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ASSESSMENT OF SOIL BULK DENSITY AND MOISTURE CONTENT OF LIGHT-GRAY-BROWN ARABLE SOILS AT THE RAINFED CONDITION

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ОЦЕНКА ПОКАЗАТЕЛЕЙ ПЛОТНОСТИ И ВЛАЖНОСТИ СВЕТЛО-СЕРО-КОРИЧНЕВЫХ ПОЧВ В БОГАРНЫХ УСЛОВИЯХ

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Abstract. The article discusses the effects of different tillage methods, predecessors, and mineral fertilizers on the soil bulk density and soil moisture content of light-gray-brown soils at the rainfed condition. The results of the research conducted during the years 2014-2017 under cereal crops reveal that the soil bulk density and soil moisture content exhibit dynamic changes within the vegetation period, depending on the tillage method, the growth stages of the crops and other factor. Furthermore, there is differentiation in the moisture content and soil bulk density between the topsoil and the subsoil layer. During the research period moisture content varies depending on precipitation, crop growth stages, predecessors. Optimum moisture level is observed within periods of relatively higher precipitation and intensive growth stage of crops. Soil bulk density has varied within the range of 0.97-1.53 g/cm³. Favorable physical condition has been observed under the conventional and minimum tillage. Based on the research findings, the bulk density and moisture content of light-gray-brown arable soils can be assessed satisfactory through relevant quantitative indicators.

Аннотация. В статье приведена информация о влиянии способов обработки, предшественника и минеральных удобрений на плотность и влажность почвы в богарных условиях. Результаты исследований, проведенных в период с 2014 по 2017 год, показывают, что плотность и влажность почвы в зависимости от предшественников, способов обработки, фаз развития растений и других факторов имеют внутривегетационную динамику. В течение исследования влажность почвы в основном менялась в зависимости от количества выпавших осадков, фаз развития растений и предшественников, а оптимальные значения влажности почвы совпадали с периодами сравнительно большего количества осадков и интенсивной фазы развития растений. Плотность почвы варьировала в интервале от 0,97 до 1,53 г/см³, высокие значения плотности были отмечены в подпахотном слое, а относительно низкие значения в пахотном слое почвы. Благоприятные физические условия наблюдались при традиционных и минимальных обработках. По результатам исследований показатели плотности и влажности светло-серо-коричневых пахотных почв в богарных условиях можно оценить «удовлетворительно» по существующим агрофизическим градациям.

Keywords: soil moisture, soil density, cultivation methods.

Ключевые слова: влажность почвы, плотность почвы, метод обработки.

Introduction

The conservation and efficient management of soil fertility are essential for sustainable agriculture and food security. In this regard, the assessment of agrophysical condition of arable soils contribute to the determination of soil fertility levels, proper soil management practices, restoration of the natural balance in the soil-ecological environment and increasing the agricultural productivity. Studying the agrophysical properties of the soil allows for improving soil fertility and productivity, as well as ensuring the optimum ratio of its phases and components [1–3]. The agrophysical properties of the soil vary depending on fertility, cover crop, predecessor, fertilization, soil-climatic conditions, and other factors. When agrotechnical measures are not applied based on scientific principles during soil cultivation, the influence of natural and anthropogenic factors can lead to soil degradation, the rate of soil degradation in most cases slows down or exceeds the self-recovery process of the soil. Therefore, the assessment of the existing agrophysical condition of the soil is of crucial importance in preventing soil degradation, reducing its intensity, and ensuring purposeful management of soil fertility.

It is known that soil density is considered an important indicator that affects the quality of agricultural lands. Studies show that increasing soil bulk density leads to a decrease in soil porosity, which in turn leads to compaction, which affects plant growth [4, 5]. Moreover, one of the dynamic agrophysical characteristics of the soil is the soil moisture content which plays a crucial role in satisfying the water demand of agricultural crops. Particularly, under rainfed conditions, soil moisture content is considered the main source of water for crops.

The aim of study was to evaluate the soil bulk density and moisture content of light-gray-brown soils under winter wheat crops and rainfed conditions in Mountain Shirvan, considering the agrotechnical applications (tillage methods, predecessors, fertilization) and to study the dynamics of these soil characteristics during the vegetation period depending on climatic conditions.

Materials and Methods

The research was conducted from 2014 to 2017 in agrocenosis of wheat field in the Gobustan regional experimental station of the Research Institute of Crop Husbandry under the rainfed condition of Mountain Shirvan. The experiments were carried out on light-gray-brown (chestnut) heavy loamy, light and medium clay soils. The average annual rainfall measures in the region are mainly 250-400 mm. The research areas were located at an altitude of 734-837 meters above sea level (N40031.456′, E48053.488′ - N40031.193′, E48053.738′).

According to the data of the Gobustan meteorological station, 263.9 mm of precipitation fell in the research areas during the growing season of wheat crops in 2014-2015, 391.9 mm in 2015-2016, and 453.8 mm in 2016-2017. 2014-2015 was unfavorable compared to the long-term average (399 mm), and 2016-2017 was slightly favorable (Table 1).

For agrophysical analyses, soil samples were taken from the topsoil (10-15 cm) and subsoil (35-40 cm) layers 3-5 times during vegetation period by using soil auger at the different wheat crops growth stages (immediately after sowing, tillering, stem elongation, heading, and ripening) under different tillage methods (conventional, minimum, no-tillage) which differed according to the fertilizer rate and predecessors (wheat, barley, field pea, fallow).

In 2014-2015, the experimental options have been differed according to the predecessor and tillage methods ($T_1(2)$ + T_c — predecessor barley + conventional tillage; T_2 + T_3 + T_4 — predecessor fallow; T_1 + T_3 — predecessor barley + minimum tillage.

In 2015-2016, options have been differed according to the tillage methods (conventional, minimum, no-tillage) and fertilizer rates (treatment with application nitroammophoska — NPK-18% and treatment without any fertilizer).

In 2016-2017, the experimental options differed from their predecessors by being cultivated with agrotechnical methods recommended for that region.

Table 1

CLIMATIC DATA OF THE AREA DURING 2014-2017 years
(Data from Gobustan meteorological station)

Month	*2014-2015*		*2015-2016*		*2016-2017*		*Long-term average precipitation and temperature*	
	P, mm	*T, °C*	*P, mm*	*T, °C*	*P, mm*	*T, °C*	*P, mm*	*T, °C*
September	24.2	19.0	26.2	19.7	71.3	17.3	31	17.1
October	36.8	9.8	78.6	11.0	50.2	12.3	45	11.2
November	54.5	4.4	21.5	5.8	19.6	3.9	36	6.0
December	23.7	2.9	18.6	2.2	35.8	−0.9	30	2.0
January	15.6	0.1	52.3	2.1	9.2	0.9	26	-0.2
February	19.6	2.1	12.3	4.2	17.1	1.2	35	0.1
March	42.6	3.7	72.7	5.6	27.6	5.6	42	3.1
April	27.6	8.6	56.4	10.5	21.5	9.5	47	9.2
May	16.4	15.7	27.8	15.9	72.3	19.3	47	14.9
June	1.1	24.6	20.2	21.3	129.2	19.8	40	19.5
Jule	1.8	24.7	5.3	23.5	0.0	24.7	14	22.6
August	4.9	24.0	0.0	25.1	0.0	25.0	13	22.0
Total	268.8		391.9		453.8		406.0	

Note: P — monthly precipitation amount, T — average monthly temperature

Standard agrophysical methods [6, 7] were used to assess soil bulk density and moisture content. Statistical analysis of the results was carried out using statistical methods applied in soil science [8] through the Minitab Release 14 software package [9], the parameters were evaluated at the 5% level of significance.

Results and Discussion

One of the effective methods for obtaining information about the agrophysical condition of cultivated soils is to compare the actual and optimal values of the diagnostic physical properties of the soils. The results of the statistical analysis (RJ-test) indicate that the distribution of agrophysical properties mostly follow a normal distribution. The normal distribution allows for comparative analysis of the mean values of the determined parameters.

The results of the conducted research show that, overall, during the years 2014-2017, the coefficient of variation (CV, %) for agrophysical properties varied within the following ranges: in the topsoil layer — W: 2.1-23.1%, ρ_b: 3.5-18.5%; in the subsoil layer — W: 1.3-31.2%, ρ_b: 2.1-13.3%. Based on the values of the coefficient of variation, it is observed that the agrophysical parameters of the soil in the research areas showed weak to moderate variability. The investigated parameters' dynamic variability during the vegetation period has been presented in tables (Tables 2–4).

As can be seen from the tables, during the study, the values of soil moisture content vary according to different options and depths following certain regularities. By paying attention to the distribution tendency of precipitation and temperature during the vegetation period (Table 1), it becomes evident that the values of soil moisture content are more influenced by climatic conditions.

Overall, the mean values of soil moisture content do not differ significantly among different tillage methods. However, a sharp dynamic variation in soil moisture content during the vegetation period of wheat crops is observed. High values of soil moisture content occur during periods of low temperature and high precipitation, while low values are observed during periods of high temperature and low precipitation. The values of soil moisture content in both the topsoil and subsoil layers decrease from the beginning to the end of the vegetation period in all research options. This can be attributed, on one hand, to reduced precipitation, and on the other hand, to the increased water demand of the wheat crops during its intensive growth stage.

Table 2

MEAN VALUES OF SOIL BULK DENSITY AND MOISTURE CONTENT (2014-2015)

Parameter	*Depth, cm*	$\overline{X}$					
		t_1	t_2	t_3	t_4	t_5	t_6
		T_1 (2)+T_c					
W	10-15	23.5±0.7	24.1±0.7	17.9±0.5	14.2±0.3	7.4±0.6	5.0±0.2
	35-40	11.2±0.4	20.8±0.5	18.0±1.8*	13.6±0.9*	10.2±0.6*	10.3±0.1
ρ_b	10-15	1.18±0.05	1.35±0.02	1.43±0.03	1.36±0.04	1.34±0.06	1.33±0.05
	35-40	1.46±0.04	1.41±0.0.4	1.49±0.05	1.45±0.03	1.32±0.03	1.40±0.9
		T_2+T_3+T_4					
W	10-15	25.1±0.5	26.1±0.6	17.7±1.4	15.3±1.4	7.8±0.5	5.3±0.2
	35-40	19.3±1.0	23.6±0.5	20.1±0.8	17.0±1.0	15.0±0.2	12.1±0.3
ρ_b	10-15	1.20±0.04	1.26±0.03	1.38±0.06*	1.37±0.03	1.34±0.04	1.42±0.05
	35-40	1.38±0.03	1.34±0.03	1.42±0.05	1.38±0.04	1.40±0.04	1.43±0.03*
		T_1+T_3					
W	10-15	25.0±0.2*	25.8±0.6	17.3±0.6	14.4±0.3	8.4±0.3	5.1±0.1
	35-40	15.8±1.6*	23.9±0.3	18.3±0.9	15.6±0.5	13.1±0.4	11.4±0.2*
ρ_b	10-15	0.97±0.04	1.12±0.03	1.18±0.04	1.23±0.06	1.35±0.05	1.37±0.04
	35-40	1.37±0.3	1.39±0.01	1.37±0.03*	1.38±0.03	1.43±0.03	1.40±0.03*

Note. W — soil moisture content (%), ρ_b — soil bulk density (g/cm^3), t_1 — immediately after sowing (11.11.14), t_2 — tillering (27.03.15), t_3 — stem elongation (01.05.15), t_4 — heading (27.05.15), t_5 — ripening stage (22.06.15), t_6 — 1.5 months after harvest (21.08.15), T_1 — disking at a depth of 5-8 cm, T_2 — plowing at a depth of 25-27 cm, T_3 — disking at a depth of 7-10 cm, T_4 — cultivation at a depth of 7-10 cm, T_c — conventional tillage at a depth of 20-22 cm, $\overline{X}$ — mean value, * — distribution is not normal

During all three years of the research, in all options, high values of soil moisture content were observed in the topsoil layer at the beginning of the vegetation period and towards the end of the vegetation period, these high values were recorded in the subsoil layer and the values of soil moisture content in the topsoil and subsoil layers have been differed from each other. The relatively higher amount of precipitation in autumn and spring have created conditions for higher soil moisture content in the topsoil layer during the vegetation period. Towards the end of the vegetation period, although the soil moisture content in the topsoil layer was characterized by lower values due to reduced rainfall, the subsoil layer retained and maintained higher moisture content values compared to the topsoil layer. It can be seen from the results of the study that the soil moisture level in rainfed condition mainly depends on the climatic conditions, including the amount of precipitation (Tables 1–4).

Table 3

MEAN VALUES OF SOIL BULK DENSITY AND MOISTURE CONTENT (2015-2016)

Fertilizer treatment	*Parameter*	*Depth, cm*	$\overline{X}$			
			t_1	t_2	t_3	t_4
		T_c				
F_0	W	10-15	25.3±0.9	27.6±0.6	24.7±0.4	10.1±0.3
		35-40	21.1±1.1	25.8±0.6	21.0±0.5	16.9±0.4
F_3		10-15	25.2±0.9	27.5±0.3	20.7±0.6	10.0±0.3
		35-40	16.9±2.4	24.6±0.4	18.8±0.5	13.7±0.5
F_0	ρ_b	10-15	1.19±0.03	0.98±0.02	1.27±0.06	1.30±0.10
		35-40	1.26±0.07	1.24±0.04	1.42±0.03	1.38±0.05
F_3		10-15	1.07±0.06	1.12±0.05	1.13±0.07	1.37±0.04
		35-40	1.37±0.0.2	1.28±0.02	1.37±0.04	1.41±0.01
		T_m				
F_0	W	10-15	24.4±1.4*	28.7±0.7	24.0±1.2	10.2±0.6
		35-40	18.2±0.8	24.5±0.4	22.3±0.4*	16.0±0.3
F_3		10-15	25.0±0.6	27.3±0.4	18.44±0.5	10.0±0.3
		35-40	18.6±1.2	23.7±0.5	17.8±0.7	13.1±0.6
F_0	ρ_b	10-15	1.29±0.06	0.99±0.05	1.37±0.04	1.41±0.04
		35-40	1.44±0.03	1.34±0.04	1.33±0.04*	1.34±0.02
F_3		10-15	1.28±0.03	1.06±0.04	1.39±0.05	1.48±0.03
		35-40	1.49±0.03	1.36±0.05	1.43±0.02	1.44±0.01
		T_0				
F_0	W	10-15	23.6±0.8	28.4±0.6	25.0±0.5	10.7±0.5*
		35-40	17.3±1.3	23.6±0.5	21.5±0.1	16.8±0.9
F_3		10-15	26.4±0.4	25.9±0.8	21.2±0.7	10.4±0.4
		35-40	17.54±1.2	24.7±0.7	19.6±0.5	15.3±0.6
F_0	ρ_b	10-15	1.39±0.03	1.12±0.06	1.39±0.03	1.43±0.06
		35-40	1.41±0.04	1.41±0.04	1.45±0.02*	1.39±0.03
F_3		10-15	1.34±0.04*	1.17±0.09	1.34±0.05	1.53±0.05
		35-40	1.37±0.03	1.34±0.05	1.46±0.03	1.35±0.6

Note. t_1 — immediately after sowing (24.11.14), t_2 — tillering (24.03.15), t_3 — heading (20.05.15), t_4 — ripening stage (14.07.16), T_0 — no-tillage, T_m — minimum tillage (disc plowing at 10-12 cm depth), T_c — conventional tillage (tillage at 20-22 cm depth), F_0 — $N_0P_0K_0$, F_3 — $N_{120}P_{60}K_{60}$, * — distribution is not normal

Thus, towards the end of the vegetation period, the decrease in air temperature and the amount of precipitation causes the soil moisture content to drop to the level of wilting point and after harvesting, the amount of moisture content in the topsoil layer have reached its minimum value (Table 2).

Overall, during the period of the research from 2014 to 2017, the soil moisture content in the topsoil and subsoil layers varied in the range of 7.4% to 28.7% and 10.2% to 25.8%, respectively. Relatively higher values of soil moisture content were observed during the vegetation period, particularly during the tillering and stem elongation stages of wheat crops. In the treatment where the predecessor was fallow, relatively higher values of soil moisture content were observed compared to other options during the years 2014-2015 (Table 2).

In the year 2016-2017, due to relatively favorable conditions during the vegetation period, the soil moisture content in both the topsoil and subsoil layers was characterized by relatively higher values during various growth stages of the wheat crops (Table 4).

Moreover, different options in the research areas showed higher values of soil moisture content corresponding to lower bulk density values. Thus, optimal bulk density values resulted in optimal soil moisture conditions, or vice versa. As seen, soil bulk density and moisture content undergo specific variations during the vegetation period, influenced by various factors such as development stages of wheat crops, experimental options, soil depth, and soil-climate conditions.

Table 4

MEAN VALUES OF SOIL BULK DENSITY AND MOISTURE CONTENT (2016-2017)

Parameter	*Depth, cm*	$\overline{X}$		
		t_1	t_2	t_3
		P_1		
W	10-15	27.8±0.4	20.9±0.6	16.7±0.5
	35-40	22.5±0.4	17.9±0.6*	19.2±0.6
ρ_b	10-15	1.14±0.02	1.17±0.06	1.18±0.05
	35-40	1.39±0.01	1.42±0.02	1.35±0.03
		P_2		
W	10-15	27.6±0.2*	18.8±0.5	15.3±0.9
	35-40	23.3±0.2	16.5±0.5	16.7±0.7
ρ_b	10-15	1.25±0.02	1.35±0.06	1.36±0.07
	35-40	1.36±0.02	1.30±0.01	1.39±0.04
		P_3		
W	10-15	26.8±0.3	19.8±0.2	13.6±0.5
	35-40	24.2±0.4	16.9±0.4*	16.1±0.4
ρ_b	10-15	1.19±0.02	1.20±0.05	1.23±0.02
	35-40	1.39±0.01	1.33±0.02	1.32±0.04

Note. t_1 — stem elongation (13.04.17), t_2 — milky stage (07.06.17), t_3 — ripening phase (15.07.17), P_1 — wheat predecessor, P_2 — fallow predecessor, P_3 — pea predecessor, * — distribution is not normal

It is known that soil the density, considered as one of the fundamental agrophysical parameters of the soil and it is important from the point of view of agriculture. Since the volume of pores occupied by soil air and soil moisture directly depends on the density of the soil, it affects many processes taking place in the soil, the composition, quantity and life activity of microorganisms [1, 3].

Therefore, any changes in soil bulk density can lead to alterations in the soil biota and the ecological functions it performs. The direction and magnitude of such changes depend on factors such as soil type, granulometric composition, tillage method, crop cover, and other factors. Changes in soil bulk density also result in changes in soil porosity and, consequently, in the air and moisture ratios within the soil. As a consequence, the processes occurring in the soil, including the nutrient uptake by wheat crops, are subject to certain changes.

Between 2014 and 2017, the soil bulk density in the topsoil layer of the soil varied within the range of 0.97-1.53 g/cm³, while in the subsoil layer, it ranged from 1.24-1.49 g/cm³. The higher values of soil bulk density, which are the main indicator of soil compaction, were observed under no-tillage and under fallow predecessor. During the research period, the highest bulk density value in the soil was recorded as 1.53 g/cm³ in 2015-2016, under no-tillage with application the fertilizer when wheat was in its total ripening growth stage in the topsoil layer. The soil's density values relatively close to the optimum range were observed under conventional and minimal tillage practices, particularly during the intensive growth stage of the wheat crops. Throughout the research period, higher soil bulk density values were observed in the subsoil layer, while relatively lower values were recorded in the topsoil layer in the research areas.

As indicated by the results of the conducted research, the bulk density and moisture content of the soil layer vary within a wider range, which is related to its sensitivity to cultivation operations and other natural-anthropogenic factors [2]. The observed soil bulk density values of the plow layer in the research area are considered favorable for the wheat crops.

During the research period of 2014-2017 in the Mountain Shirvan region, the results of investigations conducted under rainfed condition revealed that the agrophysical properties of soil, such as moisture content and bulk density, undergo dynamical changes depending on tillage methods, predecessors, cover crop, climatic conditions, growth stages of crops and other factors. Additionally, spatial and temporal variations of agrophysical properties of soil, including differentiation in the topsoil and subsoil layers are observed.

Throughout the research period, soil moisture content varies mainly depending on the amount of precipitation, the growth stage of crops, and the predecessors. During the research period, bulk density of the soil in the topsoil layer varied within the range of 0.97-1.53 g/cm^3.

The higher values were observed under winter wheat crops in 2015-2016 in no-tillage, in 2014-2015 and 2016-2017 in the fallow predecessor. Favorable soil physical conditions were observed in conventional and minimum tillage practices in the research area. Research results have shown that mineral fertilizers have a weak effect on the agrophysical properties of the soil. The evaluation of the agrophysical properties of the light-gray-brown soils shows that the agrophysical condition of the plow layer of the soil in the study area is generally favorable and satisfactory.

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