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# Complex diagnostics of crop yield in ecological trials of cereal cultivars

ABSTRACT. The report presents the results of the use of the method of rapid strain trial of spring cereals under the conditions of the northwest of Russia. The method of rapid ecological estimation of the range of crop yield responses of novel candidate cultivars of spring cereals (rapid ecological crop trial, RECT) provides an example of the system approach to the analysis of data of ecological trails. The algorithm of data treatment provides for the complex diagnostics of crop yield. In a programmed physico-agronomic experiment (carried out in 1998-2000), 3 wheat and 3 barley cultivars were characterized by rates of lesioning by different diseases including mycoses caused by *Erysiphe graminis, Puccinia recondite, Septoria nodorum and Pyrenophora teres*. Preliminary statistical data processing has shown that crop yield decreased depending on plant lesioning rate (correlation coefficient r=-0.74). Plants with adventitious shoots were lesioned more (r=0.69). Clearly, the new cultivars were more pathogen-endurable compared with standard cultivars. The plants were more often infected under the conditions when the following root rots developed: *Fusarium, Helmintosporium, Alternaria,* etc. (r=0.67). Fungus-endurable cultivars will be more preferable than fungus-resistant ones because of a better balance between the plant and the environment. The methodology of accelerated strain trail at the stage of competitive evaluations will allow to better characterize the appropriate zoning of the strains and their ranges of responses related to crop yield and resistance to fungal pathogens.

KEY WORDS: ecological trials, wheat, barley, yield, diseases

The principal natural factors that determine the crop yields of cultivars include meteorological conditions, soil treatment techniques, the use of fertilizers, and the characteristics of cultivars themselves. However, high crop yields and their maximum preservation require prevention of losses caused by pests and

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diseases. This is especially important in present time Russia where the epiphytotic conditions are aggravated [Romanenko 1999].

Plant selection for resistance to diseases has long been considered as a reasonable approach to plant protection. In the recent past, such selection implied the development of novel strains of annual plants over a period of 15–20 years during which epiphytotics caused by several diseases occurred making it possible to distinguish resistant and vulnerable strains. The transition to accelerated methods of development of novel cultivars implies, first of all, the modernization of the whole seed farming business and correction of obsolete principles of ecological and governmental trials of cultivars. New approaches to diagnostics of plant resistance to phytopathogens become increasingly important, which includes complex diagnostics allowing to distinguish cereal crops that are simultaneously resistant and endurable with regard to different pathogen groups. Therefore, candidate strains are tested in both ecological strain trials (EST) and state strain trials (SST) not only for their productivity and resistance to extreme environmental conditions but also for their resistance to diseases.

Firstly, such trials may include plant cultivation under field conditions for several years. The comprehensive characterization of plants with regard to their disease resistance is possible only when trial periods comprises epiphytotic years, i.e., those when favorable conditions for diseases develop due to the coincidence of specific temperature and humidity conditions with the relevant phase of plant development. Such an approach has an important drawback, which is a prolonged trial time.

Secondly, such trials may include infecting of plants grown in special farms, greenhouses or hothouses. Such an approach provides for a rapid recognition of plant response to a disease however, it is very expensive [Geshele 1978].

We suggest estimating plant resistance to mycoses and their fungus endurance in a programmed physico-agronomic experiment. The prerequisites of such experiments are soil and climatic provocative backgrounds against which the variability of test strains with regard to their resistance to phytopathogens may be revealed. A method has been developed at Agrophysical Research Institute, which allows making express estimates of ranges of yield responses of candidate cultivars (rapid ecological crop trial, RECT) [Stefanova 2002]. This method shortens the time required to describe ranges of response of cereal crop strains to mycoses in a specified region, i.e., to obtain a complex estimate of crop response to phytopathogens.

## METHODS

The experiments were carried out in Gatchina District of Leningrad Region at Menkovskaya Trial Station of Agrophysical Research Institute using two crops: spring barley (strains Suzdalets, Elf, and standard Krinichniy) and spring wheat (strains Krepysh, Irgina, and standard Leningradka). RECT design was that of a full $3^2$ factorial experiment (NPK × HTC, HTC = hydrothermal coefficient) employing 5 $m^2$ allotments. Study end points were natural susceptibility of wheat plants to pathogens *Puccinia recondita, Erysiphe graminis, Septoria nodorum,* and *Ustilago tritici* and barley plans to *E. grami nis, Pyrenohpora teres,* and *U. nuda*. The year 1998 was epiphytotic. The year 1999, on the whole, was unfavorable for plant diseases. The year 2000 was favorable for *E. graminis* . Strain resistance to the diseases was scored numerically. The resistance to brown root rot including that caused by *Fusarium spp* . was also studied [Fadeyev, Kuzmicheva 1977].

The field estimates of plant resistance to powdery mildew (*E. graminis* ) were obtained in field experiments during the earing phase. The rate of plant lesioning was determined visually using Krivchenko scale [Fadeyev, Kuzmicheva 1977]: 1 – very weak lesioning manifested as a light fur or separate plaques on lower leaves and interstices; 2 – weak lesioning manifested as a few plaques on lower leaves and interstices; 3 – moderate lesioning manifested as an abundant development of the fungus mainly on the lower leaves and dispersed foci of plaques on the upper leaves; and 4 – heavy lesioning manifested as all leaves and interstices being affected, the presence of mycelium in the ears, and well expressed and merging plaques.

Plant lesioning by brown rust (*P. recondita* ) was estimated at the milky ripeness phase using the scale for leafy rust suggested by N. I. Vavilov [Fadeyev, Kuzmicheva 1977]. Lesioning of different wheat plant organs by speckled blotch (*S. nodorum* ) and of barley by net blotch (*P. teres*) was estimated during the period starting from the onset of earing and ending upon the achievement of the milky ripeness of grain using a quantitative scale for visual assessment [Fadeyev, Kuzmicheva 1977]. Fifty plants from each allotment were examined. 0 – no traces of the disease; 01 – traces of lesioning; 1 – very weak lesioning (up 50 1/5 of a leaf); 2 – weak lesioning (up to 1/2 of a leaf); 3 – moderate lesioning especially of the middle leaves (up to 2/3 of a leaf), and 4 – heavy lesioning involving the middle and upper leaves (more than 2/3 of a leaf).

The susceptibility to loose smut of wheat (*U. tritici*) and barley (*U. nuda*) was determined from the onset of florification. Healthy and infected plants were counted and the percent of infected plants was calculated [Fadeyev, Kuzmicheva

1977]. 0 – high resistance; 1 – within 5% of infected plants; 2 – within 25% of infected plants; 3 – within 50% of infected plants; and 4 – more than 50% of infected plants. The coefficient of resistance to diseases was calculated for all strains [Stefanova et al. 2001]. The full structural examination of plant was carried out at the end of vegetation.

The data were treated statistically [Borovikov 2001]. The coefficient of correlation between susceptibility estimates and morphometric characteristics was calculated. After the effects of HTC and NPK on parameters under study had been confirmed by analysis of variance, the emerged dependencies were represented with a smoothed multiple regression surface obtained by least square method in the NPK×HTC×susceptibility space. Ward clustering procedure was also performed on plant susceptibility scores.

## RESULTS

The experiments revealed some nonspecific responses of plats to pathogenic challenges. Thus, in our experiments a reduction of crop yield of wheat and barley was associated with plant susceptibility to diseases, $r=-0.74$. Plants with more adventitious shoots were more affected ($r=0.69$). These observations are relevant for both, wheat and barley. Data on susceptibility of plants to different pathogens are presented in Figure 1. Cluster analysis suggests that Irgina and Krepysh wheat strains may be referred to the group of strains resistant to pathogens under elevated humidity, at difference from the susceptible standard strain Leningradka.

Among wheat strains, Krepysh showed the widest range of responses with regard to resistance to pathogens within the range of soil and climatic conditions studies. This strain was weakly affected by diseases even combined with high soil humidity and fertilizer dosages (NPK > 350 kg $ha^{-1}$). Such a wide range of responses related to the resistance of this strain to fungi [Stefanova et al. 2002] was achieved due to its exceptional resistance to leaf blotch, and, although high dosages of fertilizes increased plant susceptibility to mildew (Fig. 1), the susceptibility of the strain to rust was also minimal.

The strain Irgina was inferior to Krepysh but superior to the standard with regard to the ranges of responses related to resistance to diseases. The susceptibility of Irgina strain to mildew and rust increased with increasing dosages of fertilizers, and at a high humidity the plants were also affected by leaf blotch (Fig. 1). The standard strain Leningradka appeared to be very susceptible to leaf blotch at a high humidity under any conditions, whereas mildew and rust manifestations were seen in Leningradka plants only upon abundant mineral fertilization (Fig. 1).

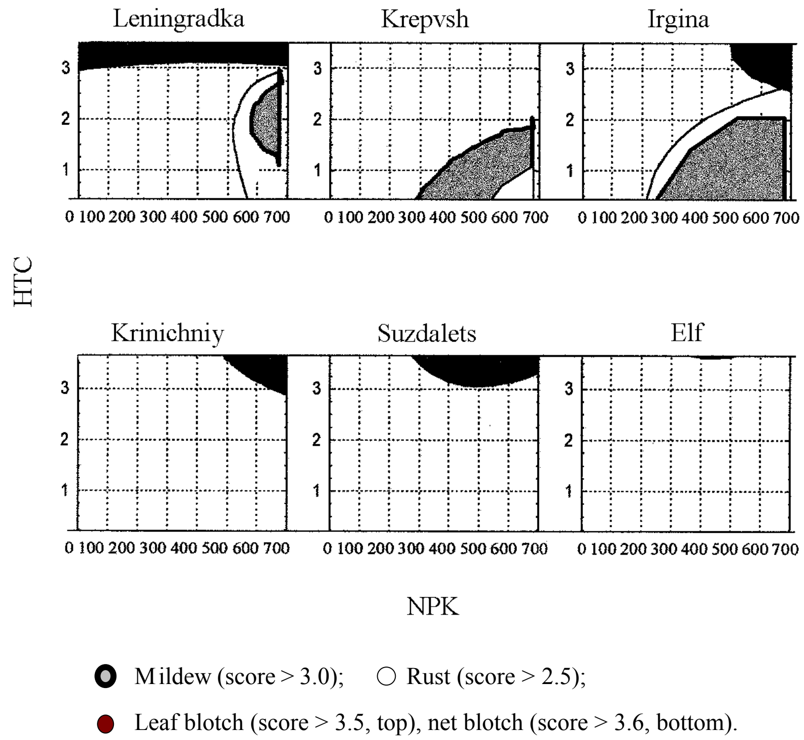


Figure 1. The rate of lesioning of strains of spring wheat (top) and spring barley (bottom) by mycoses in field experiments

With regard to the resistance of barley strains to net blotch (Fig.1, bottom), it should be noted that all three strains were affected by the disease only when HTC was high and mineral nutrition was adequate. The plants were affected more under conditions when root rot developed in seeds (r=0.67).

Root rot development is known to depend on the granulation of soil texture. In our experiments, soil was light loamy and contained 75% of physical sand, 25% of clay, and 2.83% of humus, pH being 6.4. According to our data, light soils contain more mycelium than conidia of *Fuzarium culmorum* [Shakhnazarova et al. 2000]. Bacteria content in light soils is higher than in heavy soils. A low microbiotic activity in light soils influences the development of *F. culmorum.* On the one hand, it may be suggested that the microbiotic activity enhanced the development of root rot of barley. On the other hand, barley is more vulnerable than other cereal crops to this group of phytopathogenic fungi [Romanenko 1999]. This prompts the conclusion that one of the approaches to reduction of plant mycoses load in barley crops may be reducing of foot rot infection of seeds, especially when the crops are cultivated on light soils. On the whole, the barley strain Suzdalets was found to be strongly susceptible to net blotch and, in contrast to other strains, to be affected, albeit weakly, by *Pyrenohpora teres* under dry conditions.

The strain Elf is more resistant to this disease. The standard strain Krinichniy occupied an intermediate position between the novel strains with regard to the resistance to net blotch. A consequence of lesioning of the strain Krinichniy by net blotch was a reduction in its crop yield upon abundant watering (Fig. 2). Upon a more favorable combination of HTC and NPK factors the lesioning of the plants by the fungus *P. teres* did not influence unit area crop yield. When the affected plants were excluded from the analysis, it was shown that, under the phytopathogenic challenge, the crop yields of the strains preserved due to a decreased weight of grains combined with simultaneously increased grain number per plant.

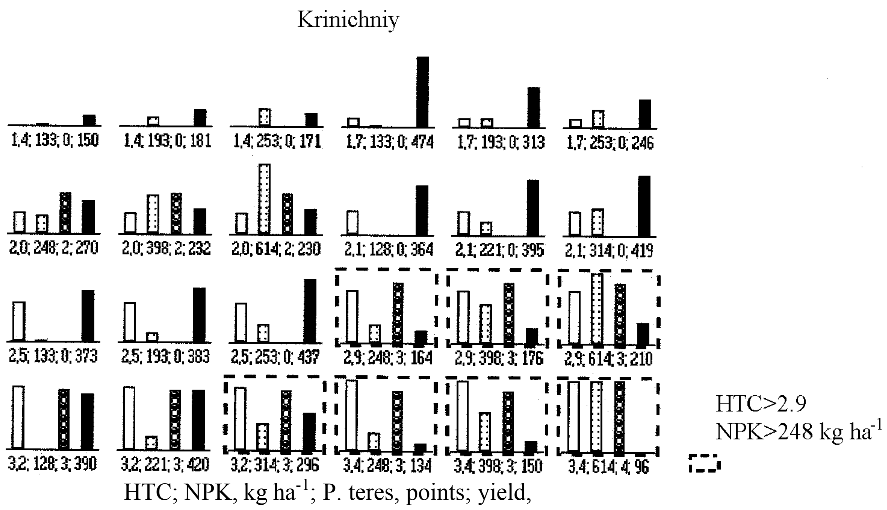


Figure 2. Bar diagrams showing the reduction in crop yields of spring barley resulting from increased humidity (HTC>2.9), mineral nutrition (NPK>248 kg ha$^{-1}$), and high scores of infection with net blotch (scores 3 and 4)

Advances in modern plant selection provide for making use of the genetic basis of the resistance of cereal strains to mycoses [Kobylanskaya, Solodukhina 1999; Ciuffetti, Tuori 1999]. Besides that, newly developed methods based on creation of component strains may also determine the stability of long-term resistance of plants to phytopathogens [Krivchenko 2001]. The use of fungicides for increasing the productivity of plants by influencing the early stages of mycosis development is still relevant. However, despite of prospects for development of new-generation fungicides, which are safe for the environment [Struck et al. 1998], the issue of the search for genotypes of increased resistance to fungal diseases and of increased fungal endurance remains to be of a high priority.

Studies on the relationships between crop yields and the resistance of plants to phytopathogens are likely to show that under conditions of a high adaptability of phytopathogens to modern means of plant protection and a narrow spectrum of genes of plant resistance to fungal pathogens, not only the genetically determined range of responses related to plant strain resistance but also plant endurance is an important characteristic of cultivar adaptability.

In this regard, plant resistance and plant endurance should be distinguished. The latter characteristic helps a cultivar to realize its productivity potential even under epiphytotic conditions regardless of its genetically determined resistance to pathogens. In wheat strains, the endurance coefficients were found to be 21.5% for Leningradka, 26.8% for Krepysh, and 64.6% for Irgina, in barley strains they were 11/8% for Krinichniy, 41.1% for Suzdalets, and 60.2% for Elf. The mean annual crop yields over a there-year period depended on diseases endurance: 224.3 ±13.07 g $m^{-2}$ for Leningradka, 243.7 ±20.33 g $m^{-2}$ for Krepysh, and 282.6 ±21.22 g $m^{-2}$ for Irgina in the case of wheat strains and 278.1 ±23.32 g $m^{-2}$ for Krinichnniy, 284.5 ±15.80 g $m^{-2}$ for Suzdalets, and 294.3 ±17.22 g $m^{-2}$ for Elf in the case of barley strains.

Thus, disease endurance is an important characteristic of plants; however, the issue of its usefulness is still debated upon on the grounds of phytosanitary requirements to grain quality. The strategy of adaptive intensification of crop production [Zhuchenko 1999] implies the search for new technologies of plant cultivation oriented towards improving the ecological compatibility of agriculture. In this regard, not only development of new disease-resistant plant strains but also distinguishing the most disease-endurable among them will make it possible to depart from the preventive use of potent fungicides.

Thus, it is expedient to further develop the methodology of programmed experiments that may allow forecasting of the ranges of responses related to disease resistance and endurance of novel cereal strains. Such forecasts may be reliable even with fewer trial years or trail sites than it is required for conventional EST (1-2 years) or SST (3 years). RECT conditions comprise those that annually provoke disease development. We believe that in an epiphytotic year a reliable estimate of diseases resistance may be obtained by RECT within a single vegetation.

Natural epiphytotics occurrence is irregular, so field data may be reliable only when they are based on several years of trials or on an experiment carried out according to a factorial HTC×NPK design in order to program conditions provoking model epiphytotics.

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