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EFFECT OF LONG-TERM FERTILIZER APPLICATION AND CROP ROTATION ON THE INFESTATION OF FIELDS BY WEEDS

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ABSTRACT

Weed competition comprises an important aspect of biological stress on crops. In recent years, concerns over the environmental effects, economic costs and long-term efficacy of conventional weed management systems have led a growing number of farmers and scientists to seek alternative systems that are less reliant on herbicides and more reliant on ecological approaches. The effects of management practices on crop growth and yields may or may not be mediated through crop–weed interaction. The research was conducted during 2004 and 2005 at the long-term experimental site of the Department of Agronomy and Experimental Methods, University of Timiriazev, Moscow to determine the effects of crop rotation and mineral fertilizers on crop grain yield and weed density. Long-term experience includes continuous of culture – winter rye, potato, barley, clover, flax and fallow, initiated since and crop rotation, included above crops since 1912. The six treatments consisted of various combinations of fertilizer: N, P, K, NPK and the control with no fertilizer application as control under weedy and weed free conditions. Results indicated that weed density was reduced by 3 times in rotational cropping than sole cropping for both winter rye and barley. Weed dry matter was also reduced 13 and 4 times, respectively, in winter rye and barley in rotational cropping than sole cropping. Application of nitrogen and NPK fertilizers reduced weed density and dry weight, while in barley the reduction in weed density and dry weight was only occurred when NPK was applied. Crop yield was higher in rotational cropping than sole cropping.

Key words: Crop rotation, mineral fertilizers, weed density, winter rye (*Secale cereale* L.), spring barley (*Hordeum vulgare* L.).

INTRODUCTION

In recent years, concerns over the environmental effects, economic costs and long-term efficacy of conventional weed management systems have led a growing

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number of farmers and scientists to seek alternative systems that are less reliant on herbicides and more reliant on ecological approaches. Herbicide expenditures typically comprise 10 to 20% of input costs for producers (Labrada, 2003). Therefore, efforts to reduce reliance on herbicides while maintaining crop yield can have a large positive impact on net return. Production systems are being developed to give crops a competitive advantage over weeds, minimize weed density as crops establish, and keep weed communities out of equilibrium to reduce the long-term buildup of troublesome weed species (Daspehov, 1967, Hume, 1982, Peterson and Nalewaja, 1992, Derksen *et al*, 1993, Gill and Arshad, 1995, Tomaso, 1995, Tabachnik and Fidell, 1996).

Crop rotations have many benefits that can influence the success of crop production enterprises. Crop rotation is an essential practice in sustainable agriculture, because of its many positive effects like increasing soil fertility and reducing crop competitiveness. A well-planned crop rotation system can help producers avoid many of the problems associated with weeds, particularly perennial weeds (Daspehov, 1967, Liebman and Elizabeth, 1993, Tabachnik and Fidell, 1996). In fact crop rotation is an effective practice for controlling serious weeds because it affects weed growth and reproduction negatively and as a result reduces weed density (Derksen *et al.*, 1993, Blackshaw *et al.*, 1994). In addition, Forcella and Lindstrom (1988) reported that after seven to eight years of weed management the number of weed seeds was about six times greater in continuous crop than in a rotated system.

Another benefit of crop rotation may be associated with a smaller chance of selecting troublesome weeds, because crop rotation also determines herbicide application and these two factors can interact to affect weed species (Ball, 1992). Therefore, the practice of rotating crops and herbicides has proved to be successful in influencing weed populations and improving crop production (Walker and Buchanan, 1982), and due to increased attention paid to agroecosystem biodiversity, adopting weed management strategies that promote weed species diversity could be encouraged (Clements *et al.*, 1994).

Results of a literature survey (234 references) indicate that weed population density and biomass production may be markedly reduced using crop rotation (temporal diversification) and intercropping (spatial diversification) strategies. Crop rotation resulted in emerged weed densities in test crops that were lower in 21 cases, higher in 1 case, and equivalent in 5 cases in comparison to continuous crop systems. Growers experience has shown that changing tillage practices without increasing crop diversity within rotations has generally led to increased weed problems, especially in sole cropping systems (Liebman and Robichaux, 1990).

Many studies in long-term experience at the Academy of Timiriazev had shown that continuous crop increased infestation of fields by weeds 2 – 3 times (Daspehov, 1967; Gruzdev and Satarov, 1969; Tulikov, 1982). Tulikov and Sugrabov (1984) and Daspehov (1967) found that crop rotation decreased weed density and their dried mass 2 – 3 and 3 – 4 times, respectively. Ghosheh and Al-Hajaj (2004) found that crop rotation decreased *Hordeum marinum* density and dry matter and weed seed in barley. Marenco and Santos

(1999) found that hyacinth bean and especially velvet bean populations in rice reduced when followed by cowpea.

The success of rotation systems for weed suppression appears to be based on the use of crop sequences that create varying patterns of resource competition, allelopathic interference, soil disturbance, and mechanical damage to provide an unstable and frequently inhospitable environment that prevents the proliferation of a particular weed species (Ugen *et al.*, 2002). The relative importance and most effective combinations of these weed control tactics have not been adequately assessed. In addition the weed-suppressive effects of other related factors, such as manipulation of soil fertility dynamics in rotation sequences, need to be examined.

Crop competitiveness can be improved through selective fertilization. The importance of inorganic fertilizers in crop productivity is well recognized. Numerous studies have shown that crop yields improve following the application of nutrients to soil, particularly nitrogen (N) potassium (K), and phosphorus (P) (Tulikov *et al.*, 1986; Dusky *et al.*, 1996; Dhima and Eleftherohorinos, 2001). However, while nutrients clearly promote crop growth, many studies have shown that fertilizers benefit weeds more than crops and following the application of fertilizers increased weed density and their biomass (Alkamper, 1976; Jeangros and Nosberger, 1990; Legere *et al.*, 1994; Santos *et al.*, 1998). Certain weed species have a lower optimal rate of N fertilizer than crops, giving weeds a competitive advantage in some situations (Tabachnik and Fidell, 1996). In many situations, particularly those with higher weed densities, added nutrients favors weed growth, often providing little added benefit in crop yield. For example, Carlson and Hill (1986) found that the addition of N fertilizer in a wheat field infested by wild oat (*Avena fatua* L.) increased the density of wild oat panicles and decreased the crop grain yield.

In contrast, the long-term studies have shown that application of nutrients into the soil reduced abundance of weed but increased their dry matter (Daspehov, 1967; Tulikov and Sugrobov, 1984). Where weed densities are low, increased N rates can markedly increase crop yield and minimize competition with weeds (Alkamper, 1976, Marenco and Santos, 1999). Legere *et al.* (1994) showed that greater P fertility improved midseason barley dry weight, but had minimal effects on weed dry weight.

Ugen *et al.* (2002) found that added N and P reduced early growth and the relative competitiveness of bean for nutrients, but K application caused bean to be more competitive. Evanylo and Zehnder (1989) reported increased competitiveness of bean with weeds with K application. Sindel and Michael (1992) observed increased competitive ability for the weedy fireweed (*Senecio madagascariensis*) in a pasture with N and P application, whereas weed growth was not increased with K application

Many short-term experiments have shown how crop rotation and mineral fertilizers affect weed communities, crop-weed interactions, and crop growth and yield. However, little is known about their combined effects in long-term experiments. The objective of this study was to determine the effects of rotation and fertilizer, and their interactions on crop yield and weeds density.

MATERIALS AND METHODS

The research was conducted during 2004 and 2005 at the long-term experimental farm of the Department of Agronomy and Experimental Methods University of Timiriazev, Moscow that was initiated in 1912. The soil type was podsols. Monthly mean 30-year average temperature and rainfall during vegetative period were recorded in a meteorological site near the experimental station (Fig.1). Long-term experience included continuous culture – winter rye, potato, barley (before 1973 oat grown), clover, flax and fallow, and 6-yr crop rotation: winter rye, potato, barley + clover, clover and flax. Weed communities occurring in plots of two of these crops were examined (winter rye and barley). The five treatments consisted of various fertilizers: N, P, K and NPK, and the control with no fertilizer added (St). The fertilizers were broadcast before planting at 100 kg N ha^{-1} as ammonium nitrate, 150 kg P_2O_5 ha^{-1} as triple super phosphate, and 120 kg K ha^{-1} as potassium chloride. The fertilizers were immediately incorporated into the soil. Individual plot size was 50 m^2 (10 by 5). Vockhod-2 winter rye was planted on 23 August 2003 and 25 August 2004, and Zazercki spring barley was planted on 3 May 2004 and 19 May 2005. Winter rye and spring barley were drilled in 15 cm rows at 6 and 5.5 million plants ha^{-1}, respectively. Immediately after seeding three permanent quadrates were staked in each plot, each quadrate measuring 50 × 50 cm. Just prior to herbicide application, quadrates were covered with polyethylene boxes to prevent herbicide drift. The boxes were removed immediately after spraying.

Weed density was counted at full tillering and wax maturity stages in permanent quadrates. At wax maturity weeds were cut at ground level, counted, oven dried at 105°C and weighed. The crops yields were determined by standard methodology from same three quadrates (Vasilev *et al.*, 2004).

Data for rye and barley parameters were normally distributed, therefore standard errors were calculated from the univariate ANOVA of the raw data and the central tendencies were described with the mean (SPSS, 1998). Weed dry weight data were transformed (natural logarithm) prior to analysis. Abnormal weed data distributions required the use of the median as an indicator of central tendency and the SE from the ANOVA of transformed (natural logarithm) data as an indicator of precision (Tabachnik and Fidell, 1996). All analyses were conducted for individual years because weed density and dry weight varied considerably among years due to the wide range of environmental conditions (Fig. 1).

RESULTS AND DISCUSSION

Long-term effects of crop rotation and mineral fertilizer application on weed density

Weed species most commonly found in continuous crop winter rye included *Viola arvensis* L., *Capsella bursa-pastoris* L., *Centaurea cyanus* L., *Matricaria inodora* L., *Equisetum arvense* L., and in continuous crop spring barley were *Raphanus raphanistrum* L., *Galeopsis speciosa* Mill., *Spergula vulgaris* L., *Matricaria inodora* L., *Equisetum arvense* L., and *Poa annua* L. were the most dominant weed species at both rotations

Weed density and dry weight were significantly higher in continuous crop fields compared to rotational cropping (Fig. 2 and Table 2). Results showed a positive role at crop rotation in reduction of weed density and dry weight at both crops and two years that coordinated with the results of other researches (Daspehov, 1967, Liebman and Dyck, 1993). As shown in Fig. 2 (A and B), weed density at full tillering stage in crop rotation winter rye and barley are 4.8 and 2.8 times lower than in continuous cropping of the same crops and at the wax maturity stage are 2 and 3.8 times lower than in continuous cropping of the same crops, respectively.

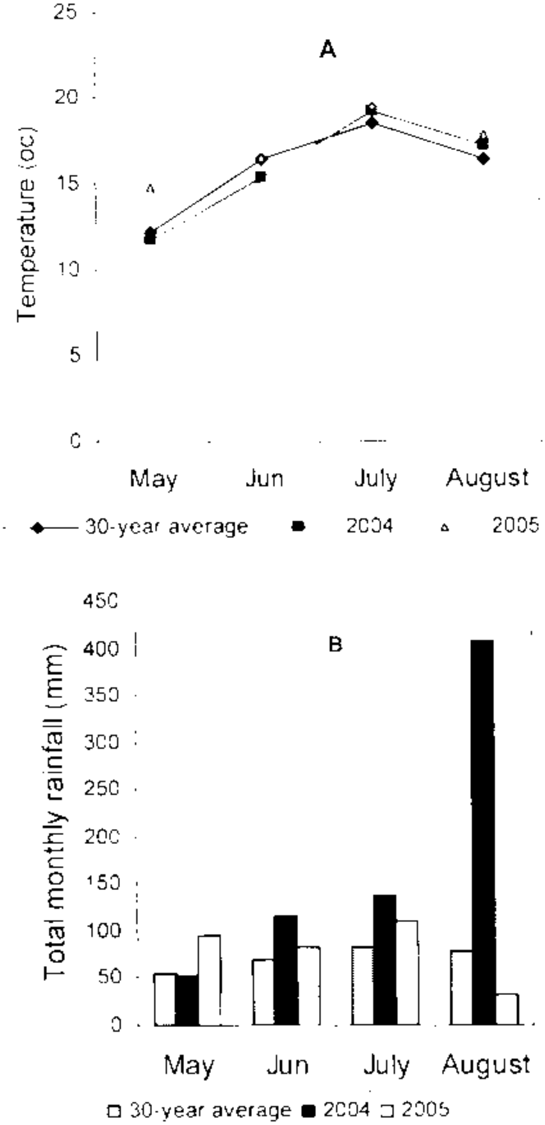

Fig. 1. Monthly means temperature and total rainfall for experimental area for 2004 and 2005, and 30-year average.

The negative effect of crop rotation on abundance of weeds may be due to the inhibitory effect of residues of the previous crops on weed seeds germination, through releasing allelochemicals, shading effects or acting as a physical barrier impeding weed seedlings development. The reduction in weed competitiveness due to crop rotation observed in this experiment is in agreement with other investigations in which cropping sequence reduced weed density (Liebman and Elizabeth, 1993, Blackshaw *et al.*, 1994).

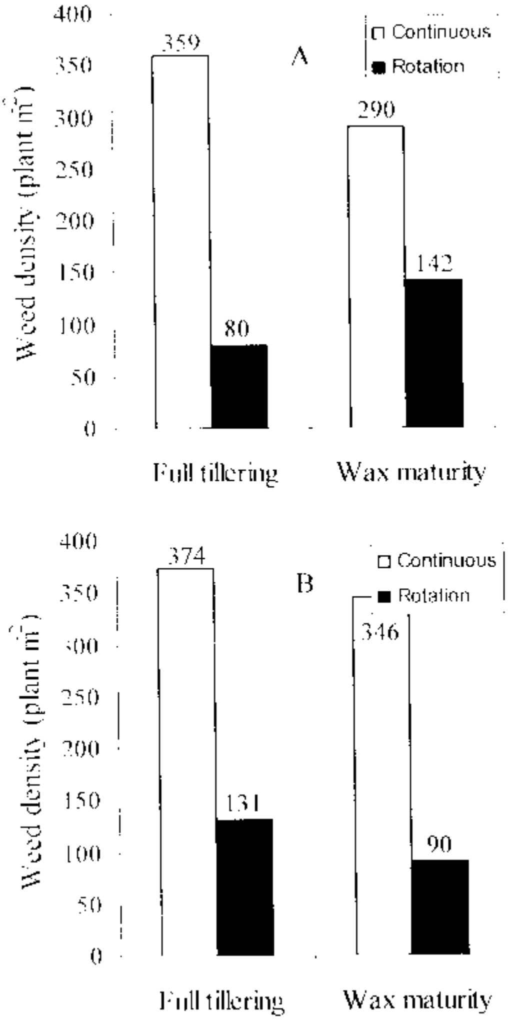

Fig.2. Long-term effects of crop rotation on total weed density (plants m^{-2}) at full tillering and wax maturity stages in winter rye (A) and spring barley (B) in 2004 and 2005 (Moscow).

Tables 1 and 2 illustrate the long-term effects of crop rotation and mineral fertilizers on weed density and dry weight. In continuous crops, mineral fertilizers application influenced weed density at both stages. In both years, total weed density in continuous crop winter rye and spring barley at both stages was the highest when P was applied (Table-1). In 2004 with P application weed density at both stages in continuous crop winter rye was recorded 440 and 477 plants at m^{-2}, respectively, but in 2005, where rainfall was lower and temperature higher P application increased weed density to 636 and 523 plants m^{-2} at the first and second sampling stages, respectively. Dusky et al. (1996) observed increased growth of lettuce (*Lactuca sativa* L.) and spiny amaranth (*Amaranthus spinosus* L.) with P application, but spiny amaranth became relatively more competitive where P was applied with a relative crowding coefficient that was three times that of lettuce.

In continuous crop winter rye, N application reduced weed density and dry weight at both growth stages, compared to control (Table-1). These reductions were greater in 2004 where environmental conditions were favorable to crop competition with weeds. Weed density reduction at full tillering in 2004 was 1.8 times compared to 6% in 2005. This may be due to drier and warmer weather in 2005. ICARDA (1984) researchers in Syria, working in a Mediterranean-type climate, showed that there was a strong interaction between weed control and nitrogen fertilization at wetter sites having severe weed infestations. No nitrogen response was obtained in the drier sites.

Table-1. Long-term effects of crop rotation and mineral fertilizers on total weed density at full tillering and wax maturity stages in winter rye and spring barley (Average 2004 and 2005) (Moscow).

	Full tillering				Wax maturity			
	2004		2005		2004		2005	
Fertilizer	No rotation	Rotation	No rotation	Rotation	No rotation	Rotation	No rotation	Rotation
				Winter rye				
St	354	117	356	41	269	96	406	226
N	193	80	337	52	73	33	255	202
P	440	91	636	52	477	115	523	140
K	355	71	354	65	211	145	296	219
NPK	230	112	331	117	156	45	238	197
95 % C.I ±	49.7	35.2	116.8	40.4	40.3	43.7	92.5	83.3
				Spring barley				
St	410	135	385	313	346	118	188	169
N	319	175	457	350	504	50	400	210
P	435	113	492	243	616	121	436	171
K	443	108	452	224	412	85	243	158
NPK	142	124	202	237	92	75	228	151
95 % C.I ±	66.9	12.6	119.6	13.7	76.4	6.3	97.1	7.2

In contrast, long-term N application in continuous spring barley not only did not reduce weed density and dry weight but also increased them at both phonological stages (Tables 1 and 2). Only in 2004 growing season, nitrogen application reduced weed density by 22 % at full tillering stage compared to control (Table-1).

In 2005, N application significantly increased weed density in continuous spring barley, where weed density increased 46% and about two times at full tillering and wax maturity stages, respectively, compared to control. Everaarts (1992) reported that N and P, but not K, application stimulated weeds growth on a sandy loam soil. Similarly, Ugen *et al.* (2002) found greater weeds growth in non-weeded bean crop with N and P application

In continuous winter rye K application had not significantly affected weed abundance at full tillering stage, but at wax maturity stage, reduced weed density (Table-1)

Crop rotation significantly reduced weed dry weight in the both crops (Table-2). Reduction weed dry weight in the crop rotation, in winter rye as compared to continuous cropping was greater with P application than other treatments.

Table-2. **Effects of crop rotation and fertilizers on dried weed biomass at maturing stage of winter cereal and spring barley in long-term experimental field in Moscow in 2004 and 2005.**

Fertilizer	**2004**		**2005**		**Means**	
	No rotation	**Rotation**	**No rotation**	**Rotation**	**No rotation**	**Rotation**
			Winter rye			
St	70.6	4.6	161.2	9.2	116.9	6.8
N	20.2	4.4	194.0	13.8	107.1	9.1
P	212.1	13.5	300.7	26.5	256.4	20.1
K	68.8	5.6	156.8	30.5	112.8	18.0
NPK	53.8	13.3	250.8	18.3	162.8	15.8
95 % C.I ±	15.4	1.5	83.3	50.1	38.9	8.0
			Spring barley			
St	95.0	48.5	146.0	121.4	84.10	84.95
N	334.0	38.8	322.1	137.5	248.80	88.15
P	154.4	52.1	235.3	98.4	153.55	75.25
K	88.7	56.6	96.1	71.8	70.35	64.20
NPK	84.4	13.0	274.8	76.7	111.65	44.85
95 % C I ±	67.9	5.8	88.7	10.4	32.3	11.7

Long-term effect crop rotation and mineral fertilizer application on grain yield

Crop rotation greatly increased crops grain yield, especially spring barley (Fig. 3). This increment was higher in 2005. Stevenson *et al.* (1998) found that barley grain yield was 23 % higher in barley-forage crop rotation than in its continuous.

Winter rye grain yield was 130 and 57% higher in rotational cropping system when followed by fallow than the sole cropping in 2004 and 2005, respectively (Fig. 3). The lower increment in winter rye grain yield in 2005 was due to lower rainfall during grain filling period The observed yield increment may be attributed to the effects of fallow on soil water reserve also to its negative effect on weed density compared to sole cropping system.

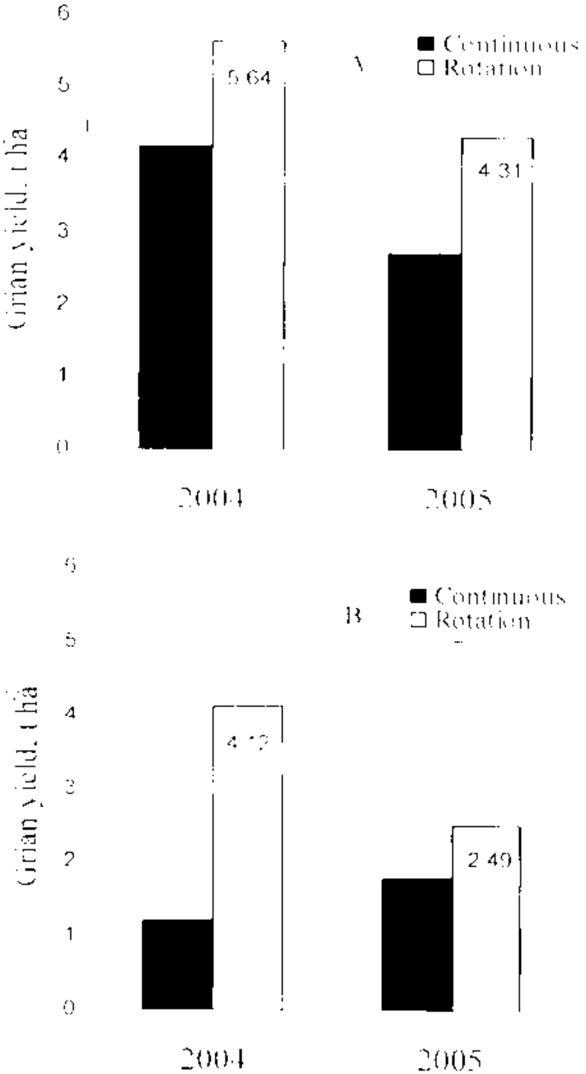

Fig. 3. Long-term effects of crop rotations on grain yield (t ha^{-1}) winter rye (A) and spring barley (B) in 2004 and 2005 (Moscow).

In 2004, spring barley grain yield in rotational cropping was 3.4 times greater than in the continuous, but not in 2005 due to higher weed infestation. Liebmen and Robichaux (1990) reported that barley yield loss due to competition by weed phonological was greatest in the seasons with the least rainfall during the vegetation period.

The long-term mineral fertilizers application increased grain yield. This increment was lower in 2005, especially under N application (Fig. 4). The reduction can be attributed to higher weed infestation and low rainfall in 2005.

In continuous spring barley N application significantly reduced grain yield (Fig. 4B). These results agree with that of Carlson and Hill (1986) and Dhima and Eleftherohorinos (2001), who found that nitrogen application increased competitive ability of weeds and consequently decreased wheat grain yield.

Grain yield of winter rye and spring barley had not shown response to P and K application (Fig. 4). In continuous winter rye response of grain yield to NPK application similar with N application (Fig. 4A) but in spring barley the highest grain yield reached in NPK treatment (Fig. 4B).

In crop rotation, especially in 2005 season differences between response of grain yield to fertilizer treatments were reduced (Fig. 4).

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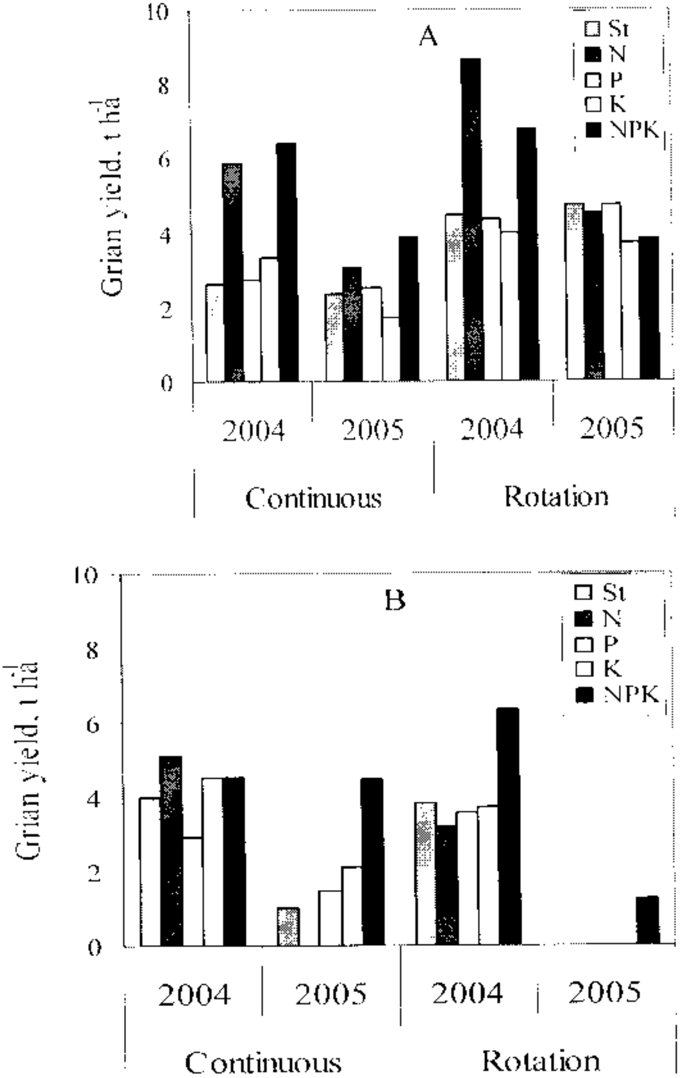

Fig.4. Long-term effects of mineral fertilizer application on grain yield (t ha^{-1}) winter rye (A) and spring barely (B), in 2004 and 2005 (Moscow)

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