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AGRICULTURAL TECHNOLOGIES AND LAND RECLAMATION

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INTERCROPPING MAIZE — COMMON BEAN ENHANCES MICROBIAL CARBON AND NITROGEN IN LOW-PHOSPHORUS SOIL UNDER MEDITERRANEAN CONDITIONS

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Abstract. The positive effect of intercropping under low phosphorus (P) conditions has already been reported in previous works. The aim of this study was to test the hypothesis that intercropping (common bean — maize) in P deficient soil, can enrich carbon (C) and nitrogen (N) of the microbial biomass (MB) through a transfer from root nodules of the plant and rhizospheric microbial flora in a field located in "Setif region" in northern Algerian agroecosystem(Mediterranean climate). The rate of nodular N sequestered in intercropped common bean was higher compared to sole crops and fallow. However, under intercropped and low P conditions, the rate of nodular N sequestered is highest over two years. Carbon of the microbial biomass (MB-C) is higher in the intercropping compared to sole crops and fallow but it is even higher in P deficient soil. Moreover, a strong correlation is established between nodular C and MB in intercropping under low P conditions. In these same conditions, the total soil respiration was the highest and the lowest C:N ratio of MB was recorded. These results showed that in low P soil, intercropping is a good solution to enhance the rhizospheric MB that can fertilize the soil and recycle mineral elements.

Keywords: Intercropping; P-Deficiency; Microbial biomass; Carbon; Nitrogen; agroecosystem

INTRODUCTION

A soil's quality affects the agroecosystems services and sustains biological productivity to promote plant growth and increase bio-availability of the essential nutrients [1, 2]. However, the effect of intercropping system on agroecosystem productivity on C and N sequestration have been well documented in either short- or long-term duration [1, 3]. The increase of C input into the soil through root residues has been confirmed for both legumes and cereals in intercropping compared to mono-cropping systems [4]. Indeed, recent studies suggest greater N storage in legumes-cereals intercropping as a result of enhancing in efficiency in use of rhizobial symbiosis (EURS) in low P soil compared to high P soil conditions [2]. On the other hand, variation in C:N ratio of soil microorganisms (fungi and bacteria) has been attributed to evaluated relative demand of soil microbes for C and N [5]. The changes of C:N ratio in MB may have important effect for N and C cycling. Considering the interspecific interaction (complementarily and facilitation) of legumes on rhizosphere MB in intercropping system, a hypothesized effect of cereals-legumes intercrops on investigating of the MB C:N and its relationship with rhizobial N_2 fixation would be tested.

Our previous studies reported that intercropping common bean-maize might be an alternative agronomical practice that is scarcely adopted in north-east Algerian agroecosystem under low P conditions [6]. In the studies reported here, we hypothesize that the presence of common bean as intercrop with maize will enhance both MB-C and MB-N through greater input of nodules C and N into the soil rhizosphere in either P deficient or P sufficient conditions. This will also result in a significant change in the C:N ratio and MB respiration. To address these hypotheses, both the intercrop and sole crop were grown in two years rotations in the same experiment sites studied in our last research experiment [2] located in Setif region in northern Algerian agroecosystem.

MATERIALS AND METHODS

The study was performed during 2012—2013; the field experiments were carried out over the same two experimental sites S1 (35°58, 11'N and 5°14, 90'E) and S2 (35°53, 37'N and 5°37, 01'E) studied in our last research [2]. Sites are located in the agroecosystem of Setif (300 km north-east of Algiers) where maize and common bean are widely cultivated as intercropping. An experiment designed to fulfil the aim of this study was carried out with one common bean cultivar (*Phaseolus vulgaris* cv. El Djadida) and one maize cultivar (*Zea mays* cv. Filou) cultivated by most farmers' fields in Algerian agroecosystem. Split-plot was used as an experimental design with four replicates. Seventy days after sowing (DAS) that corresponds to a full flowering stage, soil samples were taken from the rhizosphere of each species and fallow plot. The rhizosphere of both maize and common bean roots was bulked for each replicate in all crop treatments. The rhizosphere samples were then stored at 4°C for 72 hours before analysis. Indeed, the nodules were separated from the common bean roots, dried and weighed separately.

The soil MB-C and MB-N have been measured in physico-chemical laboratories at the national institute of agronomy research (Montpellier, France). MB-C and MB-N were determined by chloroform fumigation-extraction method modified and adjusted from Brookes and Jenkinson methods. The MB-C and MB-N were determined by calculating the difference between TOC and TN of chloroform-fumigated and unfumigated soil samples. However, the final values of microbial biomass were divided by conservation factors: KC = 0.45 and KN = 0.54 for MB-C and MB-N, respectively.

To account for problems associated with data estimation, all C and N concentrations (g plant and μg ml1 for plant and soil, respectively) in either rhizospheric soil or nodule were converted and calculated to stock (g C and N m^2).

RESULTS AND DISCUSSION

The results of this study showed that the rate of nodular N sequestered by intercropped common bean is significantly higher compared to the correspondent sole crop as well as in 2012 and 2013 seasons (Fig. 1). This joins the works of [2, 7—9]. Furthermore, our results showed a higher nodular N sequestration rates under P deficient soil relative to P sufficient soil. This suggests a more important symbiotic N_2 fixation under these conditions.

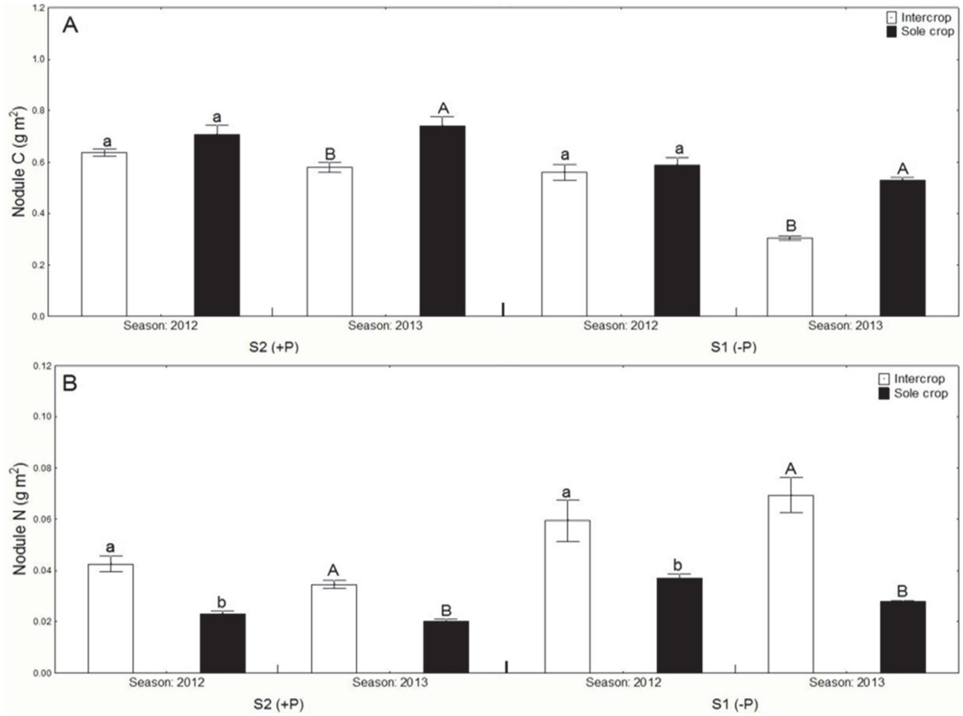

Fig. 1. C (A) and N (B) stock (g m^{-2}) in the nodule of common bean as sole crop and intercrop under S2 and S1 conditions.
Values correspond to the mean calculated with 5 replicates. Bars indicate standard errors.
For each crop,letters show significant differences between cropping systems (p < 0.05)

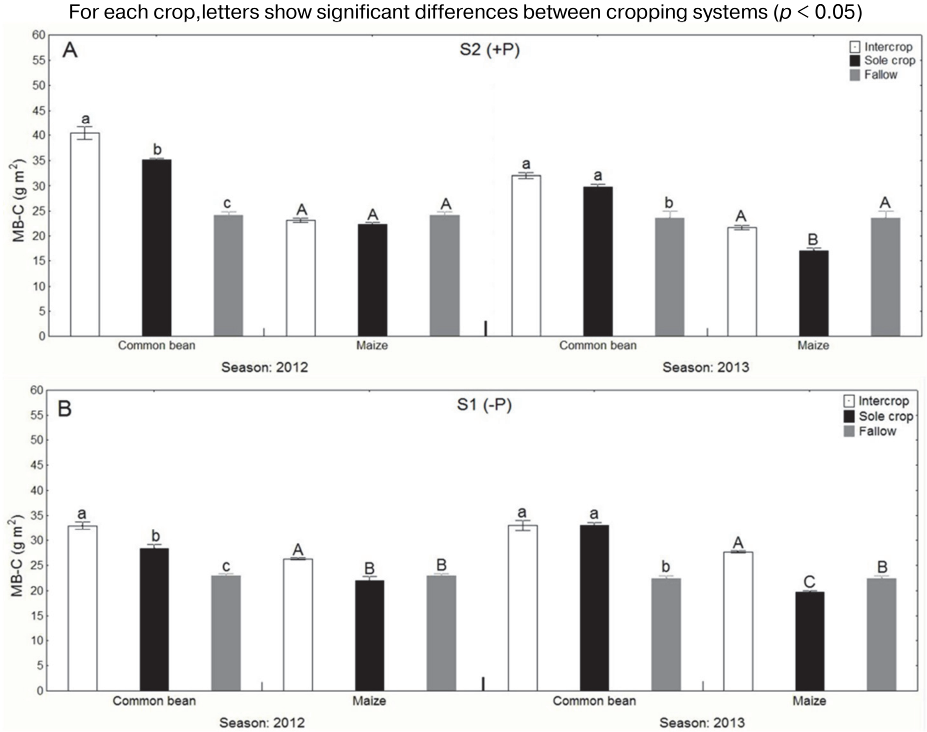

Fig. 2. MB-C (g m^{-2}) in the rhizosphere of common bean and maize as sole crop and intercrop and in the fallow under S2 (A) and S1 (B) conditions.
Values correspond to the mean calculated with 5 replicates. Bars indicate standard errors.
For each crop, letters show significant differences between cropping systems (p < 0.05)

The results show also that the N content in the rhizospheric MB is much higher under intercropping compared to their respective sole crop and fallow (Fig. 2). This result is very interesting more especially as fallow crop is currently a widespread practice in Algeria. The increase of N content in microbial biomass is highly positively correlated with N and C respectively sequestered in nodules under intercropping and P deficiency conditions (Fig. 3). That suggests a transfer of nodular nitrogen to the rhizosphere in favour of rhizospheric microorganisms after senescence of the nodules. The rate of N in rhizospheric MB is significantly higher in intercropping under low P conditions as well as in 2012 and 2013 seasons. This is confirmed in this study by the effect exerted under intercropping in low P soil on MB.

Indeed, the increase of nitrogen content in microbial biomass is highly positively correlated with nitrogen sequestered in nodules under intercropping and P deficiency conditions (Fig. 3). This suggests a transfer of nodular nitrogen to the rhizosphere in favour of rhizospheric microorganisms after senescence of the nodules. The rate of N in rhizospheric MB is significantly higher in intercropping under low P conditions as well as in 2012 and 2013 seasons. This is confirmed in this study by the effect exerted under intercropping in low P soil on MB. The study of Tang et al. has already highlighted the increasing of carbon in rhizospheric microbial biomass of intercropping compared to monocultures. As it was notified previously, under low P conditions, the plant is subjected to a stress that induces it to increase the rate of symbiotic fixation of atmospheric nitrogen. This enriched the soil microbial biomass after senescence of nodules.

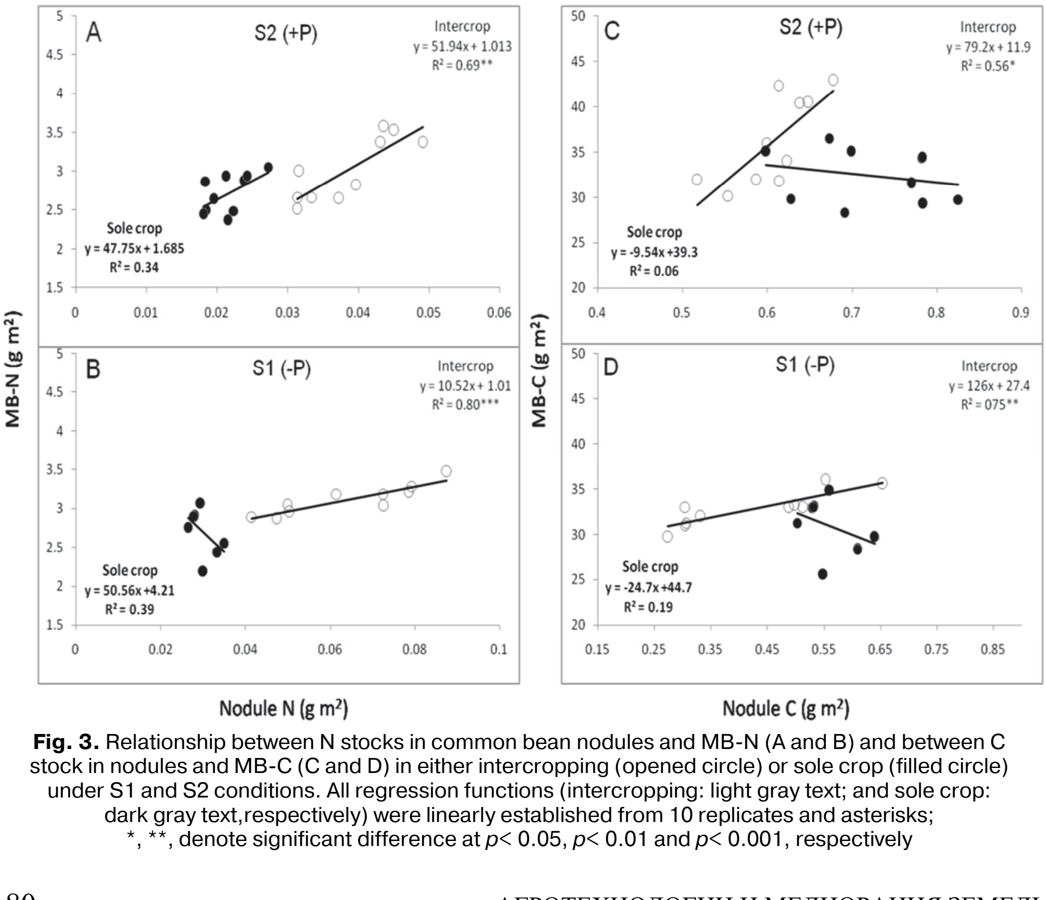

Fig. 3. Relationship between N stocks in common bean nodules and MB-N (A and B) and between C stock in nodules and MB-C (C and D) in either intercropping (opened circle) or sole crop (filled circle) under S1 and S2 conditions. All regression functions (intercropping: light gray text; and sole crop: dark gray text,respectively) were linearly established from 10 replicates and asterisks; *, **, denote significant difference at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively

Furthermore, evolution of the microbial soil respiration is proportional and positively correlated with nodule C stock in intercropping under P deficient soil (Fig. 4B). This can be justified by the fact that the intercropping in low P soil allows efficient use of environmental resources which stimulates plant growth on the one hand. Several studies have concerned the interaction between the permeability to oxygen nodular (nodular permeability) and nodular biomass [10, 11]. On the other hand, it stimulates the growth of rhizospheric microorganisms and thus enhancing their respiration [12]. They were able to show, the nodular permeability to oxygen is increased under P deficiency in controlled environment in hydroaeroponic [6, 13]. On the other hand, it stimulates the growth of rhizospheric microorganisms enhancing their respiration. Several studies have concerned the interaction between the permeability to oxygen nodular (nodular permeability) and nodular biomass.

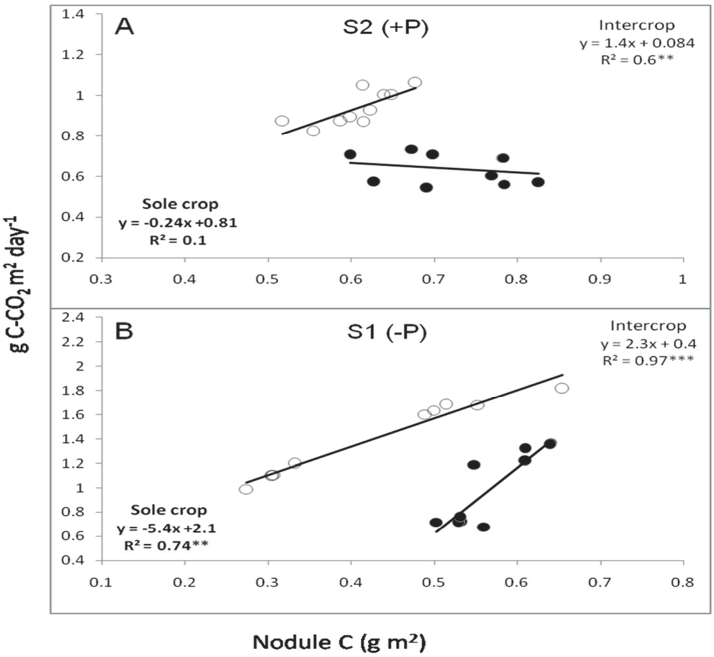

Fig. 4. Relationship between C stocks in common bean nodules and soil in either intercropping (opened circle) or sole crop (filled circle) under S1 (B) and S2 (A) conditions. All regression functions (intercropping: light gray text; and sole crop: dark gray text, respectively) were linearly established from 10 replicates and asterisks; **, ***, denote significant difference at $p< 0.05$, $p< 0.01$ and $p< 0.001$, respectively.

CONCLUSION

An increase of MB-C and MB-N was highlighted in common bean — maize intercrop under low P conditions. P deficiency causes a stress in the plant that induces an increase in symbiotic nitrogen fixation which allows increasing P availability in the soil. This increase of symbiotic N_2 fixation enriches the rhizosphere with organic matter, which has accordingly enhanced MB-C and MB-N. Enriched rhizospheric microbial flora contributes to mineralization of SOM, which stimulates rhizodeposition and growth of the plant.

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СОВМЕСТНЫЕ ПОСЕВЫ КУКУРУЗЫ И ФАСОЛИ ОБЫКНОВЕННОЙ УВЕЛИЧИВАЮТ МИКРОБНУЮ БИОМАССУ АЗОТА И УГЛЕРОДА В ПОЧВАХ С НИЗКИМ СОДЕРЖАНИЕМ ФОСФОРА В УСЛОВИЯ СРЕДИЗЕМНОМОРЬЯ

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В предыдущих работах уже сообщалось о положительном влиянии смешанных посевов в условиях низкого содержания фосфора (P). Цель данного исследования заключалась в проверке информации о том, что смешанные посевы (фасоль обыкновенная — кукуруза) на почвах с низким содержанием P могут увеличить долю углерода (C) и азота (N) микробной биомассы (МБ) путем их перемещения из корневых клубеньковых растений и ризосферной микрофлоры на поле, расположенном в регионе Setif на севере Алжира (средиземноморский климат). Количество N, сосредоточенного в клубеньках фасоли обыкновенной, было выше при выращивании в поликультуре по сравнению с монокультурой и паром. Тем не менее, несмотря на низкое содержание P в почве, при смешанном выращивании уровень N в клубеньках оказался самым высоким за два года. Содержание C в микробной биомассе (МБ-C) было выше при поликультуре по сравнению с монокультурой и паром, однако этот показатель увеличивался в почвах с дефицитом P. Кроме того, установлена сильная корреляция между клубеньковым C и МБ при поликультуре в условиях низкого P обеспечения. В тех же условиях показатель общего «дыхания почвы» имел самое высокое значение и отмечалось самое низкое соотношение C: N МБ. Полученные результаты свидетельствуют о том, что при низком содержании P в почве смешанные посевы являются продуктивным способом увеличения ризосферной МБ, которая способна повысить плодородие почвы и рециркулировать минеральные элементы. Ключевые слова: Поликультура; низкое содержание P; микробная биомасса; углерод; азот; Агроэкосистема.

Ключевые слова: глубокая обработка почвы, антропогенное воздействие, технология стриптил, полосная обработка почвы

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WATER-SAVING IRRIGATION REGIMES FOR VEGETABLE CROP PRODUCTION UNDER CONDITIONS OF VOLGA-DON INTERFLUVE

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Abstract. Irrigation regimes and rates of mineral fertilizers for obtaining the expected yields of vegetable crops under conditions of light chestnut soils of the Volga-Don interfluve are considered in the study. We established that irrigation regimes and norms of mineral fertilizers proposed in our field study for table beet *(Beta vulgaris)* and carrot (*Daucus carota)* cultivation allow yielding in the range of 60...80 t/ha. Thus, for example, the maximum yield of table beet 84.1 t/ha was obtained in the variant with 80% pre-irrigation soil moisture and $N_{230}P_{180}K_{100}$ fertilizer at a variable depth of soil moistening (0.3...0.5 m). Changes in fertilizer dose from $N_{130}P_{80}K_{20}$ to $N_{230}P_{180}K_{100}$ contributed to 63.7...84.1 t/ha yield increase, which is 10—20% higher compared to other variants. Change in soil moisture from 70—80—70 to 80—80—80% of FMC in combination with fertilizer dose from $N_{150}P_{70}K_{180}$ to $N_{210}P_{100}K_{260}$ increased carrot yields from an average of 57.9 to 81.6 t/ha. The highest yields (81.6 t/ha) were obtained when maintaining pre-irrigation soil moisture of 80—80—80% of FMC and applying $N_{210}P_{100}K_{260}$ fertilizer rate. In general, beet and carrot cultivation on light chestnut soils using drip irrigation is the most efficient. To maintain water regimes of the soil adopted by the experiment, a different irrigation frequency was required. When increasing humidity level from 70 to 90% FMC frequency of irrigation increases, and irrigation rate decreases. The total consumption of moisture in the experiments increased with an increase in moisture content — from 4,417 m^3/ha in the variant with 70% of FMC to 5105 m^3/ha in the variant with 90% of FMC. The largest total water consumption of table beet was noted in the variant with a differentiated depth of soil wetting and averaged 4,530—5,105 m^3/ha. The share of irrigation water in the total water consumption of plants increased from 73.3 to 75.7%. Application of mineral fertilizers reduces water consumption of table beet. The smallest coefficient was obtained in the second irrigation regime variant, when humidity was maintained at 80% of FMC with different wetting depth. This situation was observed in all variants of irrigation regimes and fertilizer applications. This confirms that differentiating wetting depth according to table beet growth stage makes it possible to use irrigation water more economically at all rates mineral fertilizer application.

Keywords: drip irrigation of vegetable crops, irrigation regime of vegetable crops, yield of vegetable crops, table beet and carrot water consumption, pre-irrigation soil moisture

INTRODUCTION

Currently, when growing vegetables, optimization of irrigation regime as a factor of integral significance has the first importance. It determines productivity per hectare and yield quality, total costs, water and energy resources demand, and public health situation. So, irrigation regime, irrigation technique, mechanization and automation should be improved, and new, more productive methods of irrigation should be created in order to increase efficiency of irrigation reclamation. Hence, experience of advanced farms of the region and the data of research institutions show that proper farming practices and optimal irrigation regime result in high and stable yields of vegetable crops. It is well known, that irrigation water costs, soil properties and plant productivity change depending on the irrigation methods used. Therefore, drip irrigation is promising in vegetable crop growing [1—5, 6, 7].

Cultivation of vegetable crops, in particular carrots and beetroot, on irrigated lands of the Volgograd region is important. Hence, we are conducting research, which purpose is to determine optimal combination of irrigation regime and fertilizer application in order to obtain carrot and table beet yields at the level of 60, 70, 80 t/ha.

MATERIALS AND METHODS

The research was conducted during 2015—2017 on two plots of Gorodishchensky district of Volgograd region, located in the zone of unstable moistening according to the generally accepted recommendations of B.A. Dospekhov, V.N. Pleshakov, G.F. Nikitenko [8—10]. The soils are light chestnut heavy loam, slightly water-permeable. Humus content in 0—0.5 m soil layer is 1.87...2.02%, soil density is 1.31 t/m^3, field moisture capacity (FMC) of dry soil is 22.93%. Soils of the experimental plots have 7.0...8.3 pH and are not saline.

The content of available forms of nitrogen in the first and second plots is characterized by low availability, mobile phosphorus has medium and high availability, exchangeable potassium has high and medium availability. Doses of mineral fertilizers were determined by a conventional method, according to V.I. Filin [11].

To obtain the expected yields of vegetable crops, there were two factors in the experiment: the first one is water regime of the soil (factor A), the second one — fertilizer dose (factor B).

In the first plot we studied optimal water and fertilizer regimes of the soil for cultivating table beet cultivar ‘Bordo’ from 2015 to 2017. A field two-factor experiment was conducted on the territory of individual entrepreneur ‘Kolesnikov’ in the Kuzmich village of Gorodishchensky district according to the following scheme:

1) irrigation regime — water regime of the soil was studied: irrigation was carried out along with humidity decrease to 70, 80 and 90% of FMC in active soil layer. 2 variants of soil wetting depth were planned: the first — 0.3 m during ‘planting — root formation’ and 0.5 m during ‘root formation — technical ripeness’ and the second — 0.5 m;

2) mineral fertilizers: rates of mineral fertilizers were calculated by the balance method for yields of 60, 70, 80 t/ha. In all variants according to the irrigation regime, they had the following rates: 1) $N_{130}P_{80}K_{20}$; 2)$N_{180}P_{130}K_{60}$; 3) $N_{230}P_{180}K_{100}$.

In the second plot investigations were carried out from 2015 to 2016 to study the effect of differentiated irrigation regimes and various fertilizer rates on carrot yields. The experiments were carried out on the territory of the Kuzmich village of "Kuzmichevsky’ farm in Gorodishchensky district. The experiments were based on a two-factor scheme:

The first factor — irrigation regime: 70—80—70; 70—90—80; 80—80—80% of FMC (Table 1).

Table 1

Differentiation of pre-irrigation soil moisture depending on carrot growth stages

Irrigation regime variants	Pre-irrigation soil moisture, % of FMC		
	Emergence — beginning of root formation	Beginning of root formation — beginning of technical ripeness	Beginning of technical ripeness — harvesting
1	70	80	70
2	70	90	80
3	80	80	80

The second factor — fertilizer application. The rates of mineral fertilizers were calculated by the balance method for yields of 60, 70, 80 t/ha. In all irrigation regime variants these rates were as following: 1-st — $N_{150}P_{60}K_{180}$; 2-nd — $N_{180}P_{80}K_{220}$; 3-rd — $N_{210}P_{100}K_{260}$ (80 t/ga).

In both studies season irrigation was carried out using drip irrigation.

During carrot cultivation active soil layer was 0.5 m. The irrigation rates were 250...300 m^3/ha, 208...300 m^3/ha and 250 m^3/ha. Carrots 'Mayor F1' hybrid seeds were sown using common regional agricultural techniques.

RESULTS AND DISCUSSION

The results of three-year research on light chestnut soils of the Volga-Don interfluve have shown that the applied irrigation regimes and the application rates of mineral fertilizers along with drip irrigation make it possible to obtain expected yields of table beets and carrots at a level of 60...80 t/ha.

In our experiment, to maintain the water regimes of the soil a different number of irrigations were required. The data shown in Table 2 indicate that increase in humidity from 70 to 90% of FMC results in increase in number of irrigations and irrigation rates, and irrigation rate decreases.

Table 2

The irrigation regime of table beet on average for 2015—2017

Pre-irrigation soil moisture, % of FMC	Watering rate, m^3/ha	Number of season irrigations	Irrigation rate, m^3/ha
At a depth of soil moistening 0.5 m			
70	360	9	3 240
80	240	15	3 600
90	120	32	3 840
At a depth of soil moistening 0.3—0.5 m			
70	220—360	7—5	3 340
80	148—240	11—9	3 788
90	75—120	21—19	3 855

Irrigation regime, crop yield and meteorological conditions of the growing season have a decisive influence on the amount of total water consumption. The total consumption of moisture in the experiments increased with an increase in water availability from 4,417 m^3/ha in the variant with 70% of FMC to 5,105 m^3/ha in the variant with 90% of FMC. The highest total water consumption of table beet was in the variant with a differentiated wetting depth and averaged 4,530...5,105 m^3/ha. Share of irrigation water in total water consumption of plants increased from 73.3 to 75.7%, as water availability improved (Table 3).

Table 3

Total water consumption of table beet and its structure on average for 2015—2017

Pre-irrigation soil moisture, % of FMC	Water source						Total water consumption, m^3/ha
	watering		precipitation		soil		
	m^3/ha	% from E	m^3/ha	% of E	m^3/ha	% of E	
At 0.5 m wetting depth							
70	3 240	73.3	1 045	23.7	132	3.0	4 417
80	3 600	74.6	1 045	21.6	185	3.8	4 830
90	3 840	75.7	1 045	20.6	190	3.7	5 075
At 0.3—0.5 m wetting depth							
70	3 340	73.7	1 045	23.1	145	3.2	4 530
80	3 788	75.3	1 045	20.8	198	3.9	5 031
90	3 855	75.5	1 045	20.5	205	4.0	5 105

Table 4

Yield of table beet on average for 2015—2017

Factors			Yield, t/ha
Fertilizer rate, kg of active ingredient per 1 ha	Pre-irrigation soil moisture, % of FMC	Wetting depth, m	
$N_{130}P_{80}K_{20}$	70	0.5	49.7
$N_{130}P_{80}K_{20}$	70	0.3—0.5	54.9
$N_{130}P_{80}K_{20}$	80	0.5	59.7
$N_{130}P_{80}K_{20}$	80	0.3—0.5	63.7
$N_{130}P_{80}K_{20}$	90	0.5	56.4
$N_{130}P_{80}K_{20}$	90	0.3—0.5	58.9
$N_{180}P_{130}K_{60}$	70	0.5	59.4
$N_{180}P_{130}K_{60}$	70	0.3—0.5	62.3
$N_{180}P_{130}K_{60}$	80	0.5	67.3
$N_{180}P_{130}K_{60}$	80	0.3—0.5	78.3
$N_{180}P_{130}K_{60}$	90	0.5	62.7
$N_{180}P_{130}K_{60}$	90	0.3—0.5	65.4
$N_{230}P_{180}K_{100}$	70	0.5	69.3
$N_{230}P_{180}K_{100}$	70	0.3—0.5	72.0
$N_{230}P_{180}K_{100}$	80	0.5	76.3
$N_{230}P_{180}K_{100}$	80	0.3—0.5	84.1
$N_{230}P_{180}K_{100}$	90	0.5	74.1
$N_{230}P_{180}K_{100}$	90	0.3—0.5	78.2

Our experiments showed that different irrigation regimes and fertilizer applications had a significant impact on yield and water consumption of root crops. The maximum table beet yield of 84.1 t/ha was obtained when soil wetting depth was 0.3—0.5 m, soil moisture was 80% of FMC and $N_{230}P_{180}K_{100}$ fertilizer rate (Table 4).

Depending on the variant, table beet yield increased by 8.8...11.5 t/ha after $N_{180}P_{130}K_{60}$ application and by 25.6...29.2 t/ha after $N_{230}P_{180}K_{100}$ application compared to $N_{130}P_{80}K_{20}$ fertilizer application.

While maintaining wetting depth at the level of 0.3...0.5 m and increasing soil moisture level from 70 to 90% of FMC, table beet yield varied from 54.9 to 84.1 t/ha.

In all variants of the experiment, the highest table beet yield was obtained when pre-irrigation soil moisture was 80% of FMC and fertilization rate — $N_{230}P_{180}K_{100}$. Decrease or increase of pre-irrigation soil moisture in active soil layer to 70 or 90% of FMC reduced yields of root crops by 10—15%.

According to the data obtained, mineral fertilizers also reduce beet water consumption. The lowest coefficient was in the second variant of irrigation regimes, when soil moisture was maintained at 80% of FMC with differentiated wetting depth. We observed it in all variants of irrigation regimes and fertilizer applications. This confirms that differentiation of wetting depth of the soil according to table beet growth stages makes it possible to use irrigation water more economically at all rates of mineral fertilizers (Table 5).

Table 5

Influence of irrigation regime and fertilizer application on water consumption of table beet on average for 2015—2017

Fertilizer rates, kg of active ingredient per 1 ha	Pre-irrigation soil moisture, % of FMC	Yield, t/ha	Water consumption, m^3/ha	Total water consumption, m^3/ha
At 0.5 m wetting depth				
$N_{130}P_{80}K_{20}$	70	49.7	88.87	4 417
$N_{130}P_{80}K_{20}$	80	59.7	80.90	4 830
$N_{130}P_{80}K_{20}$	90	56.4	89.98	5 075
$N_{180}P_{130}K_{60}$	70	59.4	74.36	4 417
$N_{180}P_{130}K_{60}$	80	67.3	71.77	4 830
$N_{130}P_{80}K_{20}$	90	62.7	80.94	5 075
$N_{230}P_{180}K_{100}$	70	69.3	63.74	4 417
$N_{230}P_{180}K_{100}$	80	76.3	63.30	4 830
$N_{230}P_{180}K_{100}$	90	74.1	68.49	5 075
At 0.3—0.5 m wetting depth				
$N_{130}P_{80}K_{20}$	70	54.9	82.51	4 530
$N_{130}P_{80}K_{20}$	80	63.7	78.98	5 031
$N_{130}P_{80}K_{20}$	90	58.9	86.67	5 105
$N_{180}P_{130}K_{60}$	70	62.3	72.71	4 530
$N_{180}P_{130}K_{60}$	80	78.3	64.25	5 031
$N_{180}P_{130}K_{60}$	90	65.4	78.06	5 105
$N_{230}P_{180}K_{100}$	70	72.0	62.92	4 530
$N_{230}P_{180}K_{100}$	80	84.1	59.82	5 031
$N_{230}P_{180}K_{100}$	90	78.2	65.28	5 105

In the second plot, carrots were sown on May 15. During the research years, meteorological conditions had a great influence on irrigation frequency and rates. So, for example, depending on the variant, 15...20 waterings were conducted, which amounted to irrigation rate of 4,050...4,780 m^3/ha (Table 6).

According to the data of Table 7, differentiating pre-irrigation soil moisture and different fertilizer rates had a significant impact on carrot yield and water consumption. The data obtained show that changes in carrot productivity under drip irrigation correlate with changes in total water consumption and water consumption coefficient. In addition, carrots are very responsive to mineral fertilizer application. The maximum carrot yield of 81.6 t/ha can be obtained by maintaining constant soil moisture at the level of 80—80—80% of FMC and applying fertilizers at the following rate — $N_{210}P_{100}K_{260}$.

Table 6

Carrot irrigation regime on average for 2015—2017

Var.	Pre-irrigation soil moisture, % of FMC / Irrigation rate, m^3/ha			Number of waterings	Irrigation rate, m^3/ha
	Emergence — beginning of root formation	Beginning of root formation — beginning of technical ripeness	Beginning of technical ripeness — harvesting		
1	70 / 300	80 / 250	70 / 300	15	4 050
2	70 / 300	90 / 208	80 / 250	20	4 780
3	80 / 250	80 / 250	80 / 250	18	4 500

Table 7

Influence of irrigation regime and fertilizing on carrot yields and water consumption on average for 2015—2017

Yield (actual), t/ha	Pre-irrigation soil moisture, % of FMC	Mineral fertilizer rates for the expected yields		Coefficient of water consumption, m^3/ha	Total water consumption, m^3/ha
		t/ha	kg of active ingredient per 1 ha		
57.9	70—80—70	60	$N_{150}P_{60}K_{180}$	98.07	5 678
62.8	70—90—80	70	$N_{180}P_{80}K_{220}$	92.05	5 781
71.5	80—80—80	80	$N_{210}P_{100}K_{260}$	82.38	5 890
66.3	70—80—70	60	$N_{150}P_{60}K_{180}$	85.64	5 678
72.0	70—90—80	70	$N_{180}P_{80}K_{220}$	80.29	5 781
73.6	80—80—80	80	$N_{210}P_{100}K_{260}$	80.03	5 890
68.2	70—80—70	60	$N_{150}P_{60}K_{180}$	83.26	5 678
72.7	70—90—80	70	$N_{180}P_{80}K_{220}$	79.52	5 781
81.6	80—80—80	80	$N_{210}P_{100}K_{260}$	72.18	5 890

The irrigation water was most effectively used at soil moisture levels of 80—80—80% of FMC, since there was the lowest water consumption and averaged 72.18 m^3/ha over research years.

Carrot yield 60 t/ha is achieved in the variant with pre-irrigation soil moisture of 70—80—70% of FMC in combination with fertilizer application $N_{150}P_{60}K_{180}$. So, irrigation rate was 4,050 m^3/ha, and total water consumption was 5,678 m^3/ha.

For carrot yields of 70 t/ha irrigation rate increased to 4,780 m^3/ha, and total water consumption increased to 5,781 m^3/ha. The maximum carrot yield 81.6 t/ha was obtained when soil moisture was 80—80—80% of FMC and fertilizer rate was increased to $N_{210}P_{100}K_{260}$.

Thus, our studies have shown that table beets and carrots are very responsive to the optimal combination of irrigation and fertilizer parameters. In general, application of mineral fertilizers has a significant effect on productivity and water consumption coefficient of the root crops in all irrigation regime variants.

CONCLUSIONS

Based on the data obtained, the following conclusions can be drawn.

When cultivating table beet under conditions of the Volga-Don interfluve, the optimal variant is a differentiated variant, with a variable wetting depth of soil (0.3...0.5 m).

The maximum table beet yield in this variant was obtained in the plot with soil moisture of 80% of FMC, and, depending on the variant, it was 63.7...84.1 t ha, which is 10...20% higher in comparison with other variants.

The greatest carrot yield (81.6 t/ha) was achieved in the variant with pre-irrigated soil moisture 80—80—80% of FMC combined with mineral fertilizer application $N_{210}P_{100}K_{260}$.

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ВОДОСБЕРЕГАЮЩИЕ РЕЖИМЫ ОРОШЕНИЯ ОВОЩНЫХ КУЛЬТУР В УСЛОВИЯХ ВОЛГО-ДОНСКОГО МЕЖДУРЕЧЬЯ

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Рассмотрены режимы орошения и нормы внесения минеральных удобрений для получения запланированной урожайности овощных культур в условиях светло-каштановых почв Волго-Донского междуречья. Установлено, что предлагаемые в нашем полевом исследовании режимы орошения и нормы минеральных удобрений при выращивании столовой свеклы и моркови позволяют получать урожайность в пределах 60...80 т/га. Так, например, максимальная урожайность столовой свеклы 84,1 т/га получена на варианте с влажностью 80% НВ в сочетании с внесением удобрений нормой $N_{230}P_{180}K_{100}$ при переменной глубины увлажнения почвы (0,3...0,5 м). Изменение дозы удобрений от $N_{130}P_{80}K_{20}$, до $N_{230}P_{180}K_{100}$ способствовало повышению урожая в пределах 63,7—84,1 т/га, что на 10...20% выше по сравнению с другими вариантами опыта. При возделывании моркови изменение влажности почвы от 70—80—70 до 80—80—80% НВ в сочетании с внесением дозы удобрений от $N_{150}P_{70}K_{180}$ до $N_{210}P_{100}K_{260}$ способствовало повышению урожайности корнеплодов в среднем с 57,9 до 81,6 т/га. Наиболее высокие показатели урожайности 81,6 т/га получены при поддержании предполивного порога влажности 80—80—80% НВ при норме минерального питания $N_{210}P_{100}K_{260}$. В целом, на светло-каштановых почвах выращивание столовой свеклы и моркови с применением капельного полива и внесения удобрений является наиболее эффективным.

Ключевые слова: капельное орошение овощных культур, режим орошения овощных культур, свекла столовая, морковь, урожайность овощных культур, удобрение овощных культур, коэффициент водопотребления столовой свеклы и моркови, суммарное водопотребление столовой свеклы и моркови, предполивная влажность почвы

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EFFICIENCY ESTIMATION OF STRIPTILL SOIL PROCESSING TECNOLOGY

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Abstract. This study explores the technology of chilling from the point of view of anthropogenic impact on soil. The influence of the arrangement of workers on technological rocessing is analyzed. The efficiency of resource-saving deep cultivation technology in production of row crops on example of sunflower growing in Volgograd region is estimated. We give technical and economic assessment of sunflower cultivation depending on the technological process of chilling. We defined a competitive technology of basic soil cultivation. Analysis of data obtained shows that the largest area of cross-section of the formation is produced when soil is treated with chisel tools as working organs are arranged such that they form a zone of continuous loosening, accordingly, it has the greatest anthropogenic impact. Field experiments also showed that deep loosening belts to a depth of 0.25...0.35 m, alternating with strips without treatment, are characterized by positive processes. Unprocessed areas become overcrowded (more than 1.3 g/cm^3), so they create less favorable, in comparison with processed, conditions for the development of some species of perennial weeds. Studies have shown that, with the main soil-free tillage of the soil to a depth of 0.3 m, from the stubble of winter wheat, stubble conservation was consistent: 69.67% — over the treated band using striptill technology; 76.33% — on the processed strip by a chisel with a trail of 0.7 m; 68.67% for a chisel with a trail of 0.35 m. After the passage of the aggregates on the soil surface, all stubble remains within the requirements for SRT AIST 4.6—2010 (more than 60%). The use of striptill technology reduces fuel costs by 35.5% relative to the classical chiesel, and by 27.3% relative to the minimum technology. Accordingly, the cost of wages is reduced by 37.5% compared to the classical chisel and by 24.8% compared to the minimum chisel technology.

Keywords: chiseling, band ripping, deep tillage, anthropogenic impact, striptill technology

INTRODUCTION

One of the most important ways of stabilizing and improving the economic efficiency of agricultural organizations is the further development of the intensification of production through the use of resource-saving technologies for the cultivation of agricultural crops. The right choice and rational use of soil-cultivating tools, as an executive tool of a sound manufacturing technology, is the main condition for ensuring the growth of productivity and profitability in agriculture. The greatest potential for cost reduction is in the area of basic deep tillage, while a stable reduction in costs is possible with a change in the tool setting that affects the process.

The working organs of machines for processing soil of any type affect the natural environment. Such influence over time leads to a disturbance of the ecosystem. One of the main reasons for this phenomenon is the inconsistency of farming technology. For example, ploughing often leads to erosion of the fertile layer, salinization of soils may be an undesirable consequence of irrigation, and pasture of cattle is accompanied by degradation of grass cover with appearance of conditions for erosion. Anthropogenic impact on soil can be characterized, in particular, by the mechanical destruction of natural environment, determined not only by depth, but also by cross-sectional area. The result of such undesirable effects is described by anthropogenic factor [1]. To study degree of influence of strip farming on environment, we have chosen anthropogenic impact. This made it possible to compare the various technological processes of soil cultivation, on the basis of an implement with chisel working tools, arranged with various inter-inheritance, providing outcropping to surface [2] and additional device [3] limiting zone of deformation (Strip-till) with a classic chisel, providing a zone of continuous loosening.

MATERIALS AND METHODS

To minimize anthropogenic impact on the soil, it is recommended to reduce energy costs, in particular, depth of processing. That is, change in anthropogenic impact can be characterized by the cross-sectional area of the treated formation. This fact is actual in the production of row crops, the cultivation of which provides a strip mechanical effect on the medium to be treated, as a promising environmental and economical technology. Indicators of rational use and economical use of material and energy resources, expressed in quantitative form, are the requirements of resource use and resource saving [4]. The established indicators of resource use should provide an opportunity to effective assess of resource-saving requirements. The indicator, determined by the ratio of a particular parameter to another, is the specific indicator of resource use.

Considering the fact that for different technologies ratio of treated part of soil to untreated part differs significantly, it can be assumed that the smaller the given dependence in terms of the perimeter of tool capture width, the more effective the technology of soil cultivation from the resource saving point of view. Given that the same chisel tool, working at the same depth, but tuned to a different technological process, it is logical to compare their anthropogenic impact on the meter. In this regard, we introduce the concept of anthropogenic impact coefficient of soil-cultivating tools.

Anthropogenic impact on soil can be characterized by coefficient K_{ai} determined by ratio of loosening area S_l in the transverse plane to working width B_w of the tool gripping, taking into account the depth h_{ch} of its processing:

$$K_{ai} = \frac{F}{B_w h_{ch}}, \tag{1}$$

where F — area of loosening of the formation in the transverse plane, m^2; B_w — working width of the tool, m; h_{ch} — depth of processing (chiseling), m.

Figures 1—3 show transverse profile diagrams of formation when chisel tool is operated using solid, strip and striptill technologies, respectively.

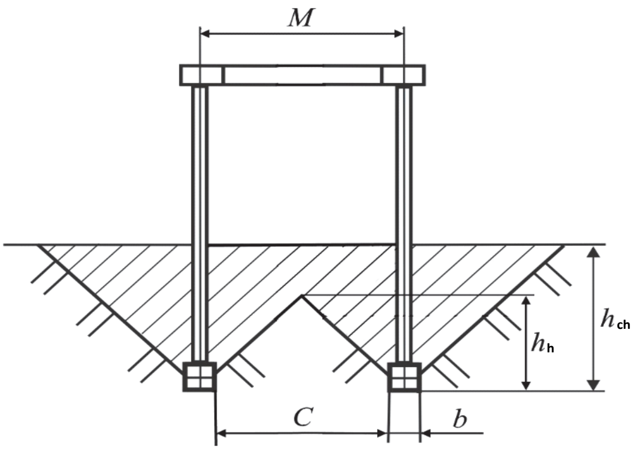

Fig. 1. Scheme of transverse profile of formation during operation of chisel tool

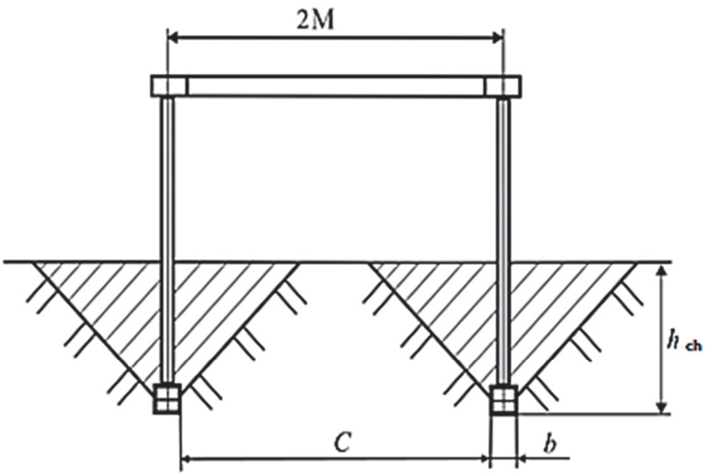

Fig. 2. Scheme of transverse profile of formation during operation of chisel tool using technology of strip processing of soil

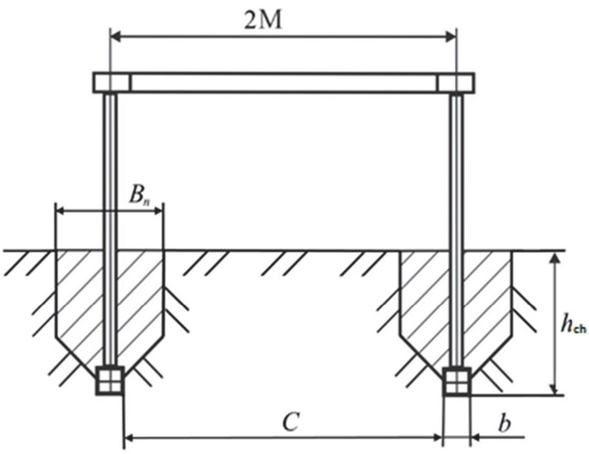

Fig. 3. Scheme of transverse profile of formation during operation cultivation tools for striptill technology

Taking into account the scheme of transverse profile of formation during the operation of chisel tool using continuous loosening technology (Figure 1) and assuming value of soil deformation angle 90°, the loosening area $F_{kп}$ transverse plane within working (technological) width of the B_w, tool is determined by depth product difference processing h_{ch} on the interfluve M and area of intrasoil comb multiplied by the number of working bodies n. After the transformation, the relationship takes the form:

$$F_k = n\left(h_ч M - \frac{(M-b)^2}{4}\right), \tag{2}$$

Taking into account the above, cross-sectional area of loosened part of formation, when processed using strip-chisel technology, the form is:

$$F_{kп} = n_п h_ч \left(h_ч + b\right). \tag{3}$$

Accordingly, cross-sectional area of loosened part of formation when processing the soil using stripteel technology,

$$F_{kc} = n\left[h_ч B_п - \left(\frac{B_п - b}{2}\right)^2\right]. \tag{4}$$

Figure 4 shows the dependence of cross-sectional area of loosened part of formation from depth, taking into account technology of soil cultivation. As can be seen from the graph, the largest cross-sectional area of loosened part of formation is formed with continuous chiseling. This is explained by the increment of the zone of continuous loosening with increasing depth of processing. The least intensity is the strip technology as a result of cutting zone of deformation of soil with disc knives.

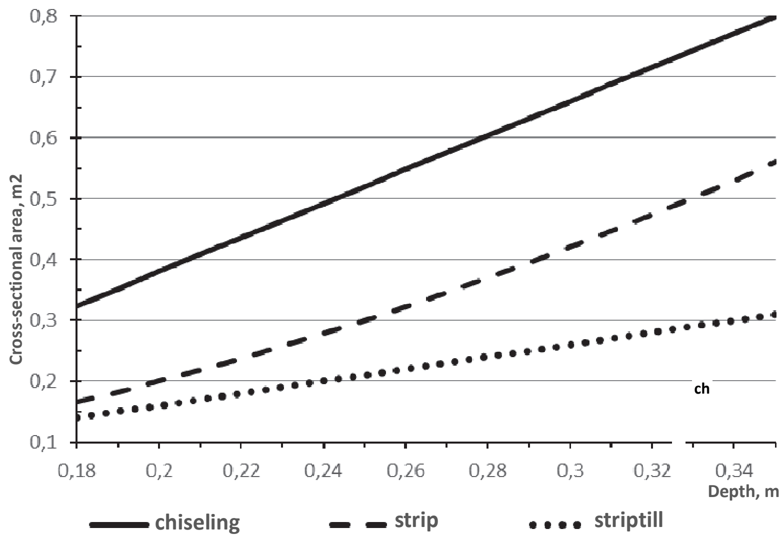

Fig. 4. Dependence of cross-sectional area of loosened part of formation from depth, taking into account processing technology

The product of the working width B_w of tool gripping to depth h_{ch} is equal to the area of loosening with chiseling, without taking into account intrusive grooves, which determines cross-sectional area when flat-cutting tool is operating.

The theoretical working width of the tool is determined by product of number of working tools on inter-stage of their arrangement in transverse plane. Taking into account the above, expressions for determining the coefficient of anthropogenic impact on soil in case of chilling depending on the technological process of processing are:

for continuous chilling

$$K_{aich} = \left(h_{ch} M - \frac{(M-b)^2}{4} \right) \Big/ M h_{ch}, \tag{5}$$

for strip chiseling

$$K_{\text{авп}} = (h_{\text{ч}} + b) / M_{\text{п}}, \tag{6}$$

for striptill technology

$$K_{\text{авс}} = \left(h_{\text{ч}} B_{\text{п}} - \left(\frac{B_{\text{п}} - b}{2} \right)^2 \right) \Big/ M_{\text{с}} h_{\text{ч}}. \tag{7}$$

According to the given expressions (5, 6 and 7), taking into account the adopted values of width of inter-trace (for chiseling — 0.35 m, strip and striptill treatments — 0.7 m), bit 0.05 m, strip 0.25 m. Calculated dependences are obtained and graphs are plotted (Fig. 5) for the effect of chilling depth on change in the coefficient of anthropogenic treatment effect for various technological processes of chilling.

According to the graph, the coefficient of anthropogenic impact on the soil with technology of strip chiseling with respect to classical chiseling decreases with increasing depth of processing from 2 to 1.43 times. With striptill it increases from 2.18 to 2.58 times.

Intensity of increase in coefficient of anthropogenic impact on soil with striptill technology relative to band-wise chiseling also increases with increasing depth of processing, but with greater intensity, from 1.09 to 1.81 times. This situation is explained by different intensity of increment in the area of soil cultivation for selected technological processes.

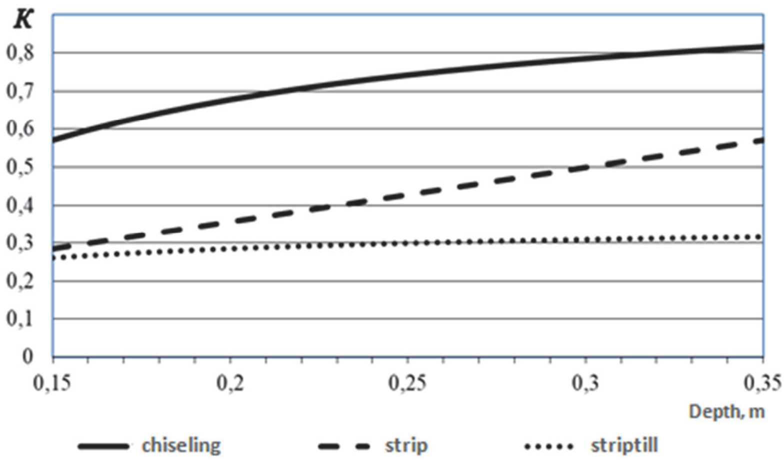

Fig. 5. Dependence of change in coefficient of anthropogenic impact on depth, for various technologies of soil cultivation

Thus, when comparing the studied soil treatment technologies by the factor of anthropogenic impact, it was found that the least coefficient of anthropogenic impact in striptill technology is due to the fact that only a part of the strip is processed. And taking into account running meter, this technology favorably differs from classical and strip chisel processing concerning anthropogenic factor.

RESULTS AND DISCUSSION

During the field experiments, we obtained results of measuring loosening area of cross section of running meter of cultivated crop for various soil cultivation technologies. The studies were carried out for a chisel tool with a trace of working tools of 0.35 m; chisel tool for strip processing of soil with a trace of working bodies 0.70 m; tools for strip processing by striptill technology (with working tools on the frame of the tool with a trail 0.7 m). The data obtained were analyzed for determination of technological unloading coefficient K_p. This coefficient represents the share of the processing area of the applied technology relative to the area under continuous processing at the same depth and is determined by the ratio of processing areas of technology under consideration with respect to continuous loosening, per running meter of the cultivated crop:

$$K_p = \frac{h * B_{\text{пм}}}{S_{\text{пм}}},$$

where B_{rm} — the width of the running meter of the cultivated crop, equal to the width of the aisle or between strip distance with the cultivated crop; h — depth of processing; S_{rm} — the processing area of technology under investigation per meter of cultivated crop.

The results of measurements and calculations are presented in Table 1.

Table 1

Area of loosening by types of basic processing

Depth h_{ch}, m	Loosening area, m² / Coefficient of technological unloading		
	Chisel	Strip processing	Striptill
0.2	0.097 / 1.45	0.049 / 2.85	0.041 / 3.43
0.25	0.146 / 1.20	0.083 / 2.10	0.055 / 3.18
0.3	0.157 / 1.34	0.110 / 1.91	0.064 / 3.27
0.35	0.190 / 1.29	0.133 / 1.84	0.076 / 3.23
0.4	0.204 / 1.37	0.163 / 1.72	0.093 / 3.00

According to the results of the study of loosening area, depending on the depth for different processing technologies, a graph was made (Figure 6).

Change in the coefficients of technological unloading for chilling, strip processing and striptill technology depending on the depth of treatments is shown in Figure 7.

Analysis of the data shows that the largest cross-sectional area of formation is formed when soil is treated with a chisel tool with working organs arranged so that they form a zone of continuous ripping, and accordingly it has the greatest anthropogenic impact.

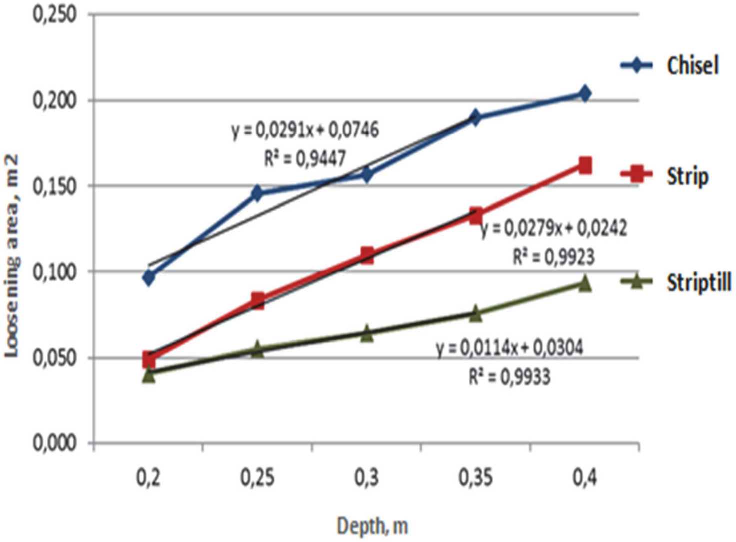

Fig. 6. Dependence of loosening area of running meter of cultivated crop from depth of processing for various technologies

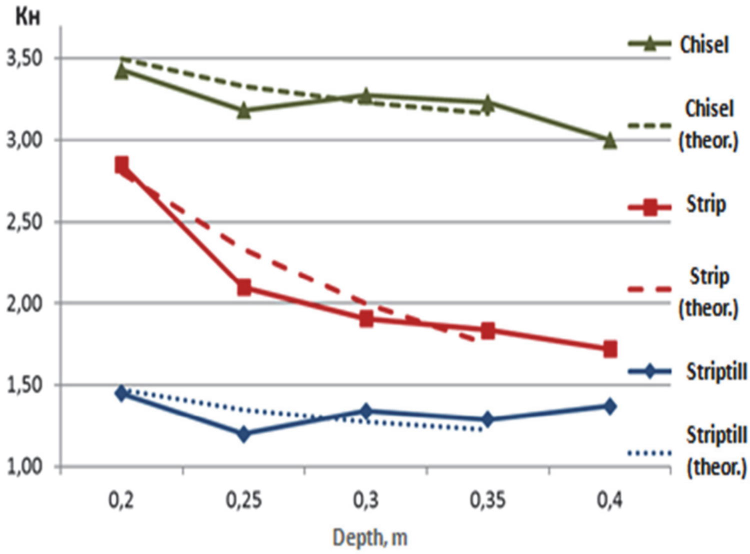

Fig. 7. Dependence of coefficient of technological unloading on depth of processing depending on technology

When chiseling in technology of strip processing, the area of loosening is much lower. This is explained by arrangement of chisel working tools on tool frame without formation of continuous loosening zone. With striptill technology (with disc knives), loosening area is the smallest with the same depth of processing. This is due to cutoff of deformation zone from chisel bit by means of disc knives.

Field experiments also showed that deep loosening belts to a depth of 0.25...0.35 m, alternating with strips without treatment, are characterized by positive processes. Unprocessed areas become overcrowded (more than 1.3 g/cm^3), so they create less favorable conditions for development of some species of perennial weeds in comparison with processed areas. Studies [5] indicate presence of cyst-forming nematodes in dense soil (9 cysts per 100 cm^3). There is an increase in nematode number in loose soil. In untreated areas, a sharp decrease in density of pathogen population (*F. graminearum* and *R. solani*) was found, and disease developed less frequently. Remaining stubble on untreated soil surface delayed this process by approximately 50% (104 weeks) compared to treated soil. Studies have shown that with the basic soil-free tillage of the soil to a depth of 0.3 m, along the stubble of winter wheat, the stubble conservation corresponded to: 69.67% — over the treated band using striptill technology; 76.33% — on processed strip by a chisel with a trail of 0.7 m; 68.67% — for a chisel with a trail of 0.35 m. After passage of aggregates on soil surface, all stubble remains within the requirements for STO AIST 4.6-2010 (more than 60%).

Figure 8 shows the results of influence of soil tillage technology on stubble conservation, as well as the conservation of stubble, taking into account the conversion to a linear meter in the production of row crops with row spacing of 0.7 m.

The production check of effectiveness of strip-technology was carried out on the basis of data obtained at the Elansk branch of Volgograd Agro-Industrial Company at the price level for 2017. Calculation of technical and economic efficiency of the technology of soil strip processing was carried out on the basis of the technique [6]. For execution of settlement operations the software product Microsoft Excel was used.

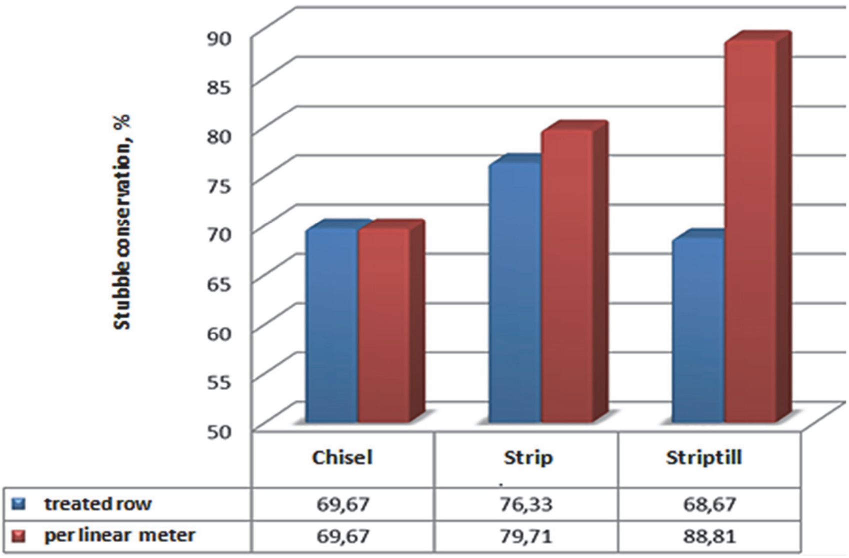

Fig. 8. Effect of soil tillage technology on stubble conservation

Currently, several basic tillage types are used in sunflower cultivation in Yelansk branch of Volgograd Agro-Industrial Company. In one part of the area two-phase processing using strip-till technology is used. According to the technology, in autumn soil is treated with strips to a depth of 0.23...0.25 m, and in spring it is produced by sowing agricultural crops. The other part of the area is treated according to minimal technology based on chisel processing, and weed control is carried out both mechanically (intercultural cultivation) and chemical (application of pesticides). In the first and third cases, processing with a rate of application of 1 l/ha is used for this purpose. In addition, in strip technology for preventive purposes during the autumn processing of strips, glyphosate was used to control weeds in the fields during the spring period.

According to the program on the basis of the MicrosoftExcel we developed product, composition and need for number and employment of units, taking into account area of production of agricultural products. Table 2 summarizes use of machines and aggregates in sunflower production for various technologies used in the farm.

Table 2

Use of machines and aggregates in sunflower production depending on various cultivation technologies

№	Model	Number	Price, rub.	Earning rub/h	Costs per hectare rub/ha	Total
1.	JohnDeere 9430	1	9,745,763	1804.77		9,745,763
2.	МТЗ-1221	1	2,240,000	553.09		2,240,000
3.	ClaasTucano 450	2	8,474,576	6277.46	1393.44	16,949,152
4.	Amazone ZAM-900	1	169,492	125.55	6.15	169,492
5.	Orthman 1 tRIPr	1	1,881,356	1393.60	215.73	1,881,356
6.	Bourgault 8910	1	5,254,237	3892.03	572.36	5,254,237
7.	Hardi-Commandor 3200	1	1,694,915	1255.49	61.54	1,694,915
8.	Zhatka	2	1	0.00	0.00	0
9.	Striegel	1	336,441	249.22	16.29	336,441
10.	John Deere-512	1	750,000	555.56	134.21	750,000
11.	KKZ-10	1	452,210	334.97	34.27	452,210
12.	KRN-5,6	2	195,510	144.82	30.42	391,020
Total for striptill technology						37,934,915
Total for classical chisel technology						36,288,315
Total for minimal chisel technology						37,140,000

Cost of machines for classical chisel processing requires an investment of 851,685 rubles which is less than for minimal chisel technology. This is due to the need to purchase machines for combating weeds. In one case, the machines are used for mechanical control of weeds, in another case — for chemical control. Cost of machines for strip technology from the presented technologies is the highest (in comparison with classical chisel which is 1,646,600 rubles more, compared to the minimum chisel which is 794,915 rubles more). This is due to the high cost of machines for strip cultivation. Virtually all of the tools for strip production are imported, and in the face of ambiguous conditions in the economic arena, their prices are continuously rising. In this regard, we would like to focus our current work on development and introduction of domestic production machines for strip processing. This will reduce the cost of such machines significantly and consequently make strip technology the most attractive for farmers.

Figure 9 shows histogram of influence of sunflower cultivation technology on amount of direct technical costs.

Based on calculation, histograms of influence of sunflower cultivation technology on value of direct production costs have been constructed (Figure 10).

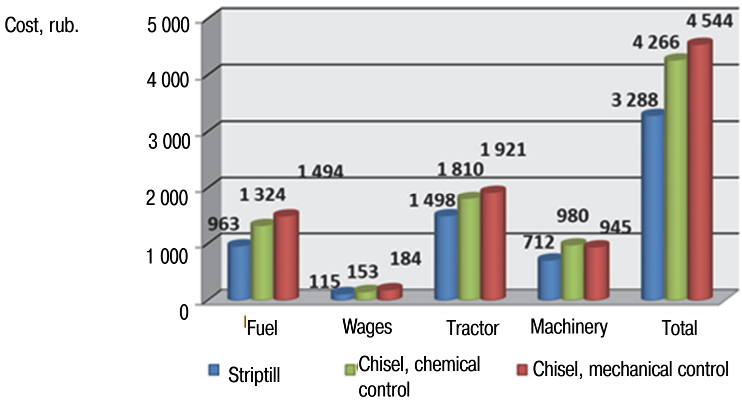

Fig. 9. Influence of sunflower cultivation technology on direct technical cost

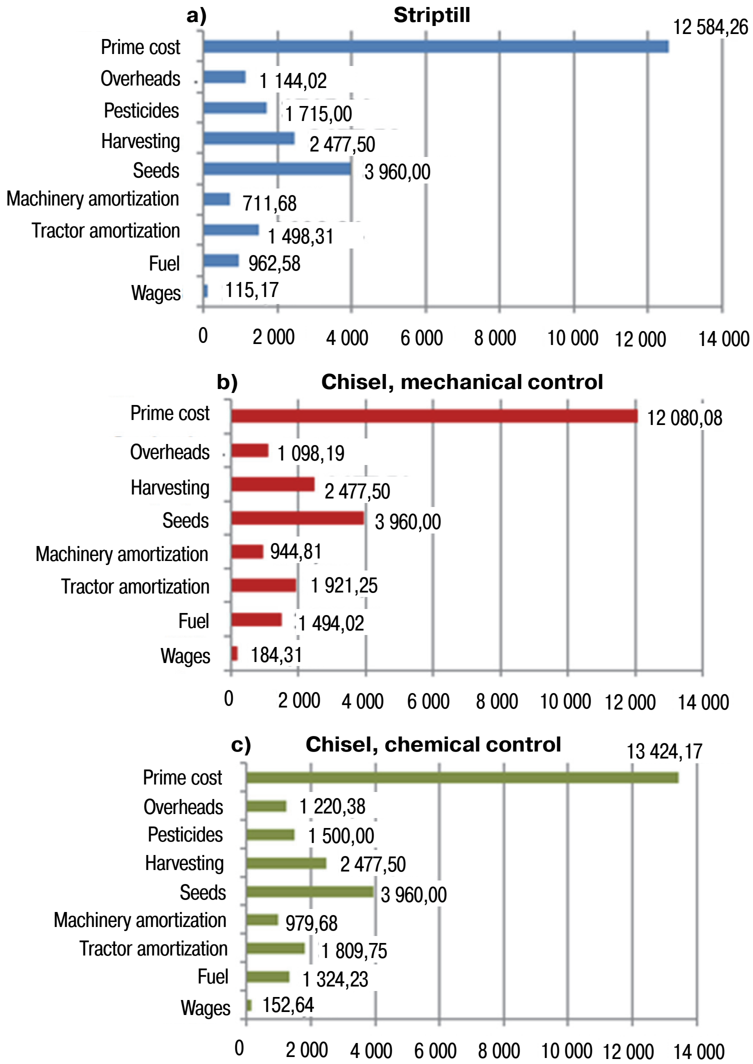

Fig. 10. Structure of direct production costs in sunflower cultivation depending on technology of basic processing:

a) striptill technology; b) chiseling with inter-row machining; c) chiseling with application of chemical pesticides

CONCLUSIONS

Analysis of the data obtained shows that degree of anthropogenic impact depends on arrangement of working organs on tool frame. The lowest coefficient is in strip processing technology.

Striptill technology has the lowest costs (3,288 rubles per hectare). This is due to both a reduction in operations and a smaller number of units in the ICC. In terms of direct costs the most expensive is classical chisel technology (4,544 rubles per hectare). Minimal chisel technology takes middle position (4,266 rubles per hectare). Striptill technology reduces fuel costs by 35.5% compared to classical chisel, and by 27.3% compared to minimum technology. Wages is reduced by 37.5% and 24.8% compared to classical chisel and minimum chisel technology, respectively. The magnitude of these changes is explained by decrease in number of technological operations of mechanical tillage, which reduces range of agricultural machines at the same time as costs of their purchase and depreciation charges, as well as required amount of fuel. Accordingly, the total direct technical costs for the classical chisel are lowered by 22.9% and for the minimal chisel technology are reduced by 27.6%.

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ОЦЕНКА ЭФФЕКТИВНОСТИ ТЕХНОЛОГИИ ПОЛОСНОЙ ОБРАБОТКИ ПОЧВЫ

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В статье рассмотрена технология чизелевания с позиции антропогенного воздействия на почву. Проанализировано влияние расстановки рабочих на технологический процесс обработки. Дана оценка эффективности ресурсосберегающей технологии глубокой обработки почвы при производстве пропашных культур на примере выращивания подсолнечника на территории Волгоградской области. Дана технико-экономическая оценка возделывания подсолнечника в зависимости от технологического процесса чизелевания. Определена конкурентоспособная технология основной обработки почвы. Анализ полученных данных показывает, что наибольшая площадь поперечного сечения пласта образуется при обработке почвы буровыми инструментами, поскольку рабочие органы расположены так, что они образуют зону непрерывного рыхления, соответственно, она оказывает наибольшее антропогенное воздействие. Полевые эксперименты также показали, что глубокие рыхлые ленты на глубину 0,25...0,35 м, чередующиеся с полосками без обработки, характеризуются положительными процессами. Необработанные площади становятся загущенными (более 1,3 г/см^3), поэтому они создают менее благоприятные по сравнению с обработанными условия для развития некоторых видов многолетних сорняков. Исследования показали, что после основной обработки почвы на глубину 0,3 м с использованием технологии полосной обработки почвы сохранялось 69,67% стерни озимой пшеницы. Использование технологии полосной обработки почвы снижает затраты на топливо на 35,5% по сравнению с классическим обработкой и на 27,3% относительно минимальной технологии. Соответственно, стоимость заработной платы снижается на 37,5% по сравнению с классической схемой и на 24,8% по сравнению с минимальной технологией.

Ключевые слова: глубокая обработка почвы, антропогенное воздействие, технология стриптил, полосная обработка почвы

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RICE CULTIVATION IN AMUR REGION

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Abstract. Rice plays an important role in the modern diet of Russian people. It occupies a leading position in area, yield, and gross grain harvest among all cereal crops. The aim of the research is development of optimal irrigation regimes that ensure rational use of water resources in southern agricultural zone of Amur Region. Setting and conducting field and laboratory experiments, system approaches and modern research methods were used. The article presents the results of studies on rice cultivation under different irrigation regimes. In the southern zone of Amur Region, along with water regimes of 70, 80, 90% of FMC, differentiated rice irrigation regimes were studied, combining differentiation of presumed humidity thresholds and wetting depth of active soil layer 75...85% of FMC (0.4 and 0.6 m); 80% of FMC (0.4 and 0.6 m). In addition, various flooding regimes of rice field (short and intermittent flooding), seeding rates, timing of sowing, rice cultivars were studied. Obtaining a rice grain yield of more than 4 tons per hectare is ensured by application of mineral fertilizers in the dose of $N_{120}P_{30}K_{30}$ and seeding rate of 5 million seeds. Optimum seeding time was set from 20 to 25 May. Based on the results of the research, irrigation water was saved, as well as yield increased by optimizing irrigation rice regimes using sprinkling by differentiating presumed moisture thresholds and wetting depth. When rice was cultivated under flooding system of irrigation, it was established that regime of shortened flooding turned to be optimal. When sprinkling in conditions of southern agricultural zone of Amur Region, differential irrigation regime of 75...85% of FMC in active soil layer was 0.4 and 0.6 m.

Keywords: rice, water regimes, sprinkling, flooding, fertilizer doses, seeding rates, varieties

INTRODUCTION

Rice is one of the most important crops in diet of Russian people. It occupies a leading position in area, yield, and gross grain harvest among all cereal crops. The demand for rice is increasing every year. Growth and stabilization of grain production in Amur region can help in solving problem of providing the population with own grain by increasing crop diversity. Amount of heat and light in the southern zone of Amur Region is sufficient to cultivate rice. Rice cultivation can contribute to increasing grain production in the area. According to the Ministry of Agriculture of the Russian Federation, area suitable for cultivating rice in the Far East is at least 240 thousand hectares. Thus, not only the population of this region, but also all of Eastern Siberia, can be provided with rice grains [1—3]. Currently in the Far Eastern Federal District rice is cultivated only in Primorsky region, but production is not enough to meet the growing food needs of the Far East [4]. Therefore, the relevance of our research is determined by the need to develop effective water regimes for rice cultivation in compliance with principles of water conservation and environmental safety requirements of production.

The aim of the research is the development of optimal irrigation regimes that ensure rational use of water resources in the southern agricultural zone of Amur Region.

MATERIALS AND METHODS

Field research has been conducted since 2005 on experimental field of Far East State Agrarian University, p. Gribskoye of Blagoveshchensk district of Amur region, located in the zone of Gribskoye irrigation system. Observations and records have been documented, while observing the requirements of techniques of the experimental case [5—7]. We studied water regime of soils: pre-irrigation soil moisture content of 70, 80, 90%, 75—85% of field moisture capacity (FMC) (0.4 and 0.6 m); 80% of FMC (0.4 and 0.6 m); 80% of FMC (0.6 m) (control) — sprinkling, shortened flooding: creating a water layer of 0.10...0.12 m after sowing, after 0.10...0.12 m seedlings till tillering phase, decreasing water layer to 0.05m before tubing phase, increasing water layer to 0.15 m until the end of milk ripeness (control); intermittent flooding: after sowing 0.10 m (10 days), then water removing, after emergence 0.07 m (2...3 days), water removing, then 0.10...0.12 m and maintained till tillering phase, water layer decreasing up to 0.05 m (10 days), increasing water layer to 0.15 m and maintaining until the end of grain ripeness; intermittent flooding: creating a layer of water 0.12 m after sowing, no water in rice field during 7 days, on the 8th day the whole cycle repeats. Then 0.10...0.12 m to tillering phase, followed by a water decreasing to 0.05 m (10 days), further increasing water layer to 0.15 m and maintaining till the end of grain milky ripeness. Fertilizer doses were control without fertilizers; $N_{60}P_{30}$; $N_{90}P_{30}K_{15}$; $N_{120}P_{30}K_{30}$. Seeding rates were 4 million (control); 5 and 6 million of seeds. Rice cultivars: dry-bottomed (early cultivar 'Volgogradskiy' of Research Institute of Irrigated Agriculture, high-yielding, resistant to sharply continental climate), and rice cultivars regionalized in Primorsky Krai, which are related to early ripening groups: round-grained — 'Dariy 23', 'Priozerny 61'; long-grained — 'Khankaisky 429', 'Khankaisky 52', 'Lugovoy', 'Rassvet' and 'Kaskad' with high technological and culinary quality. Sowing terms: 10.05—15.05; 20.05—25.05; 30.05—04.06.

The soil cover of the site is represented by meadow-brown soils. The density of soil in calculated layers (0.6 m) is 1.33 t/m^3, the lowest moisture capacity of the soil is 22.50%, porosity is 49.18%. Humus content is low 2.13%, easily hydrolyzable nitrogen is 2.7 mg/100 g, mobile phosphorus content is 37.8 mg/kg, exchange potassium content is 122.5 mg/kg.

The years of research differed significantly in the magnitude and distribution of atmospheric precipitation, which made it possible to assess effectiveness of the irrigation regimes studied.

Rice cultivation in field experiments was carried out on the basis of existing zonal recommendations supplemented by variants of studied methods. To control weed vegetation a broad spectrum post-emergence herbicide Segment was used.

Phenological observations of rice growth stages, plant density, determination of crop structure by the method of Gossortoseti (1995), photosynthetic indicators of crops according to the method of A.A. Nichiporovich (1979, 1985) were carried out in the field experiments. Humus content was determined by the method of I.V. Tyurin and B.A. Nikitin in the modification of CINAO in accordance with GOST 26213-84, aqueous and salt pH — according to potentiometric method in accordance with GOST 26483-90, total nitrogen — according to Kornfeld, easily hydrolyzed nitrogen — by the method of M.M. Konova and I.V. Tyurin, mobile phosphorus and potassium — according to B.P. Machigin — GOST 26205-91. In determining water-physical properties of the soil granulometric composition was studied according to the method of N.A. Kachinsky, density of solid phase — pyknometric method, soil density — method of cutting ring, and field moisture capacity (FMC) — by flooded areas.

Analyzes for determination of water-physical and agrochemical properties of soils were carried out in agrochemical laboratory of Department of Ecology and Soil Science of Far East State Agrarian University and in laboratory of Soybean Research Institute.

Weed infestation of seedlings and before harvesting was carried out by applying a marking — 0.25 m^2 in 10 replicates. Water balance calculations for rice checks were carried out according to the method of Rice Research Institute (1979). Total water consumption — by A.N. Kostyakov (1975).

RESULTS AND DISCUSSION

We found that irrigation frequency varied during experimental years, depending on irrigation regime and cultivar [6, 7].

To maintain soil moisture at the level of 70% of FMC depending on meteorological conditions in 2005—2007 it was required to conduct 5...8 waterings with a rate of 670 m^3/ha. Increase in pre-irrigation humidity threshold to 80% of FMC was accompanied by increase in number of waterings to 8...12 with irrigation rate of 450 m^3/ha. Maintenance of 90% of FMC in calculated soil layer was achieved by 11...15 waterings with a rate of 220 m^3/ha. In 2008, all irrigation water for entire growth season was used during 8 waterings, in 2009 — during 6 waterings and in 2010 — during 10 waterings (Table 1).

Total water consumption of irrigated rice under different weather conditions varied from 6,179...9,199 m^3/ha. The greatest average for research years was noted in the variant with maintaining soil moisture of at least 90% of FMC and amounted to 8630 m^3/ha.

As field studies showed, the most favorable for rice cultivation in terms of water availability was 2013, when precipitation during the growing season was 166 mm higher. In the variant of differentiated moistening in 2013, it was necessary to conduct 2 vegetative waterings with irrigation rate 560 m^3/ha for cultivar 'Khankaisky 429' and 530 m^3/ha for cultivar 'Rassvet'. In 2011, in the same variant, it was necessary to conduct 8 watering operations with the rate of 2,060 m^3/ha for cultivar 'Khankaiskiy 429', 6 waterings with the rate of 1560 m^3/ha for cultivar 'Rassvet'; in 2012, irrigation rate was 1,810 m^3/ha and 1,560 m^3/ha for 'Khankaiskiy' and 'Rassvet', respectively (Table 2).

Table 1

The structure of rice total water consumption, 2005—2010

Pre-irrigation moisture, % of FMC	Research years	Total water consumption (E), m^3/ha	Irrigation Rate		Precipitation moisture		Soil moisture reserves	
			m^3/ha	% of E	m^3/ha	% from E	m^3/ha	% from E
70	2005	7 585	5 460	72.0	2 050	27.0	75	1.0
	2006	8 680	3 450	39.7	5 110	58.9	120	1.4
	2007	8 635	5 460	63.2	3 070	35.6	105	1.2
	average	8 300	4 790	58.3	3 410	40.5	100	1.2
80	2005	7 640	5 510	72.1	2 050	26.8	80	1.1
	2006	8 945	3 710	41.5	5 110	57.1	125	1.4
	2007	8 900	5 720	64.3	3 070	34.5	110	1.2
	2008	6 885	4 270	62.0	2 415	35.1	200	2.9
	2009	6 179	2 700	43.7	3 325	53.8	154	2.5
	2010	8 587	4 450	51.8	4 962	57.7	125	1.4
	average	7 856	4 393	55.9	3 488	44.1	132	1.8
90	2005	7 931	5 810	73.3	2 050	25.8	71	0.9
	2006	9 199	3 970	43.2	5 110	55.5	119	1.3
	2007	8 760	5 590	63.8	3 070	35.0	100	1.2
	average	8 630	5 123	60.1	3 410	38.8	96.7	1.1

Table 2

The structure of total water consumption of rice varieties under different sprinkler irrigation regimes

Pre-irrigation moisture, % of FMC	Research years	Total water consumption (E), m^3/ha	Irrigation Rate		Precipitation moisture		Soil moisture reserves	
			m^3/ha	% of E	m^3/ha	% of E	m^3/ha	% of E
Variant 1: 75% ... 85% of FMC, 0.4 and 0.6 m	‘Khankayskiy 429’							
	2011	3 750	2 060	54.9	2 410	64.3	–720	–19.2
	2012	4 830	1 810	37.5	3 520	72.9	–500	–10.4
	2013	5 598	560	10.0	5 460	97.5	–422	–7.5
	average	4 726	1 476	31.3	3 797	80.3	–547	–11.6
	‘Rassvet’							
	2011	3 010	1 560	51.8	2 170	72.1	–720	–23.9
	2012	4 180	1 560	37.3	3 120	74.6	–500	–11.9
	2013	5 198	530	10.2	5 090	97.9	–422	–8.1
	average	4 129	1 216	29.4	3 460	83.8	–547	–13.2
Variant 2: 80% of FMC, 0.4 and 0.6 m	‘Khankayskiy 429’							
	2011	3 780	2 160	57.1	2 410	63.8	–790	–20.9
	2012	5 040	2 160	42.8	3 520	69.8	–640	–12.6
	2013	5 646	690	12.2	5 460	96.7	–504	–8.9
	average	4 822	1 670	34.6	3 797	78.7	–645	–13.3
	‘Rassvet’							
	2011	3 200	1 820	56.9	2 170	67.8	–790	–24.7
	2012	4 300	1 820	42.3	3 120	72.5	–640	–14.8
	2013	5 306	800	15.1	5 010	94.4	–504	–9.5
	average	4 269	1 480	34.7	3 434	80.4	–645	–15.1
Variant 3: 80% of FMC, 0.6 m (control)	‘Khankayskiy 429’							
	2011	4 420	2 380	53.8	2 410	54.5	–370	–8.3
	2012	5 780	2 380	41.1	3 630	62.8	–230	–3.9
	2013	6 190	680	11.0	5 460	88.2	50	0.8
	average	5 463	1 813	33.2	3 833	70.1	–183	–3.3
	‘Rassvet’							
	2011	4 010	2 040	50.9	2 340	58.3	–370	–9.2
	2012	4 930	2 040	41.4	3 120	63.2	–230	–4.6
	2013	5 820	680	11.7	5 090	87.5	50	0.8
	average	4 920	1 587	32.3	3 516	71.4	–183	–3.7

In structure of the total water consumption of rice varieties under different irrigation regimes, share of atmospheric moisture over whole growing season in 2011 was 54.5...72.1%, in 2012 — 62.8...74.6%, in 2013 — 87.5...97.9%. The results of field studies showed that soil moisture is used only in the initial period of rice development, and it accounts for about 1% of total water consumption. The share of irrigation water in the structure of rice total water consumption varied 10.0—15.1% (in 2013) to 50.9...57.1%.

The results of the research showed that the optimal parameters of rice irrigation regime during sprinkling are formed under differentiated moistening: maintaining the pre-irrigation humidity at level more than 75% of FMC in 0.4 m layer during the sowing — tillering period, in 0.6 m layer — at level more than 85% of FMC during tillering — wax ripeness of grain, which contributes to reduction of irrigation water costs for obtaining projected grain yield.

The water balance of rice card-check is represented by income and expense items. In the incoming part there is an irrigation norm, which is supplied to maintain necessary water layer in checks, and precipitation. The expenditure part includes balance items used to maintain water layer in checks, water consumption, filtration, leakage, flow, and technological water removing.

In structure of water balance of irrigation card-check, the largest water consumption was 4,224 m^3/ha of expenditure part in the first variant of shortened flooding in cultivar ‘Khankayskiy 429’.

The lowest water consumption was noted in the second variant of intermittent flooding in ‘Rassvet’ cultivar and amounted to 2,859 m^3/ha of expenditure part.

The main indicators of water balance of card-check in experiment variants did not change significantly. The filtration was 1,726...2,480 m^3/ha of expenditure part. The flow rate for water was 417...631 m^3/ha in the first variant with shortened flooding. The volume of technological water removing varied from 3,200 to 4,367 m^3/ha on average over the research years (Table 3).

The highest irrigation rates 12,534 m^3/ha and 11,249 m^3/ha were established in the third variant with intermittent flooding for ‘Khankayskiy 429’ and ‘Rassvet’, respectively. The lowest irrigation rates were established at shortened flooding regime (9,811 m^3/ha and 8,758 m^3/ha for ‘Khankayskiy’ and ‘Rassvet’ cultivars, respectively), which is connected primarily with check flooding scheme and water layer.

The study of influence of seed rates on rice yield showed that the maximum yield was obtained at a rate of 5 million seeds. Increase in seed rate resulted in high plant density which consequently led to yield decrease.

Cultivating ‘Volgogradskiy’ rice cultivar under sprinkling irrigation with 80% of FMC, applying mineral fertilizers $N_{120}P_{30}K_{30}$ and at seeding rate of 5 million seeds, yield was 4.6 t/ha.

Depending on soil and climatic factors and factors studied, Primorsky rice cultivars formed the following grain yields: ‘Dariy 23’ (3.52 t/ha), ‘Priozerny 61’ (3.85 t/ha), ‘Rassvet’ (sprinkling — 4.19 t/ha, shortened flooding — 5,4 t/ha), ‘Lugovoy’ (4,2 t/ha), ‘Kaskad’ (sprinkling — 4.8 t/ha, flooding — 5.5 t/ha), ‘Khankayskiy 429’ (sprinkling — 4.38 t/ha, intermittent flooding of the IV type — 5.6 t/ha) [8—10]. The optimum time for rice sowing — 20 to 25 May — was established in the southern zone of Amur Region.

Table 3

Water balance of card-check under different regimes of rice flooding, average for 2011—2013

Indicators	Cultivar					
	'Khankayskiy 429'			'Rassvet'		
	irrigation regime					
	Variant 1: shortened flooding (sowing 0.12 m once, 0.12 cm shoots to tillering, 0.05 m 12 days, 0.15 m t o the end of milky ripeness)	Variant 2: intermittent flooding (after sowing 0.10 m — 10 days, after emergence of 0.07 m 2—3 days, 0.12 m at the appearance of 2—3 leaves till tillering, 0.05 m 10 days, 0.15 m to the end of milky ripeness)	Variant 3: intermittent flooding (after sowing 0.12 m once, after 7 days 0.12 m, after 7 days 0.10 m till tillering, 0.05 m 10 days, 0.15 m till the end of milky ripeness)	Variant 1: shortened flooding (sowing 0.12 m once, 0.12 cm shoots to tillering, 0.05 m 12 days, 0.15 m to the end of milky ripeness)	Variant 2: intermittent flooding (after sowing 0.10 m — 10 days, after emergence of 0.07 m 2—3 days, 0.12 m at the appearance of 2—3 leaves till tillering, 0.05 m 10 days, 0.15 m to the end of milky ripeness)	Variant 3: intermittent flooding (after sowing 0.12 m once, after 7 days 0.12 m, after 7 days 0.10 m till tillering, 0.05 m 10 days, 0.15 m till the end of milky ripeness)
Water input, m^3/ha						
Irrigation Rate	9 811	11 786	12 534	8 758	9 543	11 249
Precipitation	4 250	4 243	4 237	3 697	3 720	3 907
Total	14 061	16 029	16 788	12 455	13 263	15 156
Expenditure water, m^3/ha						
Maintaining water level	2 200	4 600	4 300	2 200	3 900	4 333
Change in moisture reserves in aeration zone	–254	–146	–136	–254	–146	–136
Filtration	2 470	2 201	2 480	2 015	1 726	1 846
Water consumption	4 224	3 705	3 870	3 470	2 859	3 201
Leakage loss	651	614	693	567	459	574
Flowing	591	543	631	515	417	523
Technological water removing	3 333	3 967	4 367	3 200	3 400	4 367
Total	13 723	15 776	16 477	12 221	12 907	14 980
Discrepancy, m^3/ha	338	254	311	234	356	176
Discrepancy, %	2.4	1.6	1.8	1.8	2.7	1.2

CONCLUSIONS

The possibility of rice cultivation is proved on the basis of effective use of irrigation water by optimizing water regime of soil. When sprinkling under conditions of the southern zone of Amur Region, optimal regimes were: differential irrigation regime with 75...85% of FMC in 0.4 and 0.6 m active soil layer, intermittent flooding of the

IV type of cultivar ‘Khankayskiy 429’ and shortened flooding of ‘Rassvet’ cultivar. Grain rice yield of more than 4 tons/ha is achieved by application of mineral fertilizers in the rate $N_{120}P_{30}K_{30}$ and seeding rate of 5 million seeds. The optimal sowing time was also identified — May 20—25.

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ОСОБЕННОСТИ ВОЗДЕЛЫВАНИЯ РИСА В УСЛОВИЯХ АМУРСКОЙ ОБЛАСТИ

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В статье представлены результаты исследований возделывания риса при разных режимах орошения (70, 80, 90% НВ). В условиях южной зоны Амурской области также были изучены режимы орошения риса, сочетающие в себе дифференцирование предполивных порогов влажности и глубины промачивания активного слоя почвы 75—85% НВ (0,4 и 0,6 м); 80% НВ (0,4 и 0,6 м). Кроме того, были изучены разные режимы затопления рисового поля слоем воды (укороченное и прерывистое затопление), нормы высева семян, сроки сева, сорта риса. Получение урожайности зерна риса более 4 т/га обеспечивается внесением минеральных удобрений в дозе $N_{120}P_{30}K_{30}$ и нормой высева 5 млн всхожих семян. Оптимальные сроки сева были установлены с 20 по 25 мая. По результатам исследований, за счет проведения оптимизации режимов орошения риса в условиях дождевания, посредством дифференцирования предполивных порогов влажности и глубин промачивания наблюдалась экономия оросительной воды и увеличение урожайности. При возделывании риса в условиях затопления было установлено, что оптимальными считаются режим укороченного затопления.

Ключевые слова: рис, водные режимы, дождевание, затопление, дозы удобрений, нормы высева, сорта

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CROP ROTATIONS ENSURING THE GREATEST YIELDS UNDER DRY CONDITIONS OF THE LOWER VOLGA REGION WATER-SAVING IRRIGATION REGIMES FOR VEGETABLE CROP PRODUCTION UNDER CONDITIONS OF VOLGA-DON INTERFLUVE

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Abstract. An estimation of various agro-biological methods in crop rotation of dry-steppe zone of light chestnut soils of the Lower Volga region is given. The effectiveness of a grain-fallow four-field crop rotation has been established, where green manure crop mass of winter rye, straw and leaf-weed mass of crops are plowed in soil, which increases organic matter and nutrient content in soil, reduces humus loss, and stabilizes grain yields. It was noted that only in four-field grain-fallow green manure crop rotation there is a positive balance of the main nutrients in the soil per hectare, where additional organic matter enters arable layer of soil in the form of winter rye green manure crop. In this variant, the balance was: nitrogen +39.7; phosphorus +0.7 and potassium +49.9 kg/ha. In six-field grain crop rotation with ginger as a sidereal crop, a positive balance is achieved only for phosphorus +14.1 and potassium +35.5 kg/ha, for phosphorus there is a negative balance of –3.5 kg/ha. In the eight-field grain crop rotation with 50% of legume crops, a positive balance is achieved only for potassium, +29.8 kg/ha. The balance of humus can be regulated by the structure of areas, alternation of crops in field crop rotations, application of plant residues in the form of sidereal crops, straw, leaf-weed mass, decrease in the proportion of fallow and tilled crops in the structure of biotivated crop rotations. The most complete biologization is possible in green manure crops, where humus losses decrease 1.5 times or more. A positive balance of organic matter is ensured in four-field biologized grain-fallow crop rotation — +3.33 t/ha.

Keywords: biologization, field crop rotation, light chestnut soil, organic matter, green manure crop, humus

INTRODUCTION

To improve efficiency of agriculture in the Lower Volga region, it is necessary to develop and introduce field biological crop rotations and resource-saving cultivation methods of grain crops. The biologization of agriculture assumes introduction of green manure fallows, leguminous and intermediate crops in crop rotation for green fertilizing, application of straw and leafy mass of crops into soil. Therefore, complex study of agro-biological methods in field crop rotations using bioresources capable of restoring natural balance and soil fertility and increasing yield of grain produce per hectare of arable land has particular relevance and novelty [1—4].

MATERIALS AND METHODS

The studies were carried out on experimental field of Nizhnevolzhsky Research Institute of Agriculture. The soil of the experimental plot is light chestnut heavy loam with 1.74% humus content in top soil, pH 8.1. Content of easily hydrolyzable nitrogen is 2—7 mg/100 g soil, mobile phosphorus is 3—11 mg/100 g and exchangeable potassium is 30—40 mg/100 g soil. Replication was four-fold. The area of the experimental plot was 200 m^2. Precipitation in 2013—2014; 2014—2015, 2015—2016 and 2016—2017 research years was 435.5 mm; 266.8 mm; 554.8 mm and 374.9 mm, respectively, compared to average annual value of 339.7 mm. Winter wheat 'Kamyshanka 5', oat 'Golozerny', sorghum 'Kamyshinskoe 31', pea 'Aksaysky usaty 10', chick pea 'Privo 1', safflower 'Aleksandrit', camelina 'Yubilyar', winter rye 'Saratovskaya 7'.

The effectiveness of biologization was studied in field crop rotations:

1) Grain-fallow four-field: black fallow — winter wheat — sorghum for grain — oats (control);

2) Grain-fallow green manure four-field: green manure fallow (winter rye) — winter wheat — sorghum for grain — oats;

3) Grain-fallow green manure six-field: green manure fallow (camelina) — winter wheat — sorghum for grain — chickpeas — safflower — oats;

4) Grain eight-field: peas — winter wheat — chickpeas — safflowers — peas — sorghum for grain — chickpea — oats.

In the first control crop rotation straw of winter wheat and oats, leaf sorghum mass was removed from the field. In the second, third and fourth crop rotations leaf mass of crops remained in the field was plowed in the soil with a heavy disc harrow. The main soil cultivation method in all variants was deep chiseling at 0.30...0.32 m with a surface layer rotation to a depth of 0.20...0.22 m. It was carried out using OCHO-5-40 tool with multifunctional working bodies of the modular type "RANCHO" (blade and a wide chisel). Before discing of winter wheat and oats straw, leafy mass of sorghum and safflower, ammonium nitrate was added in the calculation of 10 kg of active ingredient per 1 ton. Green manure crops — winter rye and camelina were sown in spring because of unfavorable autumn conditions. For this reason, in 2015 and 2016, instead of winter wheat, spring wheat 'Kamyshinskaya 3' was sown. The rest crops were sown on time in established optimal terms.

RESULTS AND DISCUSSION

The circle of organic matter in crop rotations makes it possible to estimate possible loss of soil fertility due to removing of plant residues of cultivated crops from the field [5, 6]. Great importance in supply of organic matter to soil in crop rotations belongs to green manure crops, which compensate loss of organic matter due to humification of green and root mass entering the soil (Table 1).

Table 1

Circulation of organic matter in biologized crop rotations, t/ha of crop rotation area (average for 2014—2017)

Variant	Crop rotation	Accumulated	Removed	Applied	Balance
1 (control)	Grain-fallow four field	5.43	4.31	1.12	–3.19
2	Grain-fallow green manure four-field	7.13	1.90	5.23	+3.33
3	Grain-fallow green manure six-field	5.92	1.75	4.17	+2.42
4	Grain eight-field	5.64	1.84	3.80	+1.96

Table 1 shows that in biologized crop rotations more organic matter returns to soil, and all of them exceed control. Applied organic matter in grain-fallow green manure four— and six-field rotations is higher by 4.11 and 3.05 t/ha respectively, grain eight-field crop rotation — by 2.68 t/ha. A positive balance of organic matter is ensured in these crop rotations. The highest value is observed in four-field biologized grain-fallow crop rotation +3.33 t/ha, the lowest in eight-field grain-cropped rotation +1.96 t/ha. In six-field grain-fallow green manure crop rotation +2.42 t/ha.

Removal of basic nutrients from soil by field crop yields has reached critical values recently [7]. Therefore, it is very important to return them annually to soil with organic matter of cultivated crops in form of straw and leaf mass (Table 2).

Table 2

Circulation of basic nutrients in top soil applied with organic matter of field crops in biologized crop rotations, kg/ha of crop rotation area (average for 2014—2017)

Variant	Accumulated			Removed			Applied			Applied with ammonium nitrate			Balance		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
1 (control)	66.7	15.1	45.0	59.2	13.0	36.5	7.5	2.1	8.5	7.5	2.1	8.5	–51.7	–10.8	–28.0
2	97.8	23.9	63.9	43.7	11.6	7.0	54.1	12.3	56.9	83.4	12.3	56.9	+39.7	+0.7	+49.9
3	80.0	17.9	49.5	46.1	10.7	7.0	33.9	7.2	42.5	60.2	7.2	42.5	+14.1	–3.5	+35.5
4	85.4	17.1	45.6	55.9	11.6	7.9	29.5	5.5	37.7	49.4	5.5	37.7	–6.5	–6.1	+29.8

Table 2 shows that four-field grain-fallow green manure crop rotation is the only crop rotation which has positive balance of basic nutrients in soil per ha of crop rotation area, where in addition to straw and leafy mass of cultivated crops organic matter in form of winter rye green manure crop is additionally supplied to top soil. In this variant the balance was: nitrogen +39.7; phosphorus +0.7 and potassium +49.9 kg/ha. In six-field grain-fallow biologized crop rotation with camelina green manure, a positive balance was achieved only for phosphorus +14.1 and potassium +35.5 kg/ha, for phosphorus there was a negative balance –3.5 kg/ha. In eight-field grain crop rotation with 50% of leguminous crops, a positive balance was achieved only for potassium +29.8 kg/ha. For nitrogen and phosphorus, this rotation showed a negative balance of –6.5 and –6.1 kg/ha, respectively. The negative nitrogen balance in this variant is due to the fact that straw of leguminous crops before its plowing was not applied with ammonium nitrate, which apparently should be done, as share of legumes in structure of crop rotation is 50%. Also, when sowing crops in biologized crop rotations, it is necessary to add phosphorus fertilizer in form of superphosphate due to negative balance of this element, especially in six- and eight-field crop rotations. In the control variant, where all straw and leafy mass of field crops is removed from the field, a negative balance of nitrogen, phosphorus and potassium is provided: –51.7; –10.8 and –28.0 kg/ha of crop rotation area, respectively.

Humus balance can be regulated by structure of areas, alternation of crops in field crop rotations, application of plant residues in form of green manure, straw, leafy mass, reduction in proportion of black fallow and tilled crops in biologized crop rotations. The most complete biologization is possible in crop rotations, where losses of humus decrease 1.5 times or more. Short-term cereal rotations adopted in the Lower Volga region contribute to uncompensated and significant humus losses, which reach 500—700 kg/year/ha of arable land. The most accessible measure to reduce humus deficiency is application of straw and leafy mass of field crops (average of 2.5...3.0 t/ha), which reduces annual deficit in three-, four-field grain-fallow crop rotations by about 50—100 kg [8, 11]. Increased losses of organic matter intensified processes of reducing soil fertility (Table 3).

Table 3

Humus balance in field biologized crop rotations, t/ha (average for 2014—2017)

Variant	Crop rotation	Humus balance		
		Mineralization	Humification	Balance
1 (control)	Grain-fallow four-field	0.76	0.15	–0.61
2	Grain-fallow green manure four-field	0.48	0.66	+0.18
3	Grain-fallow green manure six-field	0.46	0.45	–0.01
4	Grain eight-field	0.53	0.40	–0.13

Table 3 shows that four-field grain-fallow control rotation with black fallow has the highest (0.76 t/ha) mineralization degree of organic matter, which is higher by 58.3, 65.2 and 43.4% compared to four-, six- and eight-field rotations, respectively. The highest humification of organic matter is ensured in four-field grain-fallow crop rotation with green manure — 0.66 t/ha, which is 0.51 t/ha higher compared to the control. Six- and eight-field crop rotations exceed the control in humification of organic matter by 0.30 and 0.25 t/ha, respectively. Favorable positive balance of humus (+0.18 t/ha) is formed in four-field grain-fallow crop rotation with winter rye green manure. In other variants a negative balance of humus is observed: –0.61 t/ha in the control, –0.01 t/ha in six-field and –0.13 t/ha in eight-field rotation.

In the Lower Volga region, the greatest grain yield is provided in four-field grain-fallow and grain-fallow-cropped rotations, including various groups of field crops with different vegetation season, which are more resistant to unfavorable weather conditions. This allows observing principle of technological diversity, which reduces negative changes in agroecosystems under unilateral anthropogenic influence [9, 10]. To estimate crop rotation, yield of grain from one hectare of arable land was calculated (Table 4).

Table 4

Grain yield in field biologized crop rotations, t/ha of crop rotation area (average for 2014—2017)

Variant	Crop rotation	2014	2015	2016	2017	Average
1 (control)	Grain-fallow four-field	1.53	1.25	2.40	1.96	1.79
2	Grain-fallow green manure four-field	1.63	1.25	2.73	1.99	1.90
3	Grain-fallow green manure six-field	1.17	1.29	2.64	1.92	1.75
4	Grain eight-field	0.88	1.65	2.95	1.90	1.84
LSD_{05}		0.04	0.05	0.05	0.08	—

Table 4 shows that the largest yield of grain from one ha of crop rotation was achieved in 2016, in other years it was similar. This indicator is the highest in four-field grain green manure crop rotation with winter rye green manure — 1.90 t/ha, which exceeds the control by 0.11 t/ha or 6.1%. In eight-field grain biologized crop rotation (without black fallow but with 50% of legumes) grain yield is 1.84 t/ha, which is 0.05 t/ha or 2.8% higher than the control variant. Six-field grain green manure crop rotation with camelina green manure is at the same level of grain per hectare of crop rotation area with control and is 1.75 t/ha.

CONCLUSIONS

The highest positive balance of organic matter is ensured in four-field biologized grain-fallow crop rotation (+3.33 t/ha), the lowest one is in eight-field grain crop rotation (+1.96 t/ha).

A positive balance of nutrient elements is ensured only in four-field grain-fallow crop rotation, where in addition to straw and leaf-weed crops, additional organic matter enters the arable soil layer in the form of winter rye green manure crop. Here the balance was +39.7; phosphorus +0.7 and potassium +49.9 kg/ha. In six-field grain-fallow crop rotation with camelina green manure, a negative balance was achieved only for phosphorus –3.5 kg/ha. In eight-field grain with 50% leguminous crops nitrogen and phosphorus have negative balances of –6.5 and –6.1 kg/ha, respectively. Therefore, it is necessary to apply phosphorus fertilizer in form of superphosphate when planting in rows, and in eight-field crop rotation ammonium nitrate should be added to straw of legumes.

Four-field grain-fallow crop rotation with winter rye green manure has a positive effect on improvement of soil fertility, where the most favorable humus balance is +0.18 t/ha. A negative balance of humus was observed in the control variant (–0.61 t/ha), six-field (–0.01 t/ha) and eight-field biologized crop rotations (–0.13 t/ha).

The use of effective resource-saving methods of cultivating field crops using renewable bioresources (straw, leaf, stubble and root residues, green manure crops) provides an increase in productivity of arable land in four- and eight-field crop rotations by 6.1 and 2.8%, respectively.

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ПОЛЕВЫЕ СЕВООБОРОТЫ, ОБЕСПЕЧИВАЮЩИЕ НАИБОЛЬШИЙ ВЫХОД РАСТЕНИЕВОДЧЕСКОЙ ПРОДУКЦИИ В УСЛОВИЯХ СУХОСТЕПНОЙ ЗОНЫ НИЖНЕГО ПОВОЛЖЬЯ

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Приводится оценка различных агробиологических приемов в полевых севооборотах сухостепной зоны светло-каштановых почв Нижнего Поволжья. Установлена эффективность зернопаропропашного четырехпольного севооборота, в котором заделывается в почву сидеральная масса озимой ржи, солома и листостебельная масса культур, что увеличивает поступление органического вещества и элементов питания в почву, снижает потери гумуса в почве, стабилизирует выход зерновой продукции.

Ключевые слова: биологизация, полевой севооборот, светло-каштановая почва, органическое вещество, элементы питания, гумус, выход зерна, Нижнее Поволжье

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OPTIMIZATION OF INNOVATIVE STRIP-TILL TECHNOLOGY OF MAIZE CULTIVATION FOR GRAIN ON BLACK SOILS IN STEPPE ZONE OF VOLGOGRAD REGION

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Abstract. Studies carried out in steppe zone of chernozem soils of Volgograd region have established that winter wheat after fallow and maize are the best precursors for maize, cultivated for grain under strip-till technology. Growing maize after sunflower annually led to a significant decrease in crop yields. $N_{66}P_{32}K_{32}$ turned to be the best rate of mineral fertilizers. Seeding rate of 60 thousand seeds per ha was optimal for early maize hybrids. It was found that total water consumption over the three-year period was 2653 m³/ha with fertilizer rate $N_{66}P_{32}K_{32}$, and corn and sunflower rose to 2,700 and 2,695 m³/ha. At $N_{66}P_{32}K_{32}$, winter wheat plants used moisture most economically. The water consumption coefficient, which shows moisture consumption for creation of a ton of produce, was 421.0 m³/t. For corn, it increased by 34.1, and for sunflower by 247.7 m³/t. In control after all precursors, moisture consumption per ton of grain sharply increased: according to winter wheat, water consumption coefficient was equal to 551.9 m³/t, corn and sunflower were 53.0 and 360.1 m³/t more. The maximum values of dry matter accumulation in 2013 and 2015 were recorded at flowering stage: depending on precursor, after winter wheat — 9.07 and 7.24 t/ha, after maize — 8.67 and 6.77, and after sunflower — 6.64 and 4.76 t/ha, respectively. Over the research years the largest daily increasing of dry biomass during germination-flowering was observed after winter wheat — 452 and 361 kg/ha, decreased slightly after corn — 432 and 337 kg/ha, and a significant decrease was noted after sunflower — 331 and 237 kg/ha. In arid 2014 season, during the period of precipitation deficit, the indicators were significantly lower. The best yield results were obtained in more favorable 2013 and 2015 research years. The studies showed that the best maize precursor was winter wheat — 5.524 t/ha. The lowest yield was obtained after sunflower — 3,456 t/ha. Moreover, maximum yield was achieved at fertilizer application $N_{66}P_{32}K_{32}$ — 5.324 t/ha, $N_{50}P_{16}K_{16}$ — 4.813 t/ha and in the control — 4.015 t/ha.

Keywords: maize for grain, mineral fertilizers, seeding rate, precursor, strip-till, yield

INTRODUCTION

It is important to preserve and enhance natural fertility of soil based on development and introduction of new technologies. It is essential to achieve a sharp reduction in material and energy costs [1]. A promising method is the innovative strip-till system, which allows increasing grain production, increasing yield, saving fuel, since entire soil surface of field is not processed [2—4]. The peculiarity of strip-till technology is that soil is treated with strips, while in intermediate regions the soil remains unplowed, and natural structure remains intact as in direct sowing [5—7]. Strip-till technology also contributes to better warming of soil and better contact of seeds with it [8]. Intensive cultivation of maize for grain allows for higher yields 2.4 times under unfavorable conditions and 2.1 times — in good weather conditions in comparison with the control [9, 10].

MATERIALS AND METHODS

The research was carried out on Krasnokorotkovsky experimental field in Novoanninskiy district of the Volgograd region in 2013—2015 to develop elements of the innovative strip-till technology. A three-factorial experiment was laid by the split plot method. Factor A was precursors — winter wheat after black fallow, maize for grain, sunflower; factor B — rates of mineral fertilizers — control (without fertilizers), $N_{50}P_{16}K_{16}$ ($N_{16}P_{16}K_{16}$ — for the main application + N_{34} for fertilizing, $N_{66}P_{32}K_{32}$ ($N_{32}P_{32}K_{32}$ + N_{34} for fertilizing) and factor C — seeding rates: 50, 60 and 70 thousand of seeds per ha. The registration area of third-grade plot was 182 m². The soil in the experiment is southern chernozem with a humus content of 4.7%, pH 8, total nitrogen — 84.7 mg/kg (very low), mobile phosphorus — 43.4 mg/kg (increased), exchange potassium 395.0 mg/kg (increased). Early hybrid 'NK Gitago' (FAO 200) was used.

In autumn systemic herbicide Rap was used, 36% water solution (A) at a dose of 4 l/ha with a working fluid consumption of 50 l/ha. The strips were cut in October by Ortman cultivator with a depth of 23—25 cm and a width of 25 cm with simultaneous application of main fertilizer in liquid form. The sowing was carried out by 6-row Monosem seed drill to 6...7 cm depth. In 2013 sowing was carried out on April 22, in 2014 — May 5 and in 2015 — on May 26. Herbicide Ballerina, 41.7% suspension emulsion was applied at 0.4 l/ha with a working fluid consumption of 200 l/ha for crop protection in the phase of 3—5 leaves, and Vetter cultivator was used to carry out N_{34} ammonium nitrate fertilizing in variants $N_{16}P_{16}K_{16}$ и $N_{32}P_{32}K_{32}$. In 2014 pests population (stem moth, cotton scoop) reached Economic Threshold Limit (ETL), and therefore, Karate Zeon insecticide was used for their destruction, at a dose of 0.2 l/ha. Harvesting was carried out by Akros-530 combine harvester with corn mower Orosh.

RESULTS AND DISCUSSION

The weather conditions were different. Amount of precipitation was 199 mm during sowing-full ripeness period in 2013, 127 mm in 2014 and 235 mm in 2015. The average humidity was 30% in 2013, 27% in 2014 and 31% in 2015, and the average daily air temperature was 23.0 °C, 27.1 °C and 23.7 °C, respectively. The hydrothermal coefficient was 0.75 in 2013 and this period was estimated as dry, in 2014 — 0.42 (very arid), and in 2015 — 0.92 (arid).

Field maize germination was high and averaged for 3 years 91.4% after winter wheat, 91.0% after maize and 89.9% after sunflower. Total survival reached 87.4%, 85.3% and 83.5%, respectively.

Maize vegetative period in 2013 and 2015 in fertilized variant $N_{66}P_{32}K_{32}$ after winter wheat and maize lasted 100 days, and after sunflower — 98 days. In the control, it decreased by one day according to experiment variants. In arid 2014 vegetative period was 2 days shorter: in the first fertilizer variant it was 98, 98, 96 days, and in the second — 97, 97 and 95 days.

The total water consumption over three-year period at $N_{66}P_{32}K_{32}$ fertilization after winter wheat was 2653 m³/ha, after maize and sunflower it increased to 2700 and 2695 m³/ha, respectively (Table 1). Moisture was used most economically at $N_{66}P_{32}K_{32}$

fertilization after winter wheat. The water consumption coefficient was 421.0 m^3/t. After maize and sunflower it increased by 34.1 and 247.7 m^3/t, respectively. In control variant after all precursors moisture consumption per ton of grain sharply increased: after winter wheat water consumption coefficient was 551.9 m^3/t, after maize and sunflower it was 53.0 and 360.1 m^3/t more.

Table 1

Total water consumption of maize for grain depending on precursor and fertilizer application at seeding rate 60 thousand of seeds per ha (average for 2013—2015), mi/ha

Indicators	Precursor					
	Winter wheat		Maize		Sunflower	
	untreated	$N_{66}P_{32}K_{32}$	untreated	$N_{66}P_{32}K_{32}$	untreated	$N_{66}P_{32}K_{32}$
Available moisture in 0—1,0 m (sowing), mi/ha	1 605	1 604	1 577	1 577	1 530	1 529
Precipitation during growing season, mm	187	187	187	187	187	187
Precipitation used, C = 0.7, mm	130.9	130.9	130.9	130.9	130.9	130.9
Available moisture in 0—1,0 m (before harvesting), mi/ha	252	260	178	186	134	143
Total water consumption, mi/ha	2 662	2 653	2 708	2 700	2 705	2 695
Precipitation in total water consumption, %	49.2	49.3	48.3	48.5	48.4	48.6
Soil moisture in total water consumption, %	50.8	50.7	51.7	51.5	51.6	51.4
Average daily water consumption, mi/ha	26.9	26.7	27.6	27.2	28.1	27.7
Yield, t/ha	4.823	6.302	4.477	5.933	2.966	4.030
Coefficient of water consumption, mi/t	551.9	421.0	604.9	455.1	912.0	668.7
The amount of grain per 1 mm of productive moisture, kg	18.1	23.8	16.5	21.9	10.9	14.9

The least amount of grain per mm of productive moisture (10.9 kg) was formed after sunflower at zero fertilizer application, and the largest (23.8 kg) — after winter wheat at $N_{66}P_{32}K_{32}$ fertilization.

Most leaves were formed during heading stage, and winter wheat, maize and sunflower leaf mass averaged 35.07, 33.81 and 27.20 thousand m^2/hectare. In terms of mineral nutrition, control was the least responsive, and amounted 29.30 thousand m^2/ha, at $N_{50}P_{16}K_{16}$ and $N_{66}P_{32}K_{32}$ this indicator reached 32.36 and 35.67 thousand m^2/ha. Increase in seeding rate resulted in increasing leaf area: for 50 thousand seeds/ha it was 30.74 thousand m^2/ha, for 60 thousand seeds/ha — 31.89 and for 70 thousand seeds/ha — 33.45 thousand m^2/ha.

Accumulation of dry matter in 2013 and 2015 had maximum values at flowering phase: after winter wheat — 9.07 and 7.24 t/ha, maize — 8.67 and 6.77 t/ha, and sunflower — 6.64 and 4.76 t/ha. The greatest average daily increase in dry biomass during seedlings — flowering was observed after winter wheat — 452 and 361 kg/ha, it decreased slightly after maize — 432 and 337 t/ha, and a significant decrease was recorded after sunflower — 331 and 237 kg/ha in 2013 and 2015, respectively. In dry 2014 these indicators were significantly lower. Accumulation of dry biomass was the best at $N_{66}P_{32}K_{32}$ fertilizing: in 2013 — 9.30 t/ha, in 2014 and 2015 — less by 3.55 and 2.54 t/ha. Average daily growth for 2013, 2014 and 2015 was as follows: 463, 286 and 337 kg/ha, respectively. According to the factor C, on average, over the years of study, Accumulation of dry matter at seed rates 50,000, 60,000 and 70,000 seeds/ha was 6.37, 6.60 and 6.61 t/ha. The average daily increase in the factor of seed rate was slightly lower at 50,000 seeds/ha — 317 kg/ha, and at 60,000 and 70,000 seeds/ha — 329 kg/ha. In full ripeness weight of maize dry matter after winter wheat reached 6.03 and 4.87 t/ha, after maize — 5.77 and 4.51 t/ha, after sunflower — 4.42 and 3.16 t/ha. Accumulation of dry biomass in 2014 was 4.35 t/ha after winter wheat, and after maize and sunflower it decreased by 0.35 and 2.33 t/ha.

Average daily growth of dry biomass for three-year data in flowering — full ripeness period after winter wheat was 319 kg/ha, after maize — 300 kg/ha and after sunflower — 206 kg/ha. Application of mineral fertilizers contributed to an increase in dry matter accumulation. So, at $N_{50}P_{16}K_{16}$ for research years it was 4.46 t/ha, at $N_{66}P_{32}K_{32}$ — 4.84 t/ha, and at zero fertilizing — only 3.86 t/ha have accumulated. The average daily growth of dry biomass was: without fertilizer — 240 kg/ha, at $N_{50}P_{16}K_{16}$ — 281 kg/ha, at $N_{66}P_{32}K_{32}$ — 304 kg/ha. Accumulation of dry biomass at seed rate of 50, 60 and 70 thousand seeds/ha was 4.24, 4.39 and 4.42 t/ha. The average daily plant biomass increase at seed rate of 50 thousand seeds/ha was 267 kg/ha, at 60 and 70 thousand seeds/ha it was 279 kg/ha.

Photosynthetic potential (PP) in 2013 and 2015 was maximum, it reached 2217 and 1883 thousand $m^2 \times$ day/ha after winter wheat, 2159 and 1765 $m^2 \times$ day/ha after maize, 1773 and 1400 thousand $m^2 \times$ day/ha after sunflower. PP in 2014 amounted to 1772, 1658 and 1068 thousand $m^2 \times$ day/ha after winter wheat, maize and sunflower. Application of $N_{50}P_{16}K_{16}$ and $N_{66}P_{32}K_{32}$ increased PP for three-year data to 1764 and 1897 thousand $m^2 \times$ day/ha, and without fertilizing it reached 1583 thousand $m^2 \times$ day/ha. As seed rate increased, photosynthetic potential of crops increased: at 50, 60 and 70 thousand seeds/ha it amounted to 1681, 1745 and 1818 thousand $m^2 \times$ day/ha.

In 2013, 2014, 2015 net photosynthetic rate (NP) for precursors studied was 6.39, 6.35 and 5.53 g/m^2/day, respectively. The best results were obtained in $N_{66}P_{32}K_{32}$ variant, when NP averaged 6.25 g/m^2/day, while in $N_{50}P_{16}K_{16}$ and in control fertilizer variants it decreased by 0.06 and 0.42 g/m^2/day, respectively. Optimal seed rates were 50 and 60 thousand seeds/ha, (6.19 and 6.16 g/m^2/day) and at 70 thousand seeds/ha NP was 5.92 g/m^2 /day.

On average over the research years, the largest mass of grain from commodity cobs was formed when corn was grown after winter wheat — 104.5 g. After maize and sunflower it decreased to 100.0 and 68.9 g. The weight of 1000 grains for these precursors was 255.6, 248.3 and 219.9 g, respectively. Grain mass was the best at variant with $N_{66}P_{32}K_{32}$, 50 thousand seeds/ha seed rate (100.6 g and 101.3 g, 255.2 and 252.4 g, respectively).

Maize yield was influenced not only by meteorological conditions, but also by cultivation technology studied (Table 2). The best results were obtained in more favorable

2013 and 2015 research years. Winter wheat turned to be the best maize precursor — 5.524 t/ha. The lowest yield was obtained after sunflower — 3.456 t/ha. The maximum yield was achieved at $N_{66}P_{32}K_{32}$ fertilizer application — 5.324 t/ha, and then $N_{50}P_{16}K_{16}$ (4.813 t/ha) compared to the control (4.015 t/ha). The optimal seed rate for average of 3 years was 60 thousand seeds/ha, and in unfavorable year 2014, the best was 50 thousand seeds/ha, which is confirmed by the statistical processing data.

Table 2

Corn grain yield depending on precursors, fertilizer doses and seed rates in 2013—2015, t/ha

<table>
<tr><td rowspan="3">Factors and combi-nations</td><td colspan="3" rowspan="2">2013</td><td colspan="3" rowspan="2">2014</td><td colspan="3">2015</td></tr>
<tr><td colspan="3">average 2013—2015</td></tr>
<tr><td>Winter wheat</td><td>Maize</td><td>Sun-flower</td><td>Winter wheat</td><td>Maize</td><td>Sun-flower</td><td>Winter wheat</td><td>Maize</td><td>Sun-flower</td></tr>
<tr><td rowspan="2">A</td><td rowspan="2">6.615</td><td rowspan="2">6.310</td><td rowspan="2">4.790</td><td rowspan="2">4.695</td><td rowspan="2">4.293</td><td rowspan="2">2.142</td><td>5.263</td><td>4.926</td><td>3.421</td></tr>
<tr><td>5.524</td><td>5.176</td><td>3.451</td></tr>
<tr><td rowspan="6">B</td><td colspan="3" rowspan="6">control — 4.842
N50P16K16 — 6.039
N66P32K32— 6.835</td><td colspan="3" rowspan="6">control — 3.190
N50P16K16 —3.785
N66P32K32 —4.154</td><td colspan="2" rowspan="2">control</td><td>4.012</td></tr>
<tr><td>4.024</td></tr>
<tr><td colspan="2" rowspan="2">N50P16K16</td><td>4.614</td></tr>
<tr><td>4.813</td></tr>
<tr><td colspan="2" rowspan="2">N66P32K32</td><td>4.984</td></tr>
<tr><td>5.324</td></tr>
<tr><td rowspan="6">C</td><td colspan="3" rowspan="6">50 thousand — 5.570
60 thousand — 6.081
70 thousand — 6.065</td><td colspan="3" rowspan="6">50 thousand — 3.814
60 thousand — 3.734
70 thousand — 3.581</td><td colspan="2" rowspan="2">50 thousand</td><td>4.488</td></tr>
<tr><td>4.624</td></tr>
<tr><td colspan="2" rowspan="2">60 thousand</td><td>4.615</td></tr>
<tr><td>4.810</td></tr>
<tr><td colspan="2" rowspan="2">70 thousand</td><td>4.506</td></tr>
<tr><td>4.717</td></tr>
</table>

LSD_{05} 2013: A,B,C = 0.064, AB, AC, BC = 0.110, ABC = 0.064
LSD_{05} 2014: A,B,C = 0.061, AB, AC, BC = 0.106, ABC = 0.061
LSD_{05} 2015: A,B,C = 0.066, AB, AC, BC = 0.114, ABC = 0.066

CONCLUSIONS

The experiments showed that the best maize precursors were winter wheat after black fallow and maize in cultivation of maize for grain using strip-till technology in steppe zone on chernozem soils in Volgograd region,. Sunflower was the worst maize precursor.

The best mineral nutrition was $N_{66}P_{32}K_{32}$.

Optimal seed rate for early maize hybrid was 60 thousand seeds/ha.

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ОПТИМИЗАЦИЯ ЭЛЕМЕНТОВ ИННОВАЦИОННОЙ ТЕХНОЛОГИИ СТРИП-ТИЛ ПРИ ВОЗДЕЛЫВАНИИ КУКУРУЗЫ НА ЗЕРНО В СТЕПНОЙ ЗОНЕ ЧЕРНОЗЕМНЫХ ПОЧВ ВОЛГОГРАДСКОЙ ОБЛАСТИ

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Проведенными исследованиями в степной зоне черноземных почв Волгоградской области установлено, что для кукурузы, возделываемой на зерно по технологии Стрип-тил, лучшими предшественниками являются озимая пшеница по пару и сама кукуруза. Размещение кукурузы после подсолнечника ежегодно обусловливало значительное снижение урожайности культуры. Из испытанных доз минеральных удобрений лучшей была $N_{66}P_{32}K_{32}$. Оптимальной для раннеспелых гибридов кукурузы являлась норма высева 60 тыс./га всхожих семян. Было установлено, что суммарное водопотребление за трехлетний период составило 2653 м³/га с нормой удобрения $N_{66}P_{32}K_{32}$, а кукуруза и подсолнечник — до 2700 и 2695 м³/га. С дозой удобрений $N_{66}P_{32}K_{32}$, растения озимой пшеницы использовали влагу наиболее экономично. Коэффициент водопотребления, который показывает потребление влаги для создания тонны продукции, составил 421,0 м³/т. Для кукурузы он увеличился на 34,1, а для подсолнечника — на 247,7 м³/т, соответственно. На контроле после всех предшественников потребление влаги на тонну зерна резко увеличилось: по озимой пшенице коэффициент водопотребления составлял 551,9 м³/т, кукуруза и подсолнечник — 53,0 и 360,1 м³/т. Максимальные значения накопления сухого вещества в 2013 и 2015 гг. выявлены на стадии цветения: в зависимости от предшественника, после озимой пшеницы — 9,07 и 7,24 т/га, после кукурузы — 8,67 и 6,77, а после подсолнечника — 6,64 и 4,76 т/га, соответственно. За годы исследований наибольшее ежедневное увеличение сухой биомассы во время прорастания-цветения наблюдалось после озимой пшеницы — 452 и 361 кг/га, несколько уменьшилось после кукурузы — 432 и 337 кг/га, а после подсолнечника отмечено значительное снижение — 331 и 237 кг/га. В засушливый сезон 2014 года, в период дефицита осадков, показатели были значительно ниже. Наилучшие результаты урожайности были получены в более благоприятные по увлажнению годы исследований в 2013 и 2015 гг. Исследования показали, что лучшим предшественником кукурузы была озимая пшеница — 5,524 т/га. Самый низкий урожай был получен после подсолнечника — 3,456 т/га. Кроме того, максимальный выход был достигнут при применении удобрений $N_{66}P_{32}K_{32}$ — 5,244 т/га, $N_{50}P_{16}K_{16}$ — 4,813 т/га, а на контроле — 4,015 т/га.

Ключевые слова: кукуруза на зерно, минеральные удобрения, норма высева, предшественник, Стрип-тил, урожайность

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LOCAL IRRIGATION METHODS FOR VEGETABLE PRODUCTION IN SOUTH OF RUSSIA

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Abstract. In the Southern Federal District, where the Volgograd region occupies a significant territory, cultivation of vegetable crops is impossible without irrigation. There was a large number of wide-spread sprinklers in the USSR. Each unit of this system watered at least 60 to70 hectares, required a lot of water pressure that resulted in high operating costs. Therefore, currently, such local irrigation methods as drip and subsoil irrigation have a broad development perspective. Both irrigation methods favorably differ from sprinkling by a significant increase in yield of vegetable crops, irrigation water saving, ease of operation and rapid investment return. In this regard, the main goal of our research, conducted at Volgograd State Agricultural University, is development of techniques and technologies for drip and subsoil irrigation that allow receiving projected vegetable yields while maintaining soil fertility and environmental safety. The research have shown that it is possible to obtain planned yields of 60, 70 and 80 t/ha of zucchini and table beet using drip irrigation in steppe zone of southern Russia on light chestnut soils. Therefore, it is necessary to observe irrigation regimes with maintaining pre-irrigation moisture (PIM) 75—85—75 and 85% of field moisture capacity (FMC) simultaneously with application of calculated doses of mineral fertilizers. Moreover, it is important to apply increased doses of mineral fertilizers with decrease in intensity of irrigation regime due to reduction in soil moisture content to 75% of FMC. The planned radish yield of 80 tons per hectare with subsoil irrigation can be obtained in variants with differentiated soil moisture 75—85—75% of FMC and 1.4 m distance n t between humidifiers, and also maintaining constant soil moisture at 85% of FMC at plots with 1.2 and 1.4 m distances.

Key words: planned yield, table beet, squash, radish, drip and subsoil irrigation

INTRODUCTION

In conditions of market relations, in which Russia is today, agricultural producers have lost desire to get the maximum possible yields of vegetable crops. Currently, the main issue is the need to grow such a quantity of products that can be grown considering available water, labor, financial resources [1—3].

In the Southern Federal District, where the Volgograd region occupies a significant territory, cultivation of vegetable crops without irrigation is impossible. In Soviet times, a large number of broad sprinkling equipment was used for this purpose. Each unit of this system watered at least 60 to 70 hectares, required a lot of water pressure, resulting in high operating costs. Therefore, in the present time such local methods of irrigation as drip and subsoil irrigation have a further development perspective [4—7].

Both irrigation methods favorably differ from sprinkling by a significant increase in yield of vegetable crops, irrigation water saving, ease of operation and a rapid investment return.

So, the main goal of our research was development of drip (DI) and subsoil irrigation (SI) technologies, in order to produce planned crop yields while maintaining soil fertility and environmental safety in conditions of steppe zone of southern Russia.

METHODS AND MATERIALS

The research was carried out as part of complex long-term field experiments in Research Center "Gornaya Polyana" of Volgograd State Agricultural University.

Irrigation regimes and application of mineral fertilizers were studied in 2002—2005 to obtain planned yields of 50, 60, 70 tons per hectare of pepper and aubergines, and 70, 80 and 90 tons per hectare of tomatoes under drip irrigation. After that similar studies were carried out in 2012—2014 with zucchini and table beets to produce 60, 70 and 80 t/ha of planned commercial produce under drip irrigation, and in 2014—2017 — 80 t/ha of radish using subsoil irrigation.

In field experiments with beets, zucchinis and radish, the main studied crop-forming factor was water regime of soil, which was studied in 3 variants (two permanent and one differentiated). The calculated irrigation rates were given regularly with a decrease in pre-irrigation soil moisture up to set figures.

Two of three-four years of each crop were characterized as arid. This indicated that given yield levels of vegetable crops were obtained even in the most severe weather conditions.

Zucchini 'Nevira' seeds were sown 1.4 × 0,7 m apart with drip lines along each row.

Table beet 'Egipetskaya ploskaya' seeds were sown according to the scheme: 4 rows of plants 0.4 m apart and then — row spacing 0.6 m wide; plants in a row — 0.10...0.12 m apart; drip lines were placed equidistantly between 1 and 2, 3 and 4 rows.

Black radish was sown in 3 rows 0.45 m apart, and then — row spacing 0.7 m wide. After thinning in a row, the plants were left at a distance of 0.08 m from each other.

Zonal system of vegetable growing was used, with adjustment for water regime maintaining and fertilizer rate in the variants studied.

All observations were made according to well-known procedures [8, 9]. Doses of fertilizers for obtaining planned zucchini yields were calculated according to the methodology of Professor V.I. Filin [10, 11].

The soils of the experimental section are light chestnut, typical for steppe zone of southern Russia and Volga-Don interfluve, characterized by low humus (not more than 1—2%) and low nitrate nitrogen content, medium mobile phosphorus and high exchange potassium content.

The DI plot represented a net of Netafim strips (Israel) laid either along or between plant rows. The SI system is a network of polyethylene pipes-humidifiers with point perforations laid at 0.4...0.5 m depth with protective polyethylene film screen on top and bottom along the entire length maintaining uniform moistening of the entire plot area.

RESULTS AND DISCUSSION

Studies on zucchini under DI showed (Table 1) that when applying calculated doses of mineral fertilizers, planned yields of 60, 70 and 80 t/ha can be obtained only in variants with maintaining pre-irrigation moisture threshold of 75—85—75 and 85% of FMC, since in areas with a pre-irrigation moisture of 75% of FMC deviations from planned yields were more than 10% (14.1...16.5%).

Table 1

Zucchini yield under drip irrigation (average for 2012—2014)

Yield, t/ha		Yield deviations		Variants		
planned	actual	t/ha	%	Pre-irrigation moisture, % of FMC	Fertilizer rate	
					planned yield, t/ha	kg a.i./ha
initial analysis						
60	50.1	–9.9	–16.5	75	60	$N_{180}P_{75}K_{82}$
	61.0	+1.0	1.7	75—85—75		
	62.1	+2.1	3.5	85		
70	58.4	–11.6	–16.6	75	70	$N_{210}P_{87}K_{96}$
	71.3	+1.3	1.9	75—85—75		
	73.0	+3.0	4.3	85		
80	68.8	–11.2	–14.1	75	80	$N_{240}P_{99}K_{110}$
	82.4	+2.4	3.0	75—85—75		
	83.9	+3.9	4.9	85		
repeated analysis						
60	58.4	–1.6	2.7	75	70	$N_{210}P_{87}K_{96}$
	61.0	+1.0	1.7	75—85—75	60	$N_{180}P_{75}K_{82}$
	62.1	+2.1	3.5	85		
70	68.8	–1.2	1.7	75	80	$N_{240}P_{99}K_{110}$
	71.3	+1.3	1.9	75—85—75	70	$N_{210}P_{87}K_{96}$
	73.0	+3.0	4.3	85		
80	82.4	+2.4	3.0	75—85—75	80	$N_{240}P_{99}K_{110}$
	83.9	+3.9	4.9	85		

Table 2

Table beet yield under drip irrigation (average for 2012—2014)

Yield, t/ha		Yield deviations		Variants		
planned	actual	t/ha	%	Pre-irrigation moisture, % of FMC	Fertilizer rate	
					planned yield, t/ha	kg a.i./ha
initial analysis						
60	48.2	–11.8	19.7	75	60	$N_{240}P_{150}K_{105}$
	57.2	–2.8	4.7	75—85—75		
	60.9	+0.9	1.5	85		
70	58.9	–11.1	15.9	75	70	$N_{280}P_{175}K_{123}$
	69.6	–0.4	0.6	75—85—75		
	73.3	+3.3	4.7	85		
80	72.8	–7.2	9.0	75	80	$N_{320}P_{200}K_{140}$
	82.7	+2.7	3.4	75—85—75		
	87.1	+7.1	8.8	85		
repeated analysis						
60	58.9	–1.1	1.8	75	70	$N_{280}P_{175}K_{123}$
	57.2	–2.8	4.7	75—85—75	60	$N_{240}P_{150}K_{105}$
	60.9	+0.9	1.5	85		
70	72.8	+2.8	4.0	75	80	$N_{320}P_{200}K_{140}$
	69.6	–0.4	0.6	75—85—75	70	$N_{280}P_{175}K_{123}$
	73.3	+3.3	4.7	85		
80	82.4	+2.4	3.0	75—85—75	80	$N_{320}P_{200}K_{140}$
	87.1	+7.1	8.8	85		

However, a re-analysis shows that the planned productivity of zucchini of 60 and 70 t/ha can be obtained by maintaining moisture threshold of 75% of FMC and application of increased doses of fertilizers — $N_{210}P_{87}K_{96}$ and $N_{240}P_{99}K_{110}$ with very small deviations from expected yields (–2.7) and (–1.7)%.

The results of three-year field experiments on table beets are shown in Table 2.

Mineral fertilizer application in calculated doses with irrigation water to DI system helped to obtain planned yield of table beet at the level of 60 and 70 t/ha only in variants with maintenance soil moisture threshold 75—85—75 and 85% of FMC, since in plots with a moisture 75% of FMC deviations from planned yields were 15.9% and 19.7%, respectively, which was significantly more than 10%.

Repeated analysis shows that these levels of planned table beet yield could be obtained by maintaining moisture threshold of 75% of FMC and application of increased fertilizer doses $N_{280}P_{175}K_{123}$ and $N_{320}P_{200}K_{140}$ with deviations of 1.8 and 4.0%, respectively.

The results obtained are of great practical importance, because of at current price disparity agricultural producer is allowed to plan structure of sown areas based on rising costs of both electricity for supplying irrigation water and mineral fertilizers.

The investigated regimes of zucchini and table beet drip irrigation allow to provide planned yields (Table 3).

In order to maintain a constant less intensive irrigation regime with a moisture threshold of 75% of FMC, 31 waterings (108 m^3/ha) with irrigation rate of 3348 m^3/ha were performed in experiments with zucchini: 11 waterings during the interphase periods ‘sowing — flowering’, ‘fruit formation — last harvesting’ and 2 waterings less during the period ‘flowering — beginning of fruit formation’.

Table 3

Drip irrigation regime for zucchini and beetroot(on average for 2012—2014)

Pre-irrigation moisture threshold, % of FMC	Interphase periods			Waterings for season	Irrigation rate, m^3/ha
	sowing — flowering	flowering — beginning of fruit formation	fruit formation — last harvesting		
	amount of irrigation / irrigation rate m^3/ha				
Zucchini					
75	11/108	9/108	11/108	31	3 348
75—85—75	11/108	21/54	12/108	44	3 636
85	20/54	17/54	32/54	69	3 744
table beet					
	sowing — beginning of root formation	root formation — technical maturity	technical maturity — harvesting		
75	9/134	18/134	8/134	35	4 690
75—85—75	9/134	47/54	8/134	64	4 816
85	25/54	49/54	27/54	101	5 454

While maintaining a differentiated irrigation regime with a pre-irrigation moisture threshold of 75—85—75% of FMC irrigation frequency during the season increased to 44, and irrigation rate — to 3636 m^3/ha due to 11 and 12 irrigation flows of 108 m^3/ha during periods ‘sowing — flowering’ and ‘fruit formation — last harvesting’, respectively, as well as carrying out 21 waterings of 54 m^3/ha in ‘flowering — beginning of fruit formation’.

The most intensive irrigation regime with a constant moisture threshold of 85% of FMC was provided by 69 irrigation cycles (54 m^3/ha) with the highest total irrigation water for season of 3744 m^3/ha: 20, 17 and 32 irrigation cycles were carried out in 1, 2 and 3 phase periods of zucchini development, respectively.

In table beet field experiments maintenance of a constant least intensive irrigation regime with an expected moisture threshold of 75% of FMC was ensured on average by 35 irrigation cycles (134 m^3/ha) with irrigation rate of 4690 m^3/ha (higher than in zucchini): 9 irrigations in the interphase period 'sowing — beginning of root formation', 18 during root formation — technical maturity and 8 — in subsequent period before harvesting of root crops.

While maintaining a differentiated irrigation regime with a moisture threshold of 75—85—75% of FMC, number of irrigations during the season increased to 64, and the irrigation rate was increased to 4816 m^3/ha due to 47 irrigation operations (54 m^3/ha) during inter-phase period 'sowing — beginning of root formation'.

The most intensive irrigation regime with a constant preliminary moisture threshold of 85% FMC was achieved by performing 101 irrigations (54 m^3/ha) at the highest irrigation rate of 5454 m^3/ha: 25, 49 and 27 irrigations — in the 1st, 2nd and 3rd periods of table beet development, respectively.

The results of field experiments on obtaining the planned radish harvests are shown in Table 4.

In these field experiments, the variants for obtaining a planned yield of 80 t/ha were investigated while maintaining soil moisture thresholds on the plots with laying of humidifiers in SI system at a distance of 1.2; 1.4 and 1.6 m apart.

Table 4

Radish yield under subsoil irrigation (average for 2014—2017)

Yield, t/ha		Yield deviations		Variants	
planned	actual	t/ha	%	Pre-irrigation moisture threshold, % of FMC	Distance between humidifiers, m
initial analysis					
80	59.5	–20.5	25.6	75	1.2
	58.4	–11.6	14.5		1.4
	53.5	–26.5	33.1		1.6
	79.3	–10.7	13.4	75—85—75	1.2
	78.2	–1.8	2.2		1.4
	71.0	–9.0	11.2		1.6
	83.6	+3.6	4.5	85	1.2
	82.2	+2.2	2.8		1.4
	72.9	–7.1	8.9		1.6
repeated analysis					
60	58.9	–1.1	1.8	75—85—75	1.4
	57.2	–2.8	4.7	85	1.2
	60.9	+0.9	1.5		1.4

The results obtained showed that such crop yield could be obtained in variants with a differentiated lower soil moisture threshold 75—85—75% of FMC and 1.4 m distance between humidifiers, maintaining a constant soil moisture of 85% of FMC at plots with inter-axis distances of 1.2 and 1.4 m, because of 9 combinations of the factors studied, only these three deviations from planned yield did not exceed 5%.

Table 5

Subsoil irrigation regime of radish (average for 2014—2017)

Pre-irrigation moisture threshold, % of FMC	Interphase periods			irrigations for season	Irrigation rate, m^3/ha
	sowing — flowering	flowering — technical maturity	technical maturity — harvesting		
	Number of waterings/ irrigation rate, m^3/ha				
75	1/50+3/167	6/167	5/167	15	2 722
75—85—75	1/50+3/167	19/100	5/167	28	3 286
85	1/50+9/100	16/100	9/100	35	3 450

Study on similar irrigation regimes for subsoil irrigation is shown in Table 5.

In all variants one sprinkling irrigation (50 m^3/ha) was conducted after radish sowing for better seed germination.

In order to maintain a constant less intensive irrigation regime with moisture threshold 75% of FMC, 14 vegetative irrigations (167 m^3/ha) with irrigation rate of 2,722 m^3/ha were carried out: 3 vegetative irrigations during interphase period ‘sowing — flowering’, 6 — in period ‘flowering — technical maturity’ and 1 watering less during ‘technical maturity — harvesting’.

Maintaining differentiated irrigation regime with moisture threshold 75—85—75% of FMC, number of vegetation irrigations during the season increased to 27, irrigation rate was increased to 3286 m^3/ha due to increase in irrigation number to 19 (100 m^3/ha) (instead of 6, 167 m^3/ha) in period ‘flowering — technical maturity’.

The most intensive subsoil irrigation regime of radish with a constant preliminarily humidity threshold 85% of FMC was achieved by 34 vegetation irrigations (100 m^3/ha) supplying highest total amount of irrigation water of 3450 m^3/ha in season: 9 vegetative irrigations in 1 and 3 radish development phases and 16 waterings — in the second phase.

CONCLUSIONS

Thus, the studies conducted showed that it is possible to obtain the planned yield of 60, 70 and 80 t/ha of zucchini and table beet using drip irrigation in steppe zone of southern Russia on light chestnut soils. It is necessary to observe irrigation regimes maintaining preliminary moisture threshold 75—85—75 and 85% of FMC with application of calculated doses of mineral fertilizers or to apply higher doses of mineral fertilizers reducing irrigation regime intensity by reducing soil moisture content to 75% of FMC.

Radish planned yield of 80 t/ha under subsoil irrigation can be obtained in variants with a differentiated soil moisture threshold 75—85—75% of FMC and 1.4 m distance between humidifiers, and maintaining a constant soil moisture 85% of FMC at plots with 1.2 and 1.4 m interaxial distances.

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ПОЛУЧЕНИЕ ПЛАНИРУЕМЫХ УРОЖАЕВ ОВОЩНЫХ КУЛЬТУР ПРИ ИСПОЛЬЗОВАНИИ ЛОКАЛЬНЫХ СПОСОБОВ ПОЛИВА НА ЮГЕ РОССИИ

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В Южном федеральном округе, где Волгоградская область занимает значительную территорию, выращивание овощных культур без орошения невозможно. В советское время для этого использовалось большое количество широкозахватной дождевальной техники. Каждая единица такой техники поливала не менее 60...70 га, требовала большого напора воды и больших эксплуатационных затрат. Поэтому в настоящее время имеют перспективу широкого развития такие локальные способы полива, как капельное и внутрипочвенное орошение. Оба способа полива выгодно отличаются от дождевания значительным повышением урожайности овощных культур, экономией оросительной воды, простотой эксплуатации и быстрой окупаемостью вложенных затрат. В связи с этим основной целью наших исследований, проводимых в Волгоградском государственном аграрном университете, является разработка техники и технологий капельного и внутрипочвенного орошения, позволяющих получать планируемые урожаи овощных культур при сохранении почвенного плодородия и экологической безопасности. Проведенные исследования показали, что в степной части юга России на светло-каштановых почвах можно получать планируемую урожайность 60, 70 и 80 т/га кабачков и столовой свеклы при проведении капельного орошения. Для этого необходимо соблюдать режимы орошения с поддержанием предполивного порога влажности 75—85—75 и 85% НВ одновременно с внесением расчетных доз минеральных удобрений. Либо необходимо вносить повышенные дозы минеральных удобрений при снижении интенсивности поливного режима за счет уменьшения предполивной влажности почвы до 75% НВ. Планируемую урожайность 80 т/га редьки при внутрипочвенном поливе можно получить на вариантах с дифференцированным нижним порогом влажности почвы 75—85—75% НВ и расстоянием между увлажнителями 1,4 м, а также при поддержании постоянной предполивной влажности почвы 85% НВ на участках с расстояниями 1,2 и 1,4 м.

Ключевые слова: планируемая урожайность, столовая свекла, кабачки, редька, капельное и внутрипочвенное орошение

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WATER-SAVING IRRIGATION REGIMES FOR VEGETABLE CROP PRODUCTION UNDER CONDITIONS OF VOLGA-DON INTERFLUVE

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Abstract. Soils of the southern region of Chad are developed on wind-drawn sand and colluvio-alluvium deposits of two main rivers Logone and Chari. This region of Chad is principal agricultural zone of Chad. Evaluation of physical and chemical properties of sandy soils and their fertility in this region revealed that some soils have very high content of strontium. With aim to locate areas with high content of srontium in soil, and to study its dependence on physical properties of soil and translocation of strontium in soil profile nine pedons were dug on different fields intensively used for agricultural production. Using X-ray spectrometric analysis and radiometric measuring of soil samples it has been revealed that Sr content in soil samples varies from 10 to 270 mg/kg of soil depending on type of soil, depth of soil layers, clay and organic content. Strontium content negatively correlates with total content of calcium and phosphorus in layers of soil. Low CEC of soil may be a reason of translocation of strontium from higher to lower layers of soils. Strontium content in soils do not relates with level of radioactivity of soils under study. The highest content of strontium has been found in soils developed on colluvio-alluviumdeposits. Very wide Ca/St ratioin soil samples of alluvial hydromorphic soils may cause increase of Sr content in vegetable food and drinking water. This may be one of etiological factors which directly or indirectly may cause misbalance in mineral nutrition and severe diseases of a man. It worth of considering necessity of further studies of Sr dynamic in soils under different crop production systems and how to mitigate negative effect of natural pollution of soils with this element.

Keywords: strontium, Ca/Sr ratio, sandy soil, eolian/alluvial deposits, Kashin-Beck disease, osteoarthritis

INTRODUCTION

Analyzing physical, chemical composition and level of fertility of sandy soils on agricultural fields in Southern part of Republic of Chad we found that some soils have extremely high content of strontium. Soils of this area have very specific physical and chemical properties for they are have been formed on eolian and colluvio-alluvium deposits. These deposits are historically very young and time to time are covered by new wind and flood-drawn deposits. In some low places along the rivers there are clay soils of hydromorphic type. On sandy soils at higher places farmers usually grow corn, peanut, cassava, and taro. On lower places along the river they cultivate rice, root vegetables, banana, and green vegetables. Commercial produce of these crops compose main part of people's diet.

General information known on etiological factors which may cause Kashin-Beck disease and other diseases, mostly bone abnormalities [1, 2], led us to analyze more deeply strontium status of sandy soils in mentioned area.

Chemical properties of strontium are very similar to those of barium, calcium, as they may form same salts and basis, but being heavier strontium forms less mobile hydroxide, what causes its accumulation in soils, plant and live organism tissue. The origin of Sr in soils in fact is soil-forming material usually brought by wind and floods from areas where contemporary Earth surface was an ocean bottom at Pleistocene epoch. Ocean sediments at Tibetsy area where usually strong wind is born contain the rests of sea acantarium (radiolarium) which is mainly composed of $SrSO_4$. Even the present sea weeds in oceans contain 26—140 mg per 100 g of dry matter, whereas grasses contain only around 2—3 mg/100 g d.m. Main forms of strontium salts in sea sediments are carbonate and phosphate. In all geochemical and biochemical processes calcium and strontium accompanies each other. The ratio Ca/Sr in soils formed on mother rock of eolian and alluvial sediments unavoidably determines content of strontium in soils and plants. Of course, it worth mentioning that soils and plants may be polluted by radioactive ^{90}Sr precipitated after nuclear explosions or accidents at nuclear objects, but this is a special case.

In any case, while evaluating qualities of soil, as an agricultural object, it worth paying attention to total content of strontium and its ratio to calcium. It will be helpful in finding coincidence with such diseases as Kashin-Beck and other bone abnormalities and finding means of its prevention [2—5].

MATERIALS AND METHODS

City Moundou is a capital of the southern province in Chad. All fields around the city are allocated for crop production and pastures. Soils may be considered as very young as they are formed by periodic wind-driven and alluvial deposits. With aim to study geographical distribution of strontium in soils nine pedons up to 1...1.2 m depth were dug. Locations of pedons excavated (see table 1) were purposely chosen to study influence of height above sea level, hydrology, mode of soil use (arable, pasture, crops cultivated). Having in mind to do further study on soil fertility management in this area all pedons were GPS fixed. As there are no distinguished genetic horizons of soil profile, samples were taken from regular layers 0...30, 30...50 and 50...100 cm. All agrochemical properties such as pH of water and salt extractions, cation-exchange capacity (CEC), content of total and exchangeable phosphate, calcium, magnesium, potassium in soil samples were determined by appropriate techniques [4]. Total content of P, Ca, Sr, Fe, Mn, Mg, K was determined using by X-ray spectrometer `Spectroscan Max G`.

RESULTS AND DISCUSSION

According to Atlas Cartographique of Chad main part of in the province belong to three main groups, Arenosols, Ferrasols, Flivisols. Soils in pedons: # 1, 3, 4, 5, 6, 7 pertain to sandy ferritique and ferrallitic groups. Upper layers of sandy ferrallitic soils have light brown or gray-brown color. Soils, which suffer periodic but prolong flooding, have some hydromorphic features and dark gray color (pedons # 2, 8, 9). All soils have sandy granulometric composition. Clay content in soils is in the range 2...3%, cation exchange capacity varies from 1 to 2 meq/100g.

Table 1

Geographical location and average content of Ca and Sr in main soils studded in province of Moundou (Chad)

№ Pedon	Geographical location	Height Above sea level *m*	Total content in0—30 cm layer *mg/kg*		Ca/Sr ratio	
			Sr	Ca	mass	atomic
1	8° 37′ 26.94″ N 15° 59′ 33.28″ W	474	15	469	31	69
2	8° 35′ 57.96″ N 16° 03′ 33.34″ W	400	235	827	4	7.7
3	8° 35′ 22.52″ N 16° 06′ 20.28″ W	389	16	714	45	99
4	8° 37′ 49.24″ N 16° 05′ 51.60″ W	411	14	851	61	125
5	8° 33′ 58.79″ N 16° 00′ 18.10″ W	412	11	422	38	82
6	8° 39′ 52.64″ N 16° 01′ 38.36″ W	481	8	500	63	139
7	8° 34′ 30.40″ N 16° 00′ 38.06″ W	409	12	347	29	63
8	8° 32′ 59.59″ N 16° 05′ 49.36″ W	396	9	381	42	95
9	8° 36′ 14.68″ N 16° 04′ 46.58″ W	396	273	2 310	9	19

NB: Level of water above sea level in the river = 380 m.

Soil acidity measured in KCL extraction was in the range 3.9...5.2. Content of exchangeable aluminum was very low (0.2...0.5 meq/100 g). Organic matter (OM) content in soils on higher places was in the range 0.6—0.8%. In hydromorphic soils OM content was in the range 1.1...1.3%. Granulometric composition and content of OM, phosphorus, calcium and strontium is represented in Table 2.

Table 2

Content of OM, clay, sand and selected elements in soil layers of different pedons

Pedon	Layer, *cm*	OM,%	Sand,%	Clay,%	Silt,%	pH		P	Ca	Sr
						H_2O	KCl	content, mg/kg		
1	0—30	0.79	98.67	0.8	0.6	5.3	4.8	0.075	469	75
	30—50	1.18	96.6	1.6	1.8	5.3	5.0	0.067	664	105
	>100	0.99	95.8	3.2	1.0	4.8	4.8	0.063	796	125
2	0—30	1.13	943.0	2.6	3.4	4.8	4.5	0.086	827	1175
	30—50	0.78	97.2	1.4	1.4	4.8	4.1	0.095	510	1170
	>100	0.45	96.6	1.6	1.8	4.6	4.2	0.068	880	1035
3	0—30	1.43	99.2	0.4	0.4	5.3	5.2	0.066	714	80
	30—50	0.53	98.6	0.6	0.8	5.0	5.4	0.078	246	65
	>100	0.59	96.2	1.6	2.2	4.8	4.1	0.074	389	105
4	0—30	0.84	97.6	1.0	1.4	5.2	4.9	0.109	851	70
	30—50	0.64	97.6	0.8	1.6	4.9	4.5	0.104	536	105
	>100	0.96	99.2	0.6	0.2	4.8	4.0	0.081	263	130
5	0—30	0.58	98.6	0.4	1.0	5.1	4.6	0.096	422	55
	30—50	0.71	98.2	0.8	1.0	4.6	4.0	0.080	274	85
	>100	0.51	99.2	0.6	0.2	4.3	3.9	0.083	137	130
6	0—30	0.65	99.6	0.2	0.2	5.4	4.9	0.064	499	40
	30—50	0.51	99.0	0.2	0.8	5.3	4.7	0.080	370	55
	>100	0.72	98.2	0.4	0.6	4.8	4.2	0.080	290	75

End of the Table 2

Pedon	Layer, *cm*	OM,%	Sand,%	Clay,%	Silt,%	pH		P	Ca	Sr
						H_2O	KCl	content, mg/kg		
7	0—30	0.85	97.8	0.8	1.4	5.3	4.5	0.087	347	60
	30—50	0.45	97.8	1.2	1.0	5.1	4.2	0.076	312	75
	>100	0.26	97.2	2.2	0.6	4.7	3.9	0.044	279	145
8	0—30	1.04	99.4	0.4	0.2	5.6	5.0	0.084	381	45
	30—50	0.45	98.3	0.6	1.2	5.1	4.3	0.072	187	50
	>100	0.52	98.0	1.2	0.8	4.8	4.0	0.068	470	95
9	0—30	1.54	95.0	2.2	2.8	5.5	4.8	0.136	2 310	1 365
	30—50	0.84	98.0	1.2	0.8	5.3	4.3	0.075	1 322	1 260
	>100	0.51	94.3	2.7	3.1	5.0	4.1	0.101	1 249	1 185

As other researchers found mobility of strontium very much depends on granulometric composition of soil, OM content, soil acidity, calcium and phosphate content [3, 5—7].

Eolian nature of soil formation at the area and very high content of sand allow us to expect high risk of mobility of strontium in soil profiles and high content of strontium in ground water.

The main goal pursued in our research was to evaluate dependence of strontium content on physical, chemical, hydrological properties of soils used for crop production in the province Moundou in Chad. Data presented in the Table 2 shows that the range of strontium content in soils varies very much: from very low (8...12 mg/kg) to extremely high (235...273 mg/kg). Low content of native strontium prevails in upper layersof most soils on fields located on higher elevations, and which are usedfor production of corn, peanut and cassava. It's worth mentioning that in some soils lower layers have higher content of strontium, what may be explained by (a) different content of strontium in wind-brought material in previous times, and (b) by lixiviation of strontium together with silt into lower layers of soil. But, as it has been suggested by soil scientists [1, 7], abundance of strontium is to be compared to that of its homologous element which is calcium. Statistical analysis of the data obtained confirms close correlation between strontium and calcium content in soils. Content of both elements positively correlates with amount of clay and silt in soils. But very low CEC of soils (less than 2 meq/100 g) suggests that larger amount of these elements is in form of poorly weathered material than in the form of extractable salts. This fact is also confirmed by absence of any correlation between acidity of soils and contents of Ca and Sr in soils (Table 3).

Table 3

The Pearson`s correlation matrix among measured levels of OM, clay and selected elements (*n* = 27)

Parameter	OM, %	Sand,%	Clay,%	Silt,%	pH		Total content, mg/kg		
					H_2O	KCl	P	Ca	Sr
OM, %	1								
Sand, %	0.2397	1							
Clay, %	0.1511	0.3455	1						
Silt, %	0.2065	0.0118	0.6737	1					
pH-H_2O	0.0600	–0.0384	–0.0878	0.0469	1				
pH-KCl	0.5074	0.0118	–0.1815	–0.0668	0.0104	1			
P	0.3669	0.0516	0.0434	0.4845	0.0654	0.1132	1		
Ca	0.5484	0.0975	0.5260	0.5851	–0.1074	0.1914	0.5556	1	
Sr	0.2512	0.3501	0.5556	0.6445	–0.1143	–0.190	0.4085	0.7481	1

Soil exchangeable acidity varies in the range from 4 to 5 units providing average coefficient of variation around 9.6%, which is very low for the territory under study. Calcium content in soils correlatespositively with organic matter and phosphorus content in soils, whereas content of strontium does not show such interrelation. As other researchers suggest, it can be governed by lesser activity of this element in biotic system [5, 6, 8].

Nowadays it is recognized that high accumulation of strontium in human body may cause Kashin-Beck disease, osteoarthritis and different metabolic disorders [1—4, 9—12]. That is why it is a reason of big concern for researchers, pathologists and administration in the area. Here we do not mention negative effect of radioactive strontium and other radio nuclides on wild life and human beings, as it is a specific case in quite ordinary situations.

Data presented in Tables 1and 2 shows, that high content of Sr in soils and its high mobility along the profile of soils should be of big concern as cultivation of food crops may bring problems with health of people living there. Higher content of strontium in low layers of some soils may be explained at least by two obvious factors. Firstly, it may be caused by downward movement of strontium in sandy soils during rainy season. Sandy soils with low content of clay and silt and, as consequence, with low CEC are not able to hold basic elements in upper layers of soil. Wind-translocation of weathered material from northern part of the country (Tibetsy area) is the second factor. That area is rich in strontium-containing material originated from ocean deposits of Pleistocene period. Lowest layers of soil may be formed from sandy deposits brought by the North-West wind centuries before, whereas upper layers of soils have been formed later from sand and dust delivered by wind from other directions.

Russian researchers have accumulated much information on nature of strontium content in soils and biological tissues, its mobility in different conditions, and its influence on health of people. They classified soils on basis of strontium content and established level of Ca/Sr ratioin soils which may be dangerous for human being, and find the way for soil remediation. Moreover, on basis of this data a special State regulation has been adopted which classifies soils and water on basis of strontium content. Having this information we are trying to evaluate data obtained on strontium content in sandy soils of the province Moundou in Chad.

It has been found, that mobility of strontium depends highlyon mass or atomic Ca/Sr ratio [1, 3, 5, 6, 10].Value of these ratios matters for assessment of strontium status of the soils, and this value have been used in Russia for classifying soils and drinkable water usability. For example, water which contains more than 7 mg of water soluble strontium per one liter is not portable, and not to be used in kitchen [1, 11]. Soils which have very low ratio total amount of Ca and Sr are not to be used for production of food crops. In Russia and Ukraine it has been approved that soils which have Ca/Sr ratio of extractable form is less than 140 are not suitable for agricultural production [5, 11, 13]. The reason is much recognized: such levels of strontium in water and wide ratio Ca/Sr may cause Kashin-Beck disease, osteoarthritis, 'strontium-caused rachitis', other physiological abnormalities [3, 4, 8, 10, 12, 14]. It is accepted that these diseases are a consequence of misbalance between Ca and Sr in water and food diet, that causes displacement of Ca by Sr [2, 10, 12, 14, 15].

Very high total content of strontium in sandy soils may be the cause of exhaustible supply of it by winds and floods. Furthermore, its mobility in sandy soils is very high. Strontium translocation along the soil profile and sorption of this element by soil depend on prevailing chemical composition of soil salts (sulphate, carbonate, chloride, and phosphate; OM, clay and silt content). All these factors suggest possible measures of soil remediation. Such measures may include enrichment of soil with organic material [5, 6, 9], use of phosphate fertilizers [3, 6, 9, 10]. These measures may reduce transfer factor of strontium from 0.2...0.3 to as low as 0.01...0.008 [5, 16, 17].

CONCLUSIONS

Vast majority of soils in Moundou province in Chad pertain to light sandy Arenosols, Ferralsols, and Fluvisols, which are of low fertility. Some soils have high content of strontium and calcium due to their formation from wind-brought materials originated from ocean deposits of Pleistocene period. Such soils have mostly low Ca/Sr ratio what may cause higher translocation of strontium from soil to plant and ground water, and consequently to human nutrition chain.

Future many-side and versatile research in Chad is needed to establish correlation between strontium content in soils, rate of transfer of this element to plant produce, and frequency and severity of diseases thought to be caused by high accumulation of strontium in human body.

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СОДЕРЖАНИЕ СТРОНЦИЯ В ПЕСЧАНЫХ ПОЧВАХ ЮЖНОЙ ПРОВИНЦИИ ЧАДА

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Почвы южной провинции Чада сформированы на вековых наносах песка, привнесенного из пустынной северной части страны — Сахели, и на отложения двух основных рек Чада — Логон и Чари. Эта провинция является основной сельскохозяйственной зоной Чада. Оценка физических и химических свойств отдельных образцов почв этой провинции выявила очень высокое содержание стронция в некоторых из них. С целью локализации мест с высоким содержанием стронция в почве и изучения зависимости распределения этого элемента в профиле почв было открыто 9 почвенных разрезов на различных полях, интенсивно используемых в сельском хозяйстве. Данные анализов почв, полученные с использованием рентгеновского спектрометра и радиометра, свидетельствуют о широком варьировании содержания стронция в почвенных образцах от 10 до 270 мг/кг в зависимости от типа почв, глубины почвенного слоя, содержания глины и органического вещества. Содержание стронция отрицательно коррелировало с общим количеством кальция и фосфора в почвенных образцах. Низкий уровень катионного обмена в верхних слоях почвы может быть одной из причин перемещения стронция из верхних горизонтов в нижние. Содержание стронция в почвах не зависело от уровня общей радиоактивности изучаемых почв. Наиболее высокое содержание стронция было выявлено на почвах, сформированных на аллювиальных отложениях. Сделано предположение, что очень широкое отношение Ca/Sr в образцах гидроморфных почв может быть причиной повышенного содержания стронция в растительных продуктах и питьевой воде. Это может быть одним факторов, прямо или косвенно вызывающим дисбаланс в минеральном питании, вызывающим тяжелые заболевания человека. Сделан вывод о необходимости дальнейшего изучения динамики стронциях в почвах, используемых в различных системах земледелия, и снижения отрицательного эффекта естественного загрязнения почв этим элементом.

Ключевые слова: стронций, отношение Ca/Sr, песчаные почвы, ветровые и аллювиальные отложения, болезнь Кашина, остеоартрит

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