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Nitrogen concentration in raw plant material of previous crops in winter wheat (*Triticum aestivum)* rotation in the Western Caspian strip

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ABSTRACT

Nitrogen management is a challenging task and several methods individually and in combination are in use to manage, nevertheless, nitrogen use efficiency has not been ameliorated to a level as predicted by the researchers while developing nitrogen management tools and methods. The experiments were carried out from 2012 to 2014 on meadow-chestnut heavy loamy soil at "Bikesha" farm in Tarumovsky district of the Republic of Dagestan, Russia to study the influence of previous crops which include winter wheat for green manure and fodder production, row crops and alfalfa on the winter wheat. Six treatments used in the experiment were winter wheat-three years without rotation, winter wheat-two years without rotation + natural phytocenosis for green fertilizer, winter wheat-two years without rotation + natural phytocenosis for fodder production, corn for grain, sunflower for seeds and alfalfa for hay. Nitrogen concentration in the phytomass during harvesting of precursors was determined before ploughing and mowing the natural phytocenosis for fodder production. The results showed that the maximum content of plant material in soil (25.82 t/ha), the highest nitrogen concentration (2.18 to 3.32 %) and higher productivity of winter wheat (4.67 t/ha) were demonstrated when the previous crop was alfalfa and natural phytocenosis. These findings can be used to design crop rotations enriched with the main food crop of up to 80 to 100% without compromising crop yields and soil fertility in small farms, which have a small set of crops, as well as insufficient material and technical resources.

Key words : Crop rotation, plant analysis, residual nitrogen, winter wheat

INTRODUCTION

More than 50% of land in the Western Caspian field rotation is occupied by winter wheat (*Triticum aestivum*). Alfalfa (*Medicago sativa)* occupies half of the remaining land and the rest part is under corn for grain and sunflower for seeds. The climatic conditions of the region are favorable for obtaining a second crop of forage for silage and fodder after harvesting winter wheat or barley (Pliushchikov *et al.*, 2019). In the past 70-80 years of the last century, like in the adjacent regions of the North Caucasus and the Lower Volga region, more than 30 t/ha of silage and green mass of corn, sugar sorghum and their mixtures between themselves and sunflower, Sudan grass have been yielded (Gavrilov and Filin, 1990). With crop sowing, it was possible to obtain about 2 t/ha of spring wheat and millet grain, and 3 t/ha of early ripening maize hybrids (Shakouri *et al.*, 2012). Unfortunately, now agricultural enterprises do not have the ability (financial, material and technical) even to have one crop a year (Zargar *et al.*, 2019a). In Dagestan, annually hundred-thousand hectares of irrigated arable land are un-cultivated (Zargar *et al.*, 2019b). The crop season is used only to prepare the soil for next year's harvest and to control weeds, which have remained undetermined over many years.

Several researchers (Hasanov and Arslanov, 2016; Hasanov and Arslanov, 2017) considered that the solution is to provide the opportunity for weed-field vegetation to function in the crop season and even cause an intensification of this process by irrigation. It means allowing the natural phytocenosis after

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harvesting winter wheat, cultivating it until the phase of milk or milk-wax ripening of the dominant weeds (when the maximum phytomass yield is accumulated) and thereafter to plough them for making green fertilizer (Bai *et al.*, 2013; Pal *et al.*, 2018; Xu *et al.*, 2020). The authors, mentioned above, received in the range of 16.8 to 19.7 t/ha of green mass, ploughing of which as fertilizer improved soil fertility and contributed to an increase in winter wheat productivity (Zargar and Pakina, 2014). The yield of the natural phytocenosis was 10 to 12 t/ha less than that of corn and its mixtures with pea, but this way seams more advantageous economically, because there are no additional costs for technical operation and buying seed (Koffi *et al.*, 2016; Zargar *et al.*, 2017). However, the questions on how to use the crop of the natural phytocenosis for green fertilizer or for fodder production remained unexplored so far in comparison with the three-year-long permanent crops of winter wheat and with the other most common predecessors of winter wheat: alfalfa for hay, corn for grain and sunflower for seeds. All crops need nitrogen for the production of active canopy, whose functionality will influence yield. Cereal crops also need nitrogen for storage proteins in the grain, a significant quality attribute (Bai *et al.*, 2013; Hawkesford, 2014). Applying little or no fertilizer and harvesting of crops leads to depletion of soil nitrogen reserves and deterioration of soil quality. Yields in such circumstances are clearly not sustainable (Hawkesford, 2014; Xu *et al.*, 2020). Thus, particular attention must be paid to nitrogen concentration and reserves in the phytomass of the listed precursors of winter wheat, since only on the basis of these data can a crop fertilizer system be developed in field crop rotation. Therefore, this study was conducted with an objective to determine the concentration and reserves of nitrogen in the phytomass of winter wheat precursors and their role in the formation of winter wheat productivity on meadow-chestnut heavy loamy soil of the Western Caspian.

MATERIALS AND METHODS

Site Description and Soil

The field research was conducted during 2012 to 2014 in “Bikesh”, Tarumovsky region of the Dagestan Republic, Russia. The research station is located at 41°58′ N, 47°28′ E and 130 m altitude above sea-level. The soil of the experimental field was loamy sand (fine-loamy, thermic Typic Kandiudults) with pH 6.2 and organic matter 1.6%.

Experimental Design and Treatments

The experiment was laid out in randomized block design (RBD) replicated four times for six treatments: winter wheat-three years without rotation, winter wheat-two years without rotation + natural phytocenosis for green fertilizer, winter wheat-two years without rotation + natural phytocenosis for fodder production, corn for grain, sunflower for seeds and alfalfa for hay. The area of the experimental plot was 100 m^2. Cultivars used in the experiment as per the recommendation for the region *viz.*, ‘Thunder’ of winter wheat, ‘Kizlyar blue-hybrid’ of Alfalfa, ‘hybrid ROSS-299’ of corn and ‘grade VNIIMK-100’ of sunflower.

Nitrogen concentration in the phytomass during harvesting of precursors were determined, as well as before ploughing and mowing the natural phytocenosis for fodder production *viz.,* ashing was carried out with concentrated H_2SO_4, together with hydrogen peroxide, releasing ammonia from ammonium sulfate with 40% NaOH solution and in a receiver titrated with H_2SO_4 (Hasanov and Arslanov, 2017). The content of phosphates and exchangeable potassium in the soil was determined according to Machigin’s method in the modification of CINAO (GOST 26205-91, 2019).

The total nitrogen content in plants was determined according to GOST 26205-91 (2019). Methods for determining the content of nitrogen and crude protein, which is based on the decomposition of the organic matter of the sample by boiling concentrated sulfuric acid with the formation of ammonium salts, the conversion of ammonium into ammonia, its distillation into an acid solution, the quantification of ammonia by the titrimetric method and the calculation of the nitrogen content in the test material.

Winter wheat was harvested in the first fortnight of July, other predecessors of winter wheat including sunflower was harvested in the first fortnight of August and alfalfa and corn for grain were harvested in the second fortnight of August. The irrigation was supplied as per the norms with 1000 m^3/ha of water once a week.

Soil cultivation after harvesting the precursors of winter wheat was carried out (except treatment plots 2 and 3) according to a semi-steam system, which consisted of stubble cultivation with heavy disc harrows BDT-7, ploughing to a depth of 20 to 22cm with a PN-4-35 plough, leveling the surface of the field with a small - leveler MV-6 with subsequent irrigation. Before sowing, the field was harrowed with heavy tooth harrows BZST-1 (coupled) along and across the field. Harvesting of phytomass of weed-field vegetation was mowed for fodder (treatment plot 3), ploughing of phytomass for green fertilizer (treatment plot 2) was carried out simultaneously in the first ten days of October, coinciding with the subsequent leveling off the field surface and pre-sowing harrows to the date of carrying out the same procedure with soil after alfalfa, row crops and in the control plot.

Data analysis

Statistical data analyses of winter wheat yield were carried out by the dispersion method; the average error, standard deviation (S) and coefficient of variation (V) were calculated from the nitrogen concentration in plants (Armor, 1985). The multiple regression equation was calculated based on the phytomass accumulation of the precursors inalienable from the soil, the nitrogen reserves in it and wheat yield.

RESULTS AND DISCUSSION

Results indicated that the higher concentration of total nitrogen was observed in sunflower seeds. In wheat grain it diminished by 1.9 to 2.1 times and in corn by 2.5 times compared to their content in oilseeds (Table 1). The nitrogen regime of the soil, the concentration and accumulation of this nutrient in plants was mostly determined by the species composition of phytocenosis (Mafakheri *et al.*, 2012). The precursors of winter wheat differed in many indicators of the concentration and reserves of nitrogen in the crop (Zhao *et al.*, 2003; Hasanov and Arslanov, 2016). Legumes utilize atmospheric nitrogen and assimilate in plants by a symbiotic way in the generative organs than in the leaf-stem or in the roots (Trepachev, 1999; Bayat and Zargar, 2020).

For other plant material, most of the nitrogen was concentrated in the straw of the precursors (about 0.70%). This indicator reduced 0.61% in the cut-off residues of winter wheat and corn but was inferior to the concentration in the residues of sunflower and alfalfa with 2.2% and 3.5%, respectively. This fact can be stated by the presence of this mass not only in the lower parts of the plant stems, but also in leaves (Hawkesford, 2014), which lost contact with the plants and replenished mineral content of the soil surface after drying (Xu *et al.*, 2020). This is especially true for alfalfa, since the loss of leaf apparatus was observed during the growing season and harvesting (Li *et al.*, 2017).

The nitrogen concentration in the phytomass of the natural phytocenosis was 2.5 times higher than in the straw of the other precursors. The same indicator in the root mass was comparable with the indicator obtained for corn, exceeding the values for winter wheat by 1.2 times, but less than for alfalfa by 4.1 times. This indicated the decrease of 16.3 and 19.8% of the non-alienable part of the phytomass of corn and sunflower, respectively compared to the control (Table 2). The main source for replenishing nitrogen reserves in the soil was cultivation of alfalfa in field crop rotation as a precursor to winter wheat (Table 2).

The soil significantly received greater nitrogen when alfalfa was cultivated compared to winter wheat for three years of permanent cultivation. In this study, it was impossible to place winter wheat after alfalfa in the field crop rotations annually, because in order to do this, it would be needed to reduce the area under the main grain crop by at least two times, and accordingly, increase the amount of alfalfa in the crop rotation. However, the best way to enhance the nitrogen reserves in the soil under these conditions was to create the possibility of weed - field vegetation in the crop season due to irrigation after harvesting winter wheat (Diaz and Rosenberg, 2008; Bayat *et al.,* 2019; Xu *et al.*, 2020).

The reduction in nitrogen reserves entering the soil after row crops predecessors also affected the content of this and other nutrients in the arable layer of the soil (Table 3). The methods of tillage after harvesting

Table 1. Nitrogen concentration (%) in aboveground and underground plant mass of winter wheat (mean of 2012-2014)

Production	Previous crop																	
	1			2			3			4			5			6		
	M±m	S	V (%)	M±m	S	V (%)	M±m	S	V (%)	M±m	S	V (%)	M±m	S	V (%)	M±m	S	V (%)
Main crop																		
Main	1.48±0.17	0.37	1.30	1.61±0.21	0.48	1.68	1.55±0.42	0.94	3.31	1.28±0.35	0.78	2.87	3.14±0.45	1.0	2.06	2.18±0.38	0.84	3.32
Additional	0,65±0,14	0.31	6.42	0.72±0.09	0.2	4.49	0.69±0.11	0.24	5.27	0.74±0.12	0.23	5.58	0.72±0.09	0.2	5.09	0.0	0.0	0.0
Crop residues	0,52±0,22	0.48	615	0.66±0.11	0.24	3.07	0.56±0.11	0.23	3.25	0.70±0.09	0.21	3.21	1.36±0.04	0.22	3.79	2.11±0.37	0.83	7.96
Root residues	0,40±0,09	0.2	384	0.43±0.20	0.45	8.65	0.41±0.11	0.25	4.79	0.56±0.14	0.32	5.39	0.74±0.08	0.17	3.00	2.24±0.33	0.73	2.73
Crop culture (natural phytocenosis)																		
Phytomass (hay)	0	0	0	1.74±0.07	0.15	1.86	1.75±0.08	0.17	2.11	0	0	0	0	0	0	0	0	0
Crop residues	0	0	0	1.45±0.08	0.18	7.63	1.45±0.08	0.18	7.96	0	0	0	0	0	0	0	0	0
Root residues	0	0	0	0.51±0.07	0.17	6.91	0.52±0.09	0.19	7.54	0	0	0	0	0	0	0	0	0

1 : Winter wheat - three years without rotation; 2 : Winter wheat - two years without rotation+natural phytocenosis for green fertilizer; 3 : Winter wheat - two years without rotation + natural phytocenosis for fodder production; 4 : Corn for grain; 5 : Sunflower for seeds and 6 : Alfalfa on the hay.

Table 2. Accumulation of aboveground and underground plant mass (kg/ha) by the predecessors of winter wheat and nitrogen content (mean of 2012-2014)

Previous crop	Main crop					Natural phytocenosis				Total	Including not alienated from the soil	
	Grain	Straw/leaf mass, hay	Phytomass		Total	Green mass	Residues		Total		t/ha	% to control
			Crop residues	Root residues			Crop	Root				
Phytomass accumulation, t/ha												
1-control	3.15	2.21	0.86	3.18	9.40	0.0	0.0	0.0	0.0	9.40	4.04	100.0
2	3.20	2.24	0.85	3.02	9.31	1.88	0.68	3.19	5.75	15.06	9.62	238.1
3	3.17	2.19	0.86	3.12	9.34	1.87	0.66	3.22	5.75	15.09	7.86	194.6
4	5.67	11.15	0.82	2.56	20.20	0.0	0.0	0.0	0.0	20.20	3.38	83.7
5	2.25	5.46	0.80	2.48	11.99	0.0	0.0	0.0	0.0	11.99	3.28	81.2
6	0.0	10.87	3.60	11.35	25.82	0.0	0.0	0.0	0.0	25.82	14.95	370.05
Amount of nitrogen, kg/ha												
1-control	46.62	14.36	4.47	12.72	78.17	0	0	0	0	78.17	17.19	100.0
2	51.52	16.13	5.61	12.99	86.25	32.71	9.86	16.27	58.84	145.09	77.44	450.5
3	49.14	15.11	4.82	12.79	81.6	32.72	9.57	16.74	59.03	140.19	43.92	255.5
4	72.58	82.51	4.59	14.34	174.02	0	0	0	0	174.02	18.93	110.1
5	70.65	39.31	10.88	18.35	139.19	0	0	0	0	139.19	29.23	170.6
6	0.0	236.97	75.96	250.84	563.77	0	0	0	0	563.77	326.80	1901.1

1 : Winter wheat - three years without rotation; 2 : Winter wheat - two years without rotation + natural phytocenosis for green fertilizer; 3 : Winter wheat - two years without rotation + natural phytocenosis for fodder production; 4 : Corn for grain; 5 : Sunflower for seeds and 6 : Alfalfa on the hay.

winter wheat contributed to an increase in the content of this element in the soil by 1.6 times compared to the control plots. These findings are in agreement with those results achieved by Xu *et al.* (2020). By the phase of the release of winter wheat into the tube, the nitrogen content in the soil diminished on average for all predecessors by 6.1%, which was associated with the use of plants by it for crop formation (Zhao *et al.*, 2003; Ma *et al.*, 2015; Chien *et al.*, 2016; Garakishi, 2020). But in this case, hydrolysable nitrogen in the soil under winter wheat and alfalfa remained 41.5% higher than control plots. The content of P_2O_5 and K_2O in the soil under winter wheat was higher in alfalfa, hay and natural phytocenosis for green

Table 3. Content of nutrients (mg/kg) in the arable soil layer after harvesting the predecessor and under winter wheat (mean of 2012-2014)

Previous crops	Nutrients	After harvesting previous crop	During winter wheat planting	In the stage of exit of winter wheat into the tube	± to initial
1	N	26.5	42.5	36.9	+10.4
	P2O5	18.4	20.5	19.6	+1.2
	K2O	281	345	329	+48
2	N	25.5	45.8	41.2	+6.7
	P2O5	19.2	21.6	21.3	+2.1
	K2O	322	375	360	+38
3	N6	26.1	41.6	35.4	+9.3
	P2O5	17.6	18.2	17.7	+0.1
	K2O	318	352	344	+26
4	N	22.8	36.9	33.2	+10.4
	P2O5	15.6	15.6	15.6	0.0
	K2O	320	340	320	0.0
5	N	20.3	38.0	32.1	+11.8
	P2O5	15.2	16.6	15.4	+0.2
	K2O	308	332	324	+16
6	N	31.8	56.9	52.2	+20.4
	P2O5	25.6	23.8	26.5	+0.9
	K2O	342	384	356	+14

1 : Winter wheat - three years without rotation; 2 : Winter wheat - two years without rotation + natural phytocenosis for green fertilizer; 3 : Winter wheat - two years without rotation + natural phytocenosis for fodder production; 4 : Corn for grain; 5 : Sunflower for seeds and 6 : Alfalfa on the hay.

Table 4. Influence of previous crop on the grain yield (t/ha) of winter wheat (mean of 2012-2014)

Previous crops	2012	2013	2014	Average	% to control
1	3.23	3.04	3.27	3.18	100.0
2	3.85	3.77	3.98	3.87	112.6
3	3.40	3.36	3.58	3.45	108.5
4	2.45	2.28	2.59	2.47	77.7
5	2.58	2.42	2.73	2.58	81.1
6	4.55	4.68	4.77	4.67	146.9
$LSD_{0.05}$	0.12	0.18	0.22	-	-

1 : Winter wheat - three years without rotation; 2 : Winter wheat - two years without rotation+natural phytocenosis for green fertilizer; 3 : Winter wheat - two years without rotation + natural phytocenosis for fodder production; 4 : Corn for grain; 5 : Sunflower for seeds and 6 : Alfalfa on the hay.

manure when the plants enter the tube by 8.7 and 35.2% and 4.6 and 8.2%, respectively.

The optimization of the nitrogen regime of the soil observed in the case of an enhance in the precursor phytomass inalienable from the soil, which contributed to an increase in the yield of winter wheat compared to three-years permanent crops when the crop season was used to grow the natural phytocenosis for fodder production by 8.5% and for green manure by 12.6% (Table 4). When winter wheat was sown after alfalfa, its productivity increased by 1.5 times compared to control, and sowing after corn for grain leads to a loss of 22.3%, and sunflower seed production leads to a loss of 18.9% compared to the control plots. These data indicated the inappropriate placement of winter wheat in field crop rotations after late harvested row crops, as it was also obvious in the study of Ma *et al.* (2015). In field crop rotation of Dagestan region, where winter wheat occupies more than 60% of the area, it was possible to place it on alfalfa in only one field and this was just 10 to 12.5% of the crop rotation area (Hasanov and Arslanov, 2017).

This research was devoted to improve the composition of the predecessors, that is the capabilities of the same predecessor (winter wheat for two years' constant cultivation), for additional accumulation of green mass of 16.8 to 19.7 t/ha per unit area. It was adequate to perform one irrigation after harvesting wheat using the existing irrigation network. Thus, the crop-based natural phytocenosis for green fertilizer should be considered as an independent precursor, which in its efficiency in the accumulation of organic matter and nitrogen reserves in the soil. This principle of using winter wheat in crop rotation opens up great opportunities for designing in the areas of irrigated agriculture in the Western Caspian (Hasanov and Arslanov, 2017) possibly for irrigated areas of the entire South of Russia.

CONCLUSION

The most significant reserve for optimizing the area of winter wheat in rotation of the region was to use the crop season after harvesting winter wheat to form a phytomass crop by supplying irrigation, and to use the resulting crop as green fertilizer. This allows to accumulate favorable plant material in the soil, with a favorable concentration of nitrogen. These results can be performed to design crop rotations enriched with the main food crop of up to 80 to 100% without compromising crop yields and soil fertility in small farms, which have a small set of crops as well as inadequate material and technical resources.

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