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Intermediate crops as one of the factors of optimizing the application of fertilizers and increasing soil fertility

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Abstract. Saturation of crop rotation with intermediate crops compresses the time of agricultural works: harvesting the forecrop grown, preparing the soil, applying fertilizer, sowing the next crop. Regulation of water availability of plants makes all factors of productivity manageable. Wheat on green fodder responds positively to the extended sowing time and allows collecting feed or mass for the production of grass meal in the same sequence in the autumn and spring. Continuous use of arable land in intensive irrigated crop rotation provides a high total yield of green mass mixture and row crops grown after the bean-wheat mixture on ordinary irrigated chernozem and objectively provided by any combination scheme obtaining adequate total yield for some deviations concerning the early harvest or late sowing. Spring crops in intensive crop rotation with irrigation in the south of Russia are used as insurance crops in case of winter crops. In intensive crop rotations, they play a more important role of stubble crops. Zero tillage for crop after irrigation is not inferior in efficiency to plowing. The use of mineral fertilizers in the system of two crop field is an integral agricultural method, contributing to an increase in the yield of all crops.

1. Introduction

The insurmountable obstacles to stubble drillings of hay cultivated crops in intensive crop rotations on the chernozem of the North Caucasus Federal District are the May rainy season, the soil rolled by heavy harvesting machines, the live root system of winter intermediate crops, especially fibrous, afterpaste.

A large number of studies conducted in different soil and climatic conditions of the Central Ciscaucasia (Esaulko A.N. et al., 2016; Grechishkina Yu.I. et al., 2016; Esaulko A.N. et al., 2017; Esaulko A.N. et al., 2017a) are devoted to the search for optimal agricultural practices that allow increasing the productivity of agricultural land. In order to optimize the saturation of agricultural work, it is necessary to solve a number of issues that establish the relationship between the harvest times of a forecrop grown in winter or summer sowing, soil preparation, fertilizer application, and seeds of a regular crop in rotation. Reasonable norms and terms of fertilizer application at artificial water supply management allow to regulate all factors of programming crop yields.



2. Place, program, research method

The studies were conducted in perennial experiments of the south of Russia: in the semi-desert zone on irrigated slightly saltified light-chestnut soils and on ordinary chernozem irrigated of the southern warm facies.

The influence of harvest time on agricultural crop in intermediate sowing on the yield of main row crops after them in intensive crop rotation has been studied. The place of spring crops in the intensive crop rotation during irrigation has been determined. The effectiveness of zero tillage for stubble crops during irrigation (sowing in stubble) has been determined. The time and rates of fertilizer application in a double-crop field are revealed.

The parameters of soil fertility in the crop rotation of perennial experiment were determined in accordance with generally accepted methods according to the relevant State standard GOST. The yield was taken into account by the method of continuous cleaning with recalculation to standard humidity.

Results and discussion. On the basis of long-term studies, the terms of sowing winter crops for grain and green fodder were developed, allowing them to be placed in intensive crop rotations from a technological point of view, because, as is known, their saturation of crop rotation conflicts with the terms of winter wheat sowing for grain and green fodder (table 1).

Table 1. Growth rates of vegetative mass and yield of winter wheat in connection with the terms of sowing and seeding rates in intensive crop rotation irrigated (average long-term data, t / ha).

Seeding dates	Vegetative mass				Grain			
	seeding rate, mil. pcs / ha							
	4.0	5.0	6.0	7.0	4.0	5.0	6.0	7.0
20.09	30.5	32.0	32.8	33.1	3.25	3.22	3.18	3.15
01.10	36.2	37.0	35.0	36.6	3.61	3.54	3.64	3.61
10.10	37.8	36.9	36.9	36.6	3.69	3.66	3.74	3.51
20.10	33.8	36.0	31.3	32.5	2.75	3.04	2.79	2.88

They create conditions for the formation of grain yield of about 3.6–3.7 t / ha, green mass of 37.0–38.0 t / ha and free the fields until the optimum sowing dates. An increase in seeding rates from 4–5 million pieces / ha to 6.0 or more is impractical, regardless of the purpose of growing winter wheat crop. Winter wheat on green fodder responds positively to the extended sowing time and allows collecting feed or mass for the production of grass meal with the same sequence in the autumn and spring. With the continuous use of arable land in intensive irrigated crop rotation, the total yield of green mass mixture and tilled crops grown after the wick-wheat mixture on ordinary irrigated black soil (t / ha) reaches: corn - 71.5–87.5, sorghum - 79.6– 88.2 and it is objectively provided by any combination scheme (early harvest or late sowing) of obtaining an adequate total yield with some deviations regarding the first and last dates (table 2).

Table 2. The total yield of green mass per unit area, depending on the period of harvesting the forecrop and sowing the main row crops in intensive crop rotation on ordinary irrigated chernozem (t / ha, average long-term data).

Date of harvesting and sowing before:	Forecrop of the vetch-wheat mixture plus:	
	corn	sorghum
10.05	85.9	79.6
15.05	87.5	84.5
20.05	87.5	88.2
30.05	80.6	84.4
05.06	71.5	81.2
10.06	61.9	77.2

The yield decrease, depending on the timing of harvesting the mixture and sowing of tilled crops after them in intensive crop rotation, is not pronounced sharply; nevertheless, June sowings reduce yields by 1.5 times as compared with May crops. Considering that sorghum less than other crops reduces yields from the June planting dates due to the late harvest of the winter intermediate crop, corn, grain, silage should be sown early, and later, sorghum and other purposes should be sown. Thus, the technological scheme in intensive crop rotations, saturated with intermediate crops, carries with it: when cultivating row crops for grain, sowing is until 10.05; for corn silage - until 05.06, sorghum - until 10.06. Subsequent crops, and so may be due to the use of spring intermediate crops, should be considered as stubble.

Studies in the semi-desert zone on irrigated lightly salty light-brown soils showed that the proportion of spring crops in intensive crop rotations can be brought up to the level occupied by winter wheat by means of stubble grain crops (table 3).

Table 3. The yield of grain varieties of spring grain crops in connection with the type of crop rotation on light-brown irrigated soil (average long-term data).

Crop, variety	Type of crop rotation, yield t / ha	
	extensive	intensive
Spring wheat		
Innia 66	2.24	2.87
Sete Zerks	2.51	2.37
Lermi-Roho 64	1.38	1.44
Red-River 68	-	1.99
Verdl Seeds 1812	1.59	-
Spring barley		
Odesskiy 36	2.39	2.56
Krasnodarskiy 35	3.67	3.04
Yuzhny	2.15	2.04
P, %	3.26-4.21	4.29-4.70
HCP ₀₅	0.248-0.263	0.410-0.421

Thus, the cultivation of spring wheat is advisable transfer to the stubble crop, freeing the plowing under the more productive crops in these conditions.

Innia variety is the most suitable for this purpose. The spring barley Krasnodarskiy 35 is equally suitable for placement along the extensive crop rotation, as well as in the stubble intensive sowing, but Odesskiy 36 and Yuzhny in the stubble sowings, because, regardless of the type of crop rotation and crop placement, it provides approximately equal yield. This significantly increases the proportion of spring crops in the structure of the planted acreage, gross grain production, frees fields for more productive crops in the typical crop rotation.

The tillage of irrigated soil according to general biological requirements, regardless of the crop rotation type, imposes special conditions aimed at maintaining the physical properties of the soil (Volters I.A. et al., 2018), corresponding to plant biology, but on the ordinary chernozem, irrigated by the southern warm facies, the possibilities of minimizing tillage in depth and the number of operations are sharply limited (table 4).

In addition to corn, sunflower, other crops react negatively to replacing plowing with peeling, significantly reducing the yield of green mass (7.9–13.5%). If corn consistently provides an increase in tillage to a depth of 10–12 cm, then the sunflower only in certain years increases the yield of oilseeds in fields that have been finely tilled. This is due to a change in the exchange mass, porosity of the soil, which goes beyond the optimum parameters for individual crops by the deterioration of the soil air regime.

Table 4. The effect of tillage depth on the yield of tilled crops after winter crops in intensive crop rotation on the ordinary chernozem, irrigated by the southern warm facies.

Crop, production	Yield, t / ha		HCP 0,5, t / ha	P, %
	depth of tillage, cm			
	22-22	10-12		
Corn, grain	5.68	5.78	0.004 -0.2	0.9 – 2.7
Corn, silage	45.0	40.4	0.47 – 1.19	1.0 – 2.7
Sugar beets, root vegetables	33.0	30.5	0.58 – 0.92	1.3 – 3.5
Sunflower, seeds	2.22	2.14	0.04 – 0.12	2.2 -4.6
Hemp, seeds	0.50	0.43	0.004 – 0.01	0.78 – 2.9
Sorghum, silage	51.7	44.0	0.11 – 1.70	1.0 – 2.7

Thus, from tilled crops, after winter tilled, after winter intermediate crops in intensive crop rotation only corn responds positively to replacing plowing with peeling (due to aerial roots), and sugar beet, hemp, sorghum, and sunflower require tillage to a depth of 20–22 cm, which corresponds to their biology.

As it turned out, second crops react positively to plowing and increase, compared with tillage to a depth of 10–12 cm, the yield of green mass (t / ha): maize - by 1.83, sorghum - 2.1, peas - 0.55, which is explained by the reduction in terms of soil preparation and the extension of their growing season (table 5).

Table 5. The influence of the tillage depth of the ordinary chernozem, irrigated by the southern warm facies, on the yield (t / ha) of stubble crops (average 5-year data).

Crop	Depth of tillage, cm	
	20 - 22	10 – 12
Corn	28.0	26.1
Sorghum	29.1	27.0
Peas	11.3	10.8

The study of the location, time and application rates of fertilizers in a double-crop field was preceded by reconnaissance experiments, which indicated the need for additional fertilization to the recommended norms in a single-field field (table 6).

Table 6. The effect of mineral fertilizers on the yield of one-row tilled crops (t / ha) on chernozem ordinary irrigated by the southern warm facies (average long-term data).

Crop, production	Natural agrochemical background	Crop rotation is saturated N60P60K60
Corn, grain	6.11	6.78
Sunflower, seeds	2.75	3.15
Sugar beets, root vegetables	24.1	30.9
Forage sorghum, green mass	49.0	57.3

The introduction of NPK directly under the planting crops in intensive crop rotation on the chernozem of the ordinary warm southern facies provides significant increases (t / ha): corn grain - 0.67; sunflower seeds - 0.4; sorghum green mass - 8.37; root crops of sugar beet - 6.85. This was the basis for setting up a series of multifactorial long-term and short-term experiments to study the effect of fertilizers on crop yields in various soil and climatic conditions of the North Caucasus Federal

District. Experiments have shown a high responsiveness of winter and spring wheat, spring barley to the place, time, dose and ratio of elements in fertilizers. At [[HCP]] 05 (t / ha) 0.394-0.486 Krasnodarskiy spring barley for two yields gives 3.78 t / ha of grain on a natural agrochemical background, the effect of N₉₀ P₁₁₀ + increased the yield on 5.43–6.10 t / ha.

Studies by a number of authors [1–4] showed that high rates of fertilizer in crop rotation extensive without intermediate crops are not used effectively enough, as evidenced by our research (table 7).

Table 7. Influence of the crop rotation type, fertilizer systems on crop yields on light chestnut irrigated soil (average 11-year data).

Number of field	The alternation of crops, a place in the rotation, production	Fertilizer rate ^a ,	Yield ^b , t/ha	
			production	feed units
Intensive / semi-intensive crop rotation				
1.	Sainfoin (intermediate), green mass Corn postcut, grain	aftereffect	27.5	6.05
		0	21.5	4.73
		N120P120K30	6.67	1.5
		0	4.10	6.48
2.	Winter wheat, grain Spring wheat stubble, mono feed, seeding of sainfoin (intermediate)	N220P220K30	5.51	8.0
		0	2.69	4.21
		aftereffect + N20P20	16.5	3.63
		0	11.8	2.26
3.	Sainfoin (intermediate), green mass Corn postcut, silage	aftereffect	26.3	6.76
		0	22.0	4.82
		N120P120K30	72.2	14.42
		0	43.8	8.76
4.	Winter wheat, grain Spring barley stubble (mono), seeding of sainfoin	N220P220K60	5.81	8.31
		0	2.89	4.45
		aftereffect + N20P20	19.5	4.29
		0	15.4	3.40
On average, with 1 hectare of crop rotation: intensive		N180P180K22.5	-	15.24
		0	-	9.86
Semi-Extensive / Extensive				
1.	Corn, grain	N120P120K30	7.40	11.57
		0	4.50	7.11
2.	Winter wheat (grain) seeding of sainfoin	N240P220K90	5.29	7.65
		0	2.53	3.94
3.	Sainfoin, green mass	N120P140	50.40	11.04
		0	38.3	8.43
4.	Winter wheat, grain	N240P220K80	5.96	8.59
		0	2.97	4.46
On average, 1 ha of crop rotation:		N180P175K45	-	9.72
semi-intensive		0	5	5.98

^a in the numerator fertilizer system of intensive crop rotation, in the denominator - semi-intensive

^b in the numerator, the fertilizer system in semi-intensive crop rotation, in the denominator - in extensive.

The optimal ratios of nutrients in fertilizers in the system of a two-crop field in an intensive 1: 1, 2: 0 crop rotation, regardless of the application place. The highest effect is ensured by the single application of high doses of fertilizers (N135P156K45 and N180P220K60) for spring sowing. When this is achieved, the total yield of spring barley grain is about 7.10–8.76 t / ha. Additionally,

fertilization under spring barley, especially against the background of the aftereffect N180P220K60, is ineffective. The total yield of winter and spring wheat on a natural agrochemical background is higher than spring barley and reaches 4.84 t / ha, adding NP to just one of them provided an increase of about 1.38-2.48 t / ha. In all cases, very effective row fertilizer at the rate of N23P23.

The aftereffect and the addition of mineral fertilizers for spring wheat crop is accompanied by a steady increase in the increments, depending on the doses and ratios of NPK in the fertilizers; the higher the norm for winter wheat, the lower the effectiveness of spring summer crop fertilizer. The N240P240K60 norm for winter wheat provides the highest total wheat yield (11.91 t / ha), the use of NPK against this background for spring wheat for harvesting imperceptibly increases the yield, with the exception of row fertilizer.

Consequently, the use of mineral fertilizers in the system of a two-crop field is an integral agricultural method, contributing to an increase in the yield of all crops. The most effective application of NPK is high norms with a ratio of 1: 1.22 (1): 0.33 / 0.25 under the first crop in a double-year field.

Intensive crop rotation does not have a negative effect on the yield of winter wheat in the semi-intensive zone on light-brown slightly salted soil and additionally provides collection of 16.5-19.5 t / ha of monofarm from spring wheat; in the semi-intensive with the exception of the fertilizer system - only 11.8–15.4 t / ha due to compaction with intermediate crops. Other things being equal, a fertilizer system in intensive crop rotation, as compared to semi-intensive, provides higher yields.

3. Conclusions

Winter wheat on green fodder responds positively to the extended sowing time and allows collecting feed or mass for the production of grass meal in the same sequence in the autumn and spring.

In intensive crop rotations, saturated with intermediate crops, tilled crops for grain should be sown before 10.05; for silage (corn) - until 05.06., sorghum - until 10.06. Subsequent crops should be considered as second crops.

In the system of a double-crop field, NPK application with high rates with a ratio of 1: 1.22 (1): 0.33 / 0.25 under the first crop is most effective, which contributes to increasing the yield of all crops.

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