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Competitive ability of components in mixed agrocenoses of grain crops depending on the cultivation areas

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ABSTRACT

The results of analyzing the productivity and biological efficiency of single-species and mixed crops of cereals and legumes are shown. It has been found that mixtures are inferior to single-species crops in the yield by 13 – 15 %, but more adaptive to the weather conditions.

Key words : *Biological efficiency, Coefficient of aggressiveness, Cultivation zone.*

Introduction

A significant reserve for increasing the efficiency of using biological environmental factors and increasing the production of fodder grain is the cultivation of highly productive environmentally sustainable multicomponent agrophytocenoses with the inclusion of legumes (Lapshin, 2017).

The main problem is assessing the single-species crops cultivation efficiency compared to mixed agrocenoses, and determining objective criteria to be used for comparison (Fadeeva *et al.,* 2017).

To facilitate analyzing advantages of mixtures, two tasks may be identified: the practical one — determining the advantages in production, and the biological one — assessing the changes in the biological productivity and identifying the reasons for the changes observed (Kurkin, 1984).

The study was aimed at determining the principles for creating highly productive mixed crops with the participation of legumes during harvesting for grain, depending on the growing zones.

Material and Methods

The studies were performed in the forest-steppe and steppe zones of Western Siberia and the forest-steppe zone of Eastern Siberia in 2013 – 2015.

The forest-steppe zone of Western Siberia (zone I) was located in the northern forest-steppe of the Ob region. The soil of the experimental plot was leached medium-thick medium-loamy black soil; the humus content in the 0 – 20 cm layer was about 6 %. The Selyaninov's hydrothermal index was 1.0 – 1.2.

The steppe zone of Northern Kulunda (zone II) was of the North-Kulunda Department of Siberian Research Institute of Fodder. The soil of the experimental plot was southern solonetzic shallow light loamy black soil. The climate in the zone was sharply continental, with hot summers and cold winters. The hydrothermal coefficient for the zone was less than 0.5.

The forest-steppe zone of Eastern Siberia (zone III) was of the East-Siberian Department of Siberian

Research Institute of Fodder. The soil of the experimental plot was ordinary heavy loamy black soil with 7.7 – 7.8 % humus content in the arable layer. The hydrothermal coefficient for May – August was 1.5, which corresponded to good humidification.

The vegetation season in 2013, on average across the zones, was characterized by excessive moisture and lack of heat. The vegetation season in 2014 was also unfavorable in terms of heat and moisture supply for grain fodder and leguminous crops. The agrometeorological conditions in the 2015 vegetation season in the steppe zone of Western Siberia was characterized by absence of precipitation from late May to mid-July.

Results and Discussion

To solve the practical problem, advantages of mixed crops were determined by the zones. For instance, unlike barley and wheat, the conditions were favorable for oats in all zones with the grain fodder yield of 1,040 to 3,700.0 kg/ha (depending on the conditions of the vegetation period). For barley, the conditions were more favorable in the forest-steppe zone of Western and Eastern Siberia; the yield was 2,940 and 4,210 kg/ha (Table 1). Pea and field pea in single-species crops formed a yield almost twice lower than that of cereals; legumes fell off badly and were affected by diseases. The analysis of the data showed that mixtures were not inferior to single-species crops, and in some cases exceeded single-species crops of pea (field pea) in terms of the grain yield and were more adaptive to the weather conditions.

In all areas of the studies, the oats + peas two-component mixture provided a stable and high yield (1,060 – 4,850 kg/ha), which was 10 – 13 % higher than in single-species cereal crops and 1.5 – 2 times higher than in single-species pea crops. Compared to single-species pea crops, the traditional barley-and-pea mixtures provided an average increase in the grain yield by 180 – 1,490 kg/ha. The introduction of a third component into a two-species mixture, especially wheat mixed with oats and peas, decreased the yield by 18 – 26 %, which indicated the low competitiveness of this crop and its oppression by oats and peas.

One of the important indicators in the cultivation of the mixtures was the legume component share in the grain yield. It varied on average from 3 to 32 % and depended on the cultivation zone.

Over the three years of studies, the coefficient of variation in the grain yield of cereals was 44 %, while that of oats was 52 %, of wheat — 62 %, and of peas — 31 %. Consequently, in individual years, the total yield in mixed crops depended less on the meteorological conditions than the yield in single-species crops.

To solve the second problem, i.e., to assess the biological effectiveness of mixed crops, a criterion for assessing the biological effectiveness of mixed crops — the land equivalent ratio (LER) indicator — along with the coefficient of aggressiveness were used (Kikvidze *et al.,* 2006). Using this coefficient,

Table 1. The grain yield of grain fodder species in single-species and mixed crops in various cultivation zones, kg/ha (average for 2013 – 2015)

Variant	Cultivation zone								
	Zone I			Zone II			Zone III		
	Mixture	Cereals	Legumes	Mixture	Cereals	Legumes	Mixture	Cereals	Legumes
Wheat	2,920	2,920	-	740	740	-	2,790	2,790	-
Oats	3,080	3,080	-	1,040	1,040	-	3,700	3,700	
Barley	2,940	2,940	-	770	770	-	4,210	4,210	
Peas	1,400	-	1,400	870	-	870	2,430	-	
Barley + peas	2,890	2,370	520	950	840	110	3,930	3,100	825
Oats + peas	2,650	2,220	420	1,060	970	90	4,850	3,780	1,060
Wheat + peas	2,260	1,540	720	990	890	10	3,250	2,500	750
Barley + peas + oats	2,700	1,970	730	930	850	83	4,290	3,500	790
Barley + peas + wheat	2,620	1,910	710	890	790	10	3,890	3,380	510
Oats + peas + wheat	2,560	1,970	590	950	870	0.8	3,620	2,600	1,020
Barley 20 + peas 50 + oats 20 + wheat 20	2,600	1,970	620	910	820	90	4,200	3,270	930

one can calculate the size of the land area required for obtaining the same yield of each component in monocultures as in mixed crops per unit area. The higher the LER value is, the higher the efficiency of land use in growing a mixture is; if the LER is 1, then mixed crop cultivation is ineffective from the standpoint of obtaining the product (Willey, and Rao, 1980). This indicator is calculated by the formula (1):

$$LER = (Y_{AB}/ Y_{AA}) + (Y_{BA}/ Y_{BB}) \quad .. (1)$$

where LER is the land equivalent ratio, Y_{AB} is the yield of crop A mixed with crop B, t/ha; Y_{VA} is the yield of crop B mixed with crop A, t/ha; and Y_{AA} and Y_{BB} are the productivities of crops A and B, respectively, in single-species cultivation, t/ha. The analysis of the experimental data showed that the biological efficiency of mixed crops depended on the meteorological conditions of the vegetation season, the cultivation zone, the components ratio in a mixture, and crop aggressiveness. For instance, for over the three years of the studies, the LER in the forest-steppe zone of Western Siberia for all mixtures was greater than 1, which indicated effectiveness of cultivating mixtures in this zone. The binary mixtures of barley and peas (LER = 1.17 units) and three-component mixtures, which included barley and wheat (1.16 – 1.17 units) (Table 2), were the most effective in this zone. In the three-component mixtures that included oats and wheat, the LER reduced to 1.07.

The mixtures with wheat were also less effective in the steppe zone. In the steppe zone of Northern Kulunda, the most productive binary mixtures were barley and field peas (LER = 1.21 units), and wheat and field peas (LER = 1.3 units). In the three-component mixtures in the dry conditions of the steppe zone, unfavorable conditions formed for the legume component, and its share in the grain yield was insignificant.

The forest-steppe zone of Eastern Siberia was characterized by sufficient humidification (the hydrothermal index was 1.5), which contributed to obtaining good grain yields. In this zone, it was most efficient to cultivate the two-component mixture of oats and peas (LER = 1.45) with a high contribution of the legume component to the efficiency of the mixture (0.43 units). Such a high value of the coefficient shows that obtaining the same amount of grain in single-species crops requires 1.45 times more land area and, accordingly, the relative productivity of the mixture higher by 45 %. It may be unambiguously asserted that the obtained value of "land equivalents ratios" shows the advantage of mixed crops.

Another coefficient that reflects the relationship of plants in mixed crops is the coefficient of aggressiveness (CA). Its meaning lies in the fact that in mixed crops, competition is determined by correlating the changes in the yields of both components of the mixture to their expected yields (Kurkin, 1984). This coefficient is calculated according to formula (2):

$$CA_{AB} = Y_{AB}:(Y_{AA}*Z_{AB}) - Y_{BA}:(Y_{BB}*Z_{BA}) \quad .. (2)$$

where CA is the coefficient of aggressiveness of crop A mixed with crop B; Y_{AB} is the yield of crop A per unit area mixed with crop B; Y_{AA} is the yield of crop A per unit area in single-species crops; Z_{AB} and Z_{BA} are the part of mixed crops determined initially for crops A and B, %. For crop B, the sign of the coefficient will be opposite. The zero value of the coefficient means that both components of the mixture have the same competitive ability and are in the

Table 2. The biological efficiency of mixed cereal-and-legume agrocenoses in various cultivation zones

Variant	Cultivation zone								
	Zone I			Zone II			Zone III		
	LER			LER			LER		
	Cereals	Peas	Mixtures	Cereals	Peas	Mixtures	Cereals	Peas	Mixtures
5.	0.8	37	**1.17**	1.09	0.12	**1.21**	0.73	0.33	1.06
6.	0.72	0.3	1.02	0.93	0.11	1.04	1.02	0.43	**1.45**
7.	0.52	0.51	1.03	1.2	0.1	**1.3**	0.89	0.3	1.09
8.	0.64	0.52	**1.16**	0.89	0.1	0.99	0.89	0.32	**1.21**
9.	0.65	0.51	**1.17**	0.89	0.1	0.99	0.96	0.22	**1.18**
10.	0.65	0.42	1.07	0.98	0.1	1.08	0.81	0.47	**1.28**
11.	0.65	0.46	1.11	0.93	0.1	1.03	1.02	0.38	**1.4**

same conditions. In any other case, both species will have the same numerical CA value, but the sign of the more aggressive component of the mixture will be positive, and that of the less competitive one will be negative.

In the forest-steppe zone of Western Siberia, in cereal crops mixed with peas, over the years of studies, the CA of the components varied from 0.01 to + 0.53 (Fig. 1).

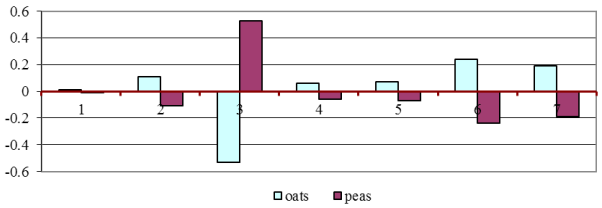

Fig. 1. Aggressiveness of the mixed crops cultivated in the forest-steppe zone of Western Siberia

In the mixtures of barley with peas, the CA approached 0, which indicated that the crops had the same competitive abilities and were in optimal growing conditions. In the most favorable conditions for legumes in a mixture with wheat, the CA of peas increased to +0.53; peas played the dominant role and provided greater contribution to the overall yield in this agrocenosis. In the mixtures with barley, in the case of harvesting for grain, the CA of cereals was 0.12 – 0.24 and determined this component's greater contribution to the total yield in the mixture.

The calculations showed that in the steppe zone of Northern Kulunda, with the low moisture reserves in the soil during the period of legume seedlings development, stressful conditions were created for plant development, and their competitiveness decreased. The value of the CA of the legume component in these conditions fell to -1.58, and its share in the agrocenosis decreased to the minimum.

Under these conditions, the cereal component showed the maximum aggressiveness, the CA increased to +1.58. Accordingly, during the vegetation season, the powerfully developed plants of the cereal component in a mixture had a strong suppressive effect on the legume component in the mixture. The CA of the legume component in the steppe zone did not exceed -0.95.

The conditions of the forest-steppe zone of Eastern Siberia were characterized by insignificant suppression of the legume component by the cereals (Fig. 2).

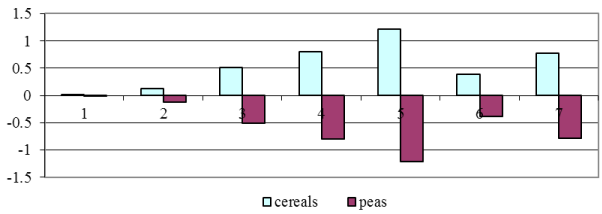

Fig. 2. Aggressiveness of the mixed crops cultivated in the forest-steppe zone of Eastern Siberia

In the mixtures of barley and oats with peas in this zone, the CA approached zero, so one can speak of favorable conditions for the growth of binary crops. The introduction of the second and the third cereal components into the mixture reduced the CA of peas to -1.21, which indicated higher competitiveness of cereals in a complex mixture, as evidenced by the high share of cereals in the yield of the mixture.

Conclusion

In the forest-steppe zone of Western Siberia, in the cultivation for grain fodder, two-component mixtures with the seeding rate of 60 – 75 % for cereals (barley or oats) and 35 – 50 % for leguminous components (peas) have an advantage. The yield is 2,300 – 2,900 kg of grain per hectare with the content of digestible protein of 106 – 110 g per fodder unit and the LER = 1.17 units.

In the conditions of the steppe zone of Western Siberia, two-component mixtures of barley and wheat with field peas are the most effective (the ratio is 60 % for the cereal and 50 % for the legume components). The yield of such cenoses remains at the reference level, and the nutritional value is 6 – 10 % higher. The LER for the zone is 1.21 – 1.3 units.

In the forest-steppe zone of Eastern Siberia, the highest grain yield has been provided by the mixtures of oats and peas (485 kg/ha) and oats 30 % + peas 50 % + barley 30 % (4,290 kg/ha) with the LER efficiency up to 1.45 units.

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