sown on 18th of March 2022 in small plot (3 m x 4 m = 12 m^2). The silicon was applied at a rate of 0.5 L ha^{-1}, sulphur 5 L ha^{-1} and a combined application of silicon and sulphur was employed at a rate of 0.5, and 5 L ha^{-1}. As a source of fertilisers, Optysil were applied with high content of Si (200 g SiO_2 L^{-1}) and sulphur liquid foliar fertiliser (1000 g SO_3 L^{-1}). All other agronomic practices was applied uniformly as per recommended packages for oat.

Data collection and statistical analysis

The data were collected from different plant based traits including: SPAD (relative leaf chlorophyll content), LAI (leaf area index), NDVI (normalized difference vegetative index), number of tillers per plant and meter square, plant height, thousands grain weight and grain yield. The NDVI was measured with Trimble GreenSeeker and SPAD with a SPAD meter (SPAD-502) from five randomly selected leaves. The data for NDVI, and SPAD were recorded at seven different developmental stages (i.e. 53, 60, 68, 76, 82, 89, 96 days after sowing). The average height of the main tiller of five plants was used to determine the plant height, which was measured from the soil's surface to the top of the spike. By using LAI-2000 Plant Canopy Analyzer (LI-COR, Inc) with one sensor we have measured the LAI five times for each small plot at several developmental stages. The harvested samples were weighted for each plot and small samples were taken to measure the moisture, thousands grain weight and grain yield. All the collected data were subjected to statistical analysis software package using Genstat 18th edition. The mean value of NDVI, SPAD, LAI, plant height, thousands grain weight, tillers per plant, tillers

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per meter square and grain yield were compared between each other by using the least significance difference at 5% significance level.

RESULTS AND DISCUSSION

Leaf reflectance traits as affected by the change in developmental stages and varietal difference

The NDVI values were highly significant ($p < 0.05$) influenced by varietal divergences, and developmental stages (*Table 2*). A significant genetic variation in NDVI profile of oat varieties has been also previously reported (Csajbók et al., 2022). In our study, NDVI has shown tendency to increase gradually where the highest values reached maximum values at 60 DAS. Across the tested varieties, the highest value of NDVI was measured in Mv Kengyel with a mean 0.84, followed by GK Kormorán, GK Pillangó and Panni which has shown the same mean (0.83). However, at the early hard dough stages the NDVI values were decreasing drastically for variety Lota (0.38) and Panni (0.34). This could be due to huge discoloration and defoliation of the leaves at the later stages due to senescence.

The developmental stages was also found an important factor that significantly dictates the relative chlorophyll content of the leaves. However, the SPAD values were statistically insignificant at 53, 60, 68, 82 and 89 DAS, while highly significant ($p < 0.05$) were observed at 76 and 96 DAS (*Table 2*). This means the relative chlorophyll content is lower at the first growth stage, but it increases following the change in oat developmental progresses. SPAD exhibited the same tendency to increase and fall as the growth stages progressed, where highest values reached maximum 82 DAS, except for Panni 76 DAS. This particular trait was also influenced by genetic difference of the tested oat varieties. It has been found that the variety Mv Pehely (59.9) and GK Kormorán (59.5) have shown the highest values for SPAD with a mean separately. At the early dough ripening stages the similar as for other leaf reflectance characteristics the lowest mean values for SPAD were founded in Lota (24.4) and Panni (18.0). In another perspective the highest NDVI and SPAD indicated the green stay nature of the varieties such as Mv Ménes and Mv Pehely which would be drought resistant feature, drought resistant varieties, where Panni and Lota are less drought resistant compared to other varieties. This further indicates variety Panni and Lota have stay green nature and short maturing variety which could be an important plant based trait under the changing climatic conditions.

Table 2: **The influence of differences in genetic interpretation on selected leaf reflectance characteristics of spring oat varieties measured at different developmental stages**

Varieties	53 DAS		60 DAS		68 DAS		76 DAS		82 DAS		89 DAS		96 DAS	
	NDVI	SPAD	NDVI	SPAD	NDVI	SPAD	NDVI	SPAD	NDVI	SPAD	NDVI	SPAD	NDVI	SPAD
GK Kormorán	0.80	44.4	0.83	52.2	0.80	54.0	0.79	57.9	0.76	59.5	0.69	56.5	0.47	40.1
GK Pillangó	0.81	46.4	0.83	52.7	0.79	53.0	0.78	56.3	0.78	57.6	0.71	52.7	0.53	40.2
Lota	0.75	44.8	079	50.4	0.77	51.7	0.77	54.9	0.73	56.3	0.65	52.7	0.38	24.4
Panni	0.82	44.2	0.83	52.7	0.80	56.5	0.79	58.4	0.76	57.3	0.69	54.2	0.34	18.0
Mv Kengyel	0.82	44.6	0.84	52.7	0.79	52.0	0.80	54.5	0.79	55.4	0.71	49.9	0.57	42.3
Mv Ménes	0.80	44.4	0.82	52.1	0.79	53.5	0.80	55.3	0.79	58.4	0.71	54.4	0.56	47.3
Mv Pehely	0.77	44.7	0.80	51.1	0.77	54.4	0.77	58.0	0.77	59.9	0.71	56.0	0.55	45.7
Mv Szellő	0.82	46.3	0.82	51.8	0.78	52.3	0.80	56.2	0.80	58.5	0.72	53.4	0.55	34.2
$LSD_{0.05}$	**0.01**	**ns**	**0.01**	**ns**	**0.01**	**ns**	**0.01**	**1.79**	**0.01**	**ns**	**0.01**	**ns**	**0.03**	**5.51**
CV (%)	**0.7**	**2.2**	**0.9**	**2.8**	**1**	**2**	**1.5**	**1.3**	**1.4**	**1.7**	**1.6**	**2.2**	**6.4**	**7.6**

Abbreviations: NDVI (normalized difference vegetative index); **SPAD** (relative chlorophyll content); **DAS** (days after sowing); **LSD0.05** (least significant differences at p=5%); **CV(%)**-coefficient of variation; **ns** (not significant)

The impact of leaf reflectance characteristics on the grain yield

The combined analysis of variance showed that the studied traits agro-morphological traits such as LAI, PH, TGW and tillers meter^{-2} were significantly ($p < 0.05$) influenced by genetic makeup of oat varieties (*Table 3*). From the result, LAI showed the same tendency as NDVI and SPAD to increase and then decreased as the growth stages progressed, where the higher values were recorded at 62 DAS. With respect to varietal difference, the varieties MV Kengyel and Mv Szellő have shown the highest for LAI with a mean values of 5.57 and 5.55, respectively. Similar with other reflectance characteristics the lowest mean values for LAI were founded in Panni (3.17) and Lota (3.15) varieties at the early dough ripening stages.

The plant height of spring oat varieties were between 0.81 cm measured in Mv Ménes to 0.94 cm in Mv Kengyel and Mv Szellő. Furthermore, Mv Szellő has shown the greatest number of tillers per plant and meter square, where the Lota showed the lowest values for both of reflectance characteristics. In terms of oats grain size, variety Lota reached the highest TGW with a mean 28.9 g, and the lowest values were in GK Kormorán (23.1 g). For the eight studied varieties under the drought conditions, Panni achieved the best grain yield (3549 kg ha^{-1}) followed by Mv Kengyel (3343 kg ha^{-1}), Mv Szellő (3331 kg ha^{-1}), Lota (3309 kg ha^{-1}), Mv Pehely (3163 kg ha^{-1}), Mv Ménes (2955 kg ha^{-1}), GK Pillangó (2858 kg ha^{-1}) and GK Kormorán (2295 kg ha^{-1})

DOI: 10.34101/ACTAAGRAR/1/12144

Table 3: **Agro-morphological traits and grain yield (kg ha^{-1}) as influenced by variation in genetic landscape of spring oat varieties**

Varieties	LAI							TGW	PH	Tillers	Tillers	GY
	53 DAS	62 DAS	68 DAS	75 DAS	83 DAS	89 DAS	98 DAS	g	cm	plant^{-1}	m^{-2}	kg ha^{-1}
GK Kormorán	3.82	5.11	4.69	4.49	4.41	4.10	3.42	23.1	0.85	3.43	155.9	2295
GK Pillangó	4.03	5.37	4.80	4.60	4.51	4.31	3.93	24.8	0.86	3.74	167.5	2858
Lota	3.66	4.74	4.20	4.05	4.06	3.74	3.15	28.9	0.85	3.29	141.4	3309
Panni	4.17	5.18	4.69	4.46	4.24	3.90	3.17	25.3	0.90	3.64	160.5	3549
Mv Kengyel	4.23	5.57	4.95	4.80	4.68	4.40	3.81	26.2	0.94	3.53	155.2	3343
Mv Ménes	4.01	5.31	5.02	5.05	5.03	4.74	4.07	25.3	0.81	3.36	156.5	2955
Mv Pehely	3.34	4.73	4.57	4.61	4.56	4.46	3.83	27.4	0.84	3.53	157.1	3163
Mv Szellő	4.57	5.55	4.96	4.88	4.95	4.50	3.78	24.5	0.94	3.84	167.6	3331
$LSD_{0.05}$	**0.41**	**0.35**	**0.26**	**0.24**	**0.35**	**0.26**	**0.30**	**1.4**	**0.03**	**ns**	**9.85**	**150.3**
CV (%)	**7**	**4.4**	**2.3**	**3**	**2.1**	**2.8**	**2.6**	**1.6**	**3.6**	**1.2**	**4.2**	**8.3**

Abbreviations: LAI (leaf area index); **TGW** (thousands grain weight); **PH** (plant height); **GY** (grain yield); **DAS** (days after sowing); **ns** (not significant); **LSD0.05** (least significant differences at *p*=5%); **CV(%)**-coefficient of variation; **ns** (not significant

The effect of silicon and sulphur on some agro-morphological traits and grain yield

As shown in the combined analysis of variance, the interaction effect between varieties and the applied silicon and sulphur containing fertilisers was significant for some traits (*Table 4*). Although their combined effect has shown higher response than their individual effects for plant stature, maximum plant height was recorded under the combined fertilisation of sulphur and silicon treated plots for variety Mv Szellő, followed by Panni (*Table 4*). When the genetic response to the applied fertilisers was used to evaluate the allometric relationship between plant height and grain weight, the tallest varieties such as GK Kormorán and Mv Szellő tends to have lowest grain weight under silicon fertilisation. It is probably as the tallest could make the plants sensitive to lodging because they have higher center of gravity (Okuno et al., 2014). However, except for variety Mv Kengyel and Mv Szellő application of silicon and sulphur during three leaves unfolded, beginning of flowering and late milk stages didn't bring any significant change on both number of tillers per plant and per square meter. This means that application of either sole or combined application of sulphur and silicon may not have any agronomic importance as far as tillers are considered. Hence, this study may suggests to adjust time and method of application these elements.

Table 4: **A combined effect of varietal divergence and nutrient supply on some selected agro-morphological traits**

Varieties	Plant height (cm)				TGW (g)				Tillers plant^{-1}				Tillers m^{-2}			
	Treatments															
	C	Si	S	Si+S	C	Si	S	Si+S	C	Si	S	Si+S	C	Si	S	Si+S
GK Kormorán	0.8	0.78	0.88	0.95	23.0	22.2	22.4	24.7	3.10	3.50	3.45	3.65	148.2	160.5	157.2	157.8
GK Pillangó	0.82	0.83	0.87	0.91	24.7	25.3	23.1	25.9	3.65	3.65	4.10	3.55	165.2	170.8	172.0	162.0
Lota	0.77	0.82	0.87	0.92	26.8	28.2	30.7	29.9	3.15	3.55	3.35	3.10	139.5	148.5	149.8	128.0
Panni	0.85	0.88	0.93	0.96	23.6	24.7	26.0	26.9	3.60	3.25	3.80	3.90	149.0	151.0	167.5	174.5
Mv Kengyel	0.88	0.95	0.97	0.96	24.8	26.3	25.9	27.8	3.10	3.00	4.40	3.60	134.5	145.2	182.8	158.5
Mv Ménes	0.75	0.81	0.83	0.86	23.9	23.6	28.7	24.9	3.45	3.15	3.25	3.60	152.5	157.0	159.0	157.5
Mv Pehely	0.75	0.84	0.9	0.86	27.7	26.6	27.0	28.3	3.50	3.65	3.40	3.55	159.5	160.5	154.8	153.5
Mv Szellő	0.88	0.96	0.98	0.97	25.2	23.1	25.7	23.8	3.30	3.45	4.45	4.15	148.8	158.0	182.5	181.0
$LSD_{0.05}$	**0.07**				**3.06**				**0.69**				**21.6**			
CV (%)	**5.8**				**8.8**				**14.6**				**10.2**			

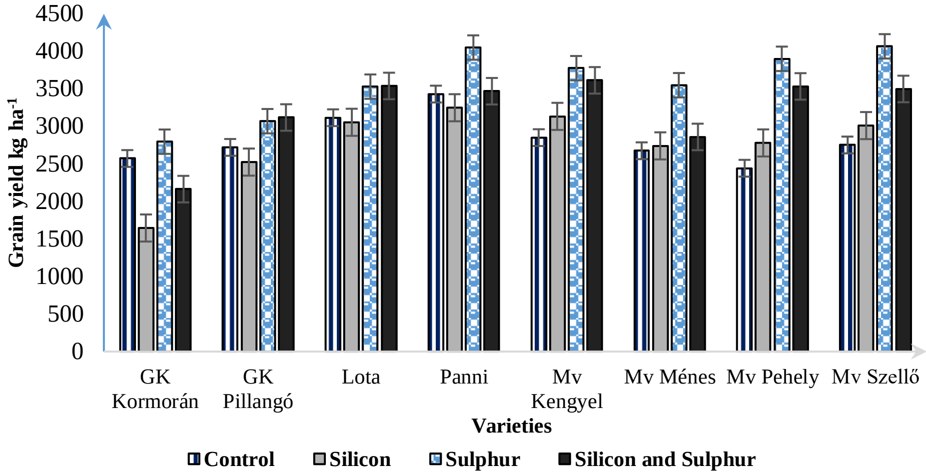
Abbreviations: TGW (thousands grain weight); **C** (control); **LSD0.05** (least significant differences at *p*=5%); **CV(%)**-coefficient of variation; **ns** (not significant)

Unlike its effect on aforementioned studied traits, application of S improves the grain yield for Panni (15.3%) and for Lota (11.7%). However, the lowest grain yield also observed from the variety GK Kormorán, GK Pillangó, Lota, Panni treated under foliar Silicon fertilisation as compared to non-treated experimental plots (*Figure 2*). These varieties had been adjusted themselves to improve the grain yield under sulphur fertilisation by about 8%, 11.3%, 11.7%, 15.3%, 24.5%, 24.6%, 37.4%, 32.3%, for GK Kormorán, GK Pillangó, Lota, Panni, Mv Kengyel, Mv Ménes, Mv Pehely, Mv Szellő, respectively (*Figure 2*). Since the experimental season was experienced a terminal drought stress, the result universally implies

DOI: 10.34101/ACTAAGRAR/1/12144

that foliar application of sulphur can improve the drought tolerance of spring oat varieties. Furthermore, a combined application of silicon and sulphur was less effective to improve grain yield than the sole application.

Figure 2: **The interaction between foliar fertilisation and varietal divergence on the grain yield under the drought conditions**



CONCLUSIONS

Application of either sulphur or silicon containing fertilisers are required to further improve yielding potential of spring oat varieties while maintain fertility of the soil. The most promising agronomic based strategy seems to rely on the sole application of sulphur, which could improve grain yield of responsive spring oat varieties such as Mv Pehely by about 37.4%. This indicates that screening and evaluation of huge number of spring oat varieties for grain qualitative traits, yield, nutrient utilization efficiency and their adaptability across divergent mega environments and season could be important to develop climate resilient oat varieties. The potential improvement in grain yield and leaf reflectance characteristics of spring oat varieties lies mainly in the extent of the variability of seasonal nutrient application and difference in genetic makeup of spring oat varieties. These has been confirmed that application of sulphur improves grain of GK Kormorán, GK Pillangó, Lota, Panni, Mv Kengyel, Mv Ménes, Mv Pehely, Mv Szellő. However, tradeoff between application of silicon and grain yield of some spring oat varieties GK Kormorán, GK Pillangó, Lota, Panni, which suggests antagonism among the applied fertiliser sources. Under the tested environmental condition, high yielding potential was observed for variety Mv Pehely, thus this variety could be drought tolerant since the season was experienced a serious of terminal moisture stress. Varietal difference, nutrient responsiveness of oat varieties, developmental stages could be considered a determinate production factor that influences the most important yield attributed traits such as LAI, SPAD, thousands grain weight and associated agronomic traits. Hence, as long as nutrient applications are considered aimed at improving grain yield and leaf reflectance traits, developmental stages should be taken into consideration as the lower LAI has been observed at 53 DAS and 83 DAS. However, since the result is based on one year experimentation, replication across year and wide range of genetic pools would be very important.

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