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КОНКУРЕНТНАЯ СПОСОБНОСТЬ КОМПОНЕНТОВ В СМЕШАННЫХ АГРОЦЕНОЗАХ ЗЕРНОФУРАЖНЫХ КУЛЬТУР

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Представлены результаты анализа урожайности и биологической эффективности одновидовых и смешанных посевов злаковых и бобовых культур в зависимости от зон возделывания. Исследования проведены в лесостепной и степной зонах Западной Сибири и в лесостепной зоне Восточной Сибири, результаты проанализированы через показатели «отношение земельных эквивалентов» и коэффициент агрессивности. В лесостепной зоне Западной Сибири при возделывании на зернофураж преимущество имели двухкомпонентные смеси с нормой высева 60–75% злакового (ячмень или овес) и 35–50% бобового компонентов (горох). Урожайность составила 23–29 ц зерна/га с содержанием переваримого протеина 106–110 г/к.ед. и показателем эффективности использования площади 1,17 ед. Наибольшим коэффициентом агрессивности (плюс 0,53) обладает горох в смеси с пшеницей. В условиях степной зоны Западной Сибири наиболее эффективны двухкомпонентные смеси ячменя и пшеницы с пелюшкой при соотношении злакового и бобового компонентов 60/50% от полной нормы высева культур. Урожайность данных ценозов отмечена на уровне одновидовых посевов, а питательность выше на 6–10%. Показатель «отношение земельных эквивалентов» для данной зоны составил 1,21–1,3 ед. Доля бобового компонента в урожае зерна трехкомпонентных смесей при неблагоприятных сухих условиях степной зоны зарегистрирована незначительной. Значение коэффициента агрессивности бобового компонента снизилось до минус 1,58 и максимально уменьшилась его доля в агроценозе. Для лесостепной зоны Восточной Сибири характерно достаточное увлажнение, что способствовало получению хорошего урожая зерна. Наибольшую урожайность обеспечили смеси овса с горохом (48,5 ц/га) и овса с горохом и ячменем (42,9 ц/га) с показателем «отношение земельных эквивалентов» до 1,45 ед. и коэффициентом агрессивности, близким к нулю. В данной зоне существуют благоприятные условия произрастания культур в бинарных посевах.

Ключевые слова: одновидовые и смешанные посевы, соотношение компонентов, зернофураж, биологическая эффективность, коэффициент агрессивности, зона возделывания

COMPETITIVE ABILITY OF COMPONENTS IN MIXED AGROCENOSIS OF FODDER GRAIN CROPS

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The results of the analysis of yield and biological efficiency of single-species and mixed crops of cereals and legumes, depending on the cultivation zones, are presented. The study was carried out in the forest-steppe and steppe zones of Western Siberia and the forest-steppe zone of Eastern Siberia.

The results were analyzed by means of Land Equivalent Ratio and the coefficient of aggressiveness. In the forest-steppe zone of Western Siberia, two-component mixtures with a seeding rate of 60–75% of cereals (barley or oats) and 35–50% of legumes (peas) had an advantage in cultivation for fodder grain. The yield was 2.3–2.9 t/ha of grain with digestible protein content of 106–110 g per feed unit and the efficiency of the area use of 1.17 units. Peas mixed with wheat had the highest coefficient of aggressiveness (plus 0.53). In the conditions of the steppe zone of Western Siberia, two-component mixtures of barley and wheat with field peas are the most effective with a ratio of cereal and legume components of 60/50% of the total seeding rate of crops. The yield of these cenoses was noted at the level of single-species crops, and the nutritional value was 6–10% higher. Land Equivalent Ratio for this zone amounted to 1.21-1.3 units. The share of the legume component in the grain yield of three-component mixtures under unfavorable dry conditions of the steppe zone was registered insignificant. The value of the coefficient of aggressiveness of the legume component decreased to minus 1.58 and its share in the agrocenosis decreased to the utmost extent. The forest-steppe zone of Eastern Siberia is characterized by sufficient moisture, which contributed to a good grain harvest. The highest yield was provided by a mixture of oats with peas (4.85 t/ha) and oats with peas and barley (4.29 t/ha), with the Land Equivalent Ratio of up to 1.45 units and the coefficient of aggressiveness close to zero. In this zone, there are favorable growth conditions for binary crops.

Keywords: single-species and mixed crops, ratio of components, fodder grain, biological efficiency, coefficient of aggressiveness, cultivation zone

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The authors declare no conflict of interest.

INTRODUCTION

Cultivation of forage crops is currently carried out mainly in single-species crops. Such agrocenoses are highly productive, but potentially unstable, since they completely depend on the external conditions of cultivation [1]. Unlike multicomponent agrocenoses, they are poorly adapted, more susceptible to stresses caused by changes in external conditions, they have fewer opportunities for transforming energy, nutrients, etc. Single-species crops are more vulnerable to the effects of harmful and pathogenic organisms and very actively and unilaterally deplete soil fertility.

A significant reserve for the use of biological environmental factors and an increase in the production of fodder grain is the cultivation of highly productive ecologically stable multicomponent agrophytocenoses with the inclusion of legumes [2, 3]. The effectiveness of mixed crops is determined by the biological compatibility of simultaneously growing components of the agrocenosis, which can be established experimentally [1, 2, 4–7]. Currently, one of the difficult questions in the study of mixed crops is the quantitative assessment of their advantages in comparison with single-species crops [7–10].

The main problem is to determine objective criteria for evaluating the effectiveness of single-species crops and mixed agrocenoses [2, 11, 12]. The biological efficiency of multicomponent crops is determined by comparing the productivity of the mixture with the productivity of two crops of mixed crops on the same area [13].

In the present studies, we studied the relationship of cereals with legumes when cultivated in single-species and mixed crops for grain under different growing conditions. The purpose of the research is to develop principles

for the design of highly productive mixed crops with the participation of a legume component when harvesting for grain, depending on the growing zones.

MATERIAL AND METHODS

The studies were carried out in the forest-steppe and steppe zones of Western Siberia and the forest-steppe zone of Eastern Siberia in 2013–2015. In 2021, the results were analyzed through the Land Equivalent Ratio (LER) and the Coefficient of aggressiveness Ratio (CA) [14]. These indicators are calculated using the formulas:

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

where LER is the ratio of land equivalents, Y_{AB} is the yield of crop A in mixed sowing with crop B, t / ha; Y_{BA} - yield of crop B in mixed sowing with crop A, t / ha; Y_{AA} and Y_{BB} - yield of crops A and B, respectively, in clean sowing, t / ha.

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

where CA is the coefficient of aggressiveness of culture A in mixed sowing with culture B; Y_{AB} - yield per unit area of crop A in mixed sowing with crop B; Y_{AA} - yield per unit area of crop A in clean sowing; Z_{AB} and Z_{BA} - part of the mixed sowing, initially determined for crops A and B (in %).

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

The steppe zone of the Northern Kulunda (II zone) is the Northern -Kulunda department of the Siberian Research Institute of Fodder Crops (SRIFC) of the Siberian Federal Scientific Center of Agrobiotechnology of the Russian Academy of Sciences. The soil of the experimental site is southern solonetzic chernozem, shallow, light loamy. The climate of the zone is sharply continental, with hot summers and cold winters. The hydrothermal coefficient for the zone is less than 0.5.

The forest-steppe zone of Eastern Siberia (III zone) is the East Siberian department of Siberian Research Institute of Fodder Crops. The soil of the experimental site is ordinary heavy loamy chernozem with a humus content in the arable horizon of 7.7–7.8%. The hydrothermal coefficient for May - August is 1.5, which corresponds to the indicators of good moisture.

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

In the experiment, the following ratios of components in mixtures were used: barley (75%) + peas (field pea) (35%), oats (75%) + peas (field pea) (35%), wheat (70%) + peas (field pea) (40%), barley (30%) + peas (field pea) (50%) + oats (30%), barley (30%) + peas (field pea) (50%) + wheat (30%), oats (30%) + peas (field pea) (50%) + wheat (30%), barley (20%) + oats (20%) + wheat (20%) + peas (field pea) (50%).

RESULTS AND DISCUSSION

To solve the practical problem of the study, the production advantages of mixed crops by zones have been determined. For oats, in contrast to barley and wheat, conditions are favorable in all zones (the yield of grain fodder is from 10.4 to 37.0 c / ha, depending on the conditions of the growing season). For barley, conditions were more favorable in the forest-steppe zone of Western and Eastern Siberia, the yield was 29.4 and 42.1 c / ha, respectively (see Table 1). Peas (field pea) in single-species crops formed a yield almost 2 times less than that of cereals, legumes lodged badly and were affected by diseases. Compared with single-species crops, the mixtures were not inferior, and in some cases exceeded single-species crops of peas (field

pea) in grain collection. They are marked more plastic to meteorological conditions.

In all research areas, a two-component mixture of oats + peas provided a stable and high yield of 10.6–48.5 c / ha. These indicators are 10-13% higher than the data of single-species crops of cereals, and 1.5-2 times higher than those of single-species crops of peas. Traditional barley-pea mixtures, on average, provided an increase in grain yield in comparison with single-species pea crops by 1.8-14.9 c / ha. The introduction of the third component into the double mixture (especially wheat mixed with oats and peas) reduced the yield by 18-26%, which indicates the low competitiveness of this crop and its oppression by oats and peas.

One of the important indicators in the cultivation of mixtures is the proportion of the legume component in the grain yield. It varied on average from 3 to 32% and depended on the cultivation area. The minimum content of peas in the mixture (3–8%) was obtained in the steppe zone of Northern Kulunda, the maximum (24–32%) - in the forest-steppe zone of Western Siberia.

The mixtures formed a more stable yield over the years, compensating for the lack of yield of one component at the expense of another. For 3 years of research, the coefficient of variation in grain yield of cereal crops was 44%, while oats - 52%, wheat - 62, peas - 31%. Consequently, the total yield of mixed crops is less susceptible to the influence of meteorological conditions in individual years than crops in single-species crops.

To solve the problem of assessing the biological effectiveness of mixed crops, the following indicators were used: LER and CA [14]. Using the LER value, the calculation of the size of the land area required to obtain in single-species crops the same amount of production of each of the components, which was formed per unit area of the mixed crop. The higher the LER value, the higher the efficiency of land use when growing a mixture, if LER = 1, then mixed cultivation of crops is ineffective for obtaining products [15].

The analysis of experimental data showed that the biological efficiency of mixed crops depends on the meteorological conditions of the growing season, the cultivation zone, the ratio of the components in the mixture and the aggressiveness of the crop. For 3 years of research in the forest-steppe zone of Western Siberia, the LER index for all mixtures was registered above 1, which indicates the effec-

Табл. 1. Урожайность зерна зернофуражных культур в одновидовых и смешанных посевах в разных зонах возделывания, ц/га (среднее за 2013–2015 гг.)

Table 1. Grain yield of fodder crops in single-species and mixed crops in different zones of cultivation, centner/ha (average for 2013-2015)

Option	Cultivation area								
	I			II			III		
	Mixture	Cereals	Legumes	Mixture	Cereals	Legumes	Mixture	Cereals	Legumes
Wheat	29,2	29,2	–	7,4	7,4	–	27,9	27,9	–
Oat	30,8	30,8	–	10,4	10,4	–	37,0	37,0	–
Barley	29,4	29,4	–	7,7	7,7	–	42,1	42,1	–
Pea	14,0	–	14,0	8,7	–	8,7	24,3	–	–
Barley + pea	28,9	23,7	5,2	9,5	8,4	1,1	39,3	31,0	8,25
Oat + pea	26,5	22,2	4,2	10,6	9,7	0,9	48,5	37,8	10,6
Wheat + pea	22,6	15,4	7,2	9,9	8,9	0,1	32,5	25,0	7,5
Barley + pea + oat	27,0	19,7	7,3	9,3	8,5	0,83	42,9	35,0	7,9
Barley + pea + wheat	26,2	19,1	7,1	8,9	7,9	0,1	38,9	33,8	5,1
Oat + pea + wheat	25,6	19,7	5,9	9,5	8,7	0,8	36,2	26,0	10,2
Barley + pea + oat + wheat	26,0	19,7	6,2	9,1	8,2	0,9	42,0	32,7	9,3

tiveness of the cultivation of mixtures in this zone. The most effective in this zone were the binary mixtures of barley with peas (LER 1.17 units) and three-component mixtures containing barley with wheat (LER 1.16–1.17 units) (see Table 2). In three-way blends containing oats and wheat, the LER decreased to 1.07.

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

The forest-steppe zone of Eastern Siberia is characterized by sufficient moisture (HTC = 1.5), which contributes to obtaining good grain yields. In this area, it is most efficient to cultivate a two-component mixture of oats and peas (LER 1.45 units) with a high contribution of the legume component to the efficiency of the mixture (LER 0.43 units). The high value of the coefficient shows that to obtain the same amount of grain in single-species crops, 1.45 times more land area is required, i.e. the relative productivity of the two-component mixture is 45% higher. It can be unambiguously asserted that the obtained value of the "land equivalents ratio" shows the advantage of mixed crops.

The aggressiveness coefficient represents the competition of crops in a mixed sowing, which is determined by correlating the change in the yield of both components of the mixture to the expected indicators. This coefficient is calculated by the formula (2).

For culture B, the sign of the coefficient will be opposite to culture A. A coefficient value equal to zero means that both components of the mixture have the same competitive ability and are in the same conditions. Under other circumstances, crops will have the same CA numerical value. However, the more aggressive component of the mixture will have a positive sign, the less competitive - negative.

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

In mixtures of barley and peas, CA approached zero. This indicates that the crops had the same competitive ability and were in optimal growing conditions. Under the most favorable conditions for legumes (in a mixture with wheat), the CA of peas increased to plus 0.53, peas acted as a dominant and provided a greater contribution to the overall productivity of this agrocenosis. In mixtures with barley (when harvesting for grain), the CA of cereals was plus 0.12–0.24, determining the high value

Табл. 2. Биологическая эффективность смешанных злаково-бобовых агроценозов в различных зонах возделывания

Table 2. Biological efficiency of mixed cereal and legume agrocenosis in different cultivation zones

Option	Cultivation area								
	I			II			III		
	LER			LER			LER		
	cereals	pea	mixture	cereals	pea	mixture	cereals	pea	mixture
Barley + pea	0,8	0,37	1,17	1,09	0,12	1,21	0,73	0,33	1,06
Oat + pea	0,72	0,3	1,02	0,93	0,11	1,04	1,02	0,43	1,45
Wheat + pea	0,52	0,51	1,03	1,2	0,1	1,3	0,89	0,3	1,09
Barley + pea + oat	0,64	0,52	1,16	0,89	0,1	0,99	0,89	0,32	1,21
Barley + pea + wheat	0,65	0,51	1,17	0,89	0,1	0,99	0,96	0,22	1,18
Oat + pea + wheat	0,65	0,42	1,07	0,98	0,1	1,08	0,81	0,47	1,28
Barley + pea + oat + wheat	0,65	0,46	1,11	0,93	0,1	1,03	1,02	0,38	1,4

of this component in the total productivity of the mixture.

In the steppe zone of Northern Kulunda, with low moisture reserves in the soil during the development of seedlings of legumes, unfavorable conditions were created for the development of plants, and their competitiveness decreased. Under these conditions, the CA value of the legume component dropped to minus 1.58, and its share in the agrocenosis decreased as much as possible (see Fig. 2).

Under these conditions, the cereal component showed the maximum aggressiveness, the CA increased to plus 1.58. During the growing season, the developed plants of the cereal component of the mixture exerted a strong suppressive effect on the legume component of the mixture. The coefficient of aggressiveness of the legume component in the steppe zone did not exceed –0.95.

The conditions of the forest-steppe zone of Eastern Siberia are characterized by a slight suppression of legumes by the cereal component (see Fig. 3).

In mixtures of barley and oats with peas in this zone, CA approaches zero, which indicates favorable conditions for the growth of crops in binary crops. The introduction of the second and third cereal components into the mixture reduces the CA of peas to minus 1.21, which indicates a higher competitiveness of cereals in a complex mixture, as evidenced by the high proportion of cereals in the mixture yield.

CONCLUSION

1. In the forest-steppe zone of Western Siberia, when cultivating for grain fodder, two-component mixtures with a seeding rate of 60–75% cereal (barley or oats) and 35–50% leguminous components (peas) have an advantage. The yield is 23–29 centners of grain / ha with a digestible protein content of 106–110 g / c. units and the indicator "ratio of land equivalents" 1.17 units.

2. In the conditions of the steppe zone of Western Siberia, two-component mixtures of barley and wheat with field pea are most effective (60% of the cereal and 50% of the legume component). The productivity of these cenoses was noted at the control level, the nutritional value was 6–10% higher. The indicator "ratio of land equivalents" for the zone - 1.21-1.3 units.

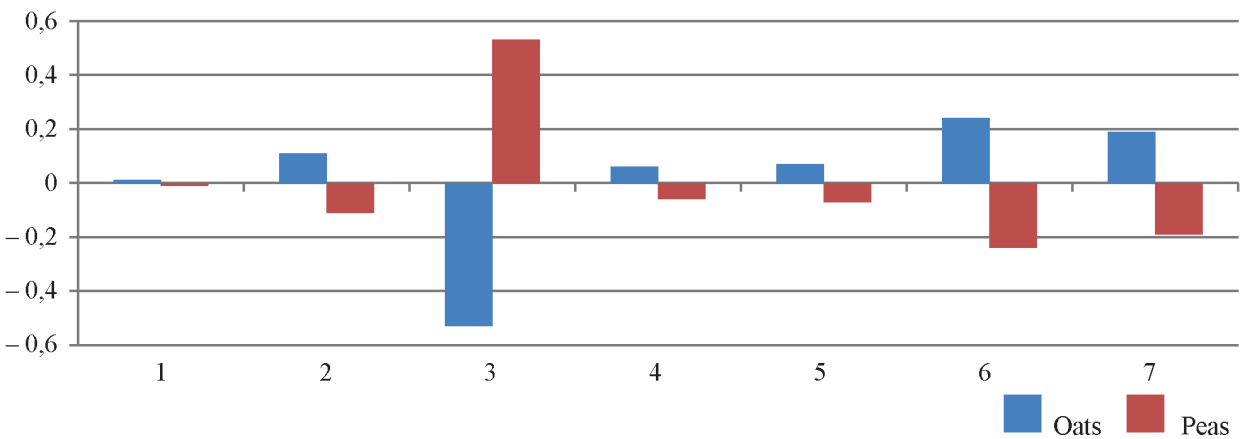

Рис. 1. Коэффициент агрессивности культур смешанных посевов в условиях лесостепной зоны Западной Сибири

Здесь и на рис. 2, 3 варианты посевов: 1. ячмень + горох, 2. овес + горох, 3. пшеница + горох, 4. ячмень + горох + овес, 5. ячмень + горох + пшеница, 6. овес + горох + пшеница, 7. ячмень + горох + овес + пшеница

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

Here and in Fig. 2, 3 sowing options: 1. barley + peas, 2. oats + peas, 3. wheat + peas, 4. barley + peas + oats, 5. barley + peas + wheat, 6. oats + peas + wheat, 7. barley + peas + oats + wheat

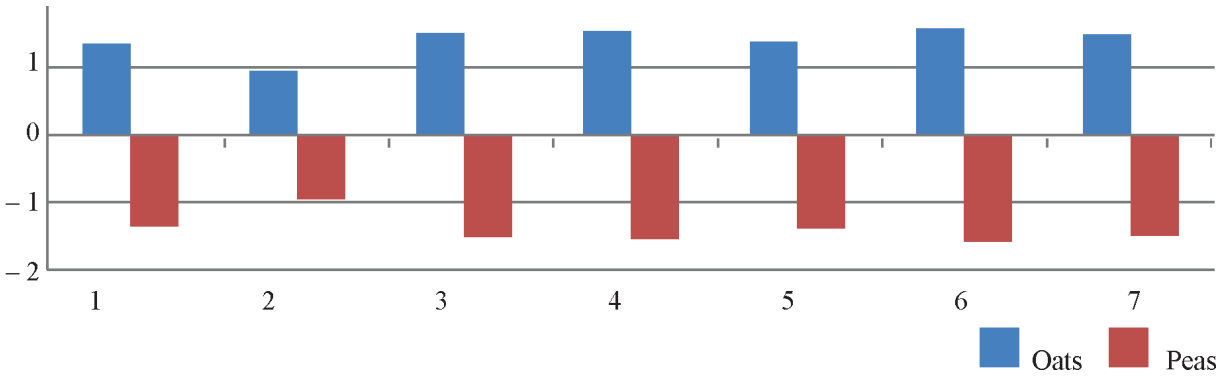

Рис. 2. Коэффициент агрессивности культур смешанных посевов в условиях степной зоны Северной Кулунды

Fig. 2. Coefficient of aggressiveness of mixed crops cultivated in the conditions of the Northern Kulunda steppe zone

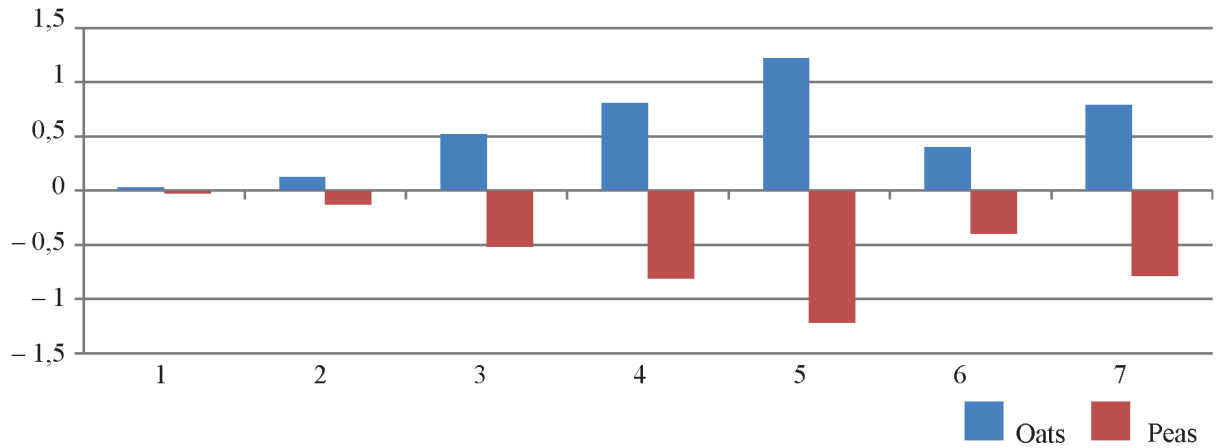

Рис. 3. Коэффициент агрессивности культур смешанных посевов в условиях лесостепной зоны Восточной Сибири

Fig. 3. Coefficient of aggressiveness of mixed crops cultivated in the forest-steppe zone of Eastern Siberia

3. In the forest-steppe zone of Eastern Siberia, the highest grain yield was provided by a mixture of oats with peas (4.85 c / ha) and oats 30% + peas 50% + barley 30% (42.9 c / ha) with the value of the "ratio of land equivalents" up to 1, 45 units.

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