EVALUATION OF MULCHING TECHNOLOGY APPLICATION FOR CULTIVATION OF AGRICULTURAL CROPS

Sofiya M. Romanova[1], Oksana I. Ponomarenko[1], Ilona V. Matveyeva[1], Luiza K. Beisembayeva[1], Nurgul B. Kazangapova[2], Zulfiya A. Tukenova[3]

[1] *Al-Farabi Kazakh National University, Al-Farabi str. 71/23, A05E3B3, Almaty, Kazakhstan*
E-mail: Sofya.Romanova@kaznu.kz
[2] *Saken Seifullin Kazakh Agrotechnical University, Pobeda str., 62, 010000, Astana, Kazakhstan*
[3] *LLC "Kazakhstan Engineering and Technology University", Al-Farabi str., 93a, 050060, Almaty, Kazakhstan*

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ABSTRACT

One of the ways to solve the problems of increasing soils fertility, maintaining fields' moisture and protection against weed grass refers to the soil mulching using different materials. The effect of transparent and black films as mulching agents of light chestnut soils in comparison to "normal" conditions (in mulching agent absence) on the transformation and the accumulation of the main ions, the values of pH and Eh in the "water-soil" ecosystem is investigated. It is found that the ions of calcium, magnesium, hydrocarbonate are accumulated by plants; the ions of sodium, sulphates and chlorides are concentrated in the soils. The pulp of cucumbers grown on soils under mulch contains also a higher concentrations of phosphorus - 1.4 - 3.6 times greater than that of the control sample (0.04 % - 0.07 %). The highest values are obtained in presence of a black film.

Keywords: mulching, fertility, films, ions, cucumbers.

INTRODUCTION

The problems of increasing of soils fertility, maintaining of moisture in the fields and protection against weed grass have always been and remain relevant to this day. One of the ways recently developed to solve these issues refers to soil mulching (coating) using different materials like straw, paper, plant residues, film materials. This method is of a particular importance in cultivation of irrigated tilled crops because of the increasing deficiency of water resources, especially in arid and semi-arid regions [1 - 2]. The mulching affects the soils water-air-heat systems. After irrigation, the soil water is lost due to root water uptake or evaporation from the soil while most of the salts are left behind [3 - 4]. The plastic mulching decreases the evaporation rate from the soil and, consequently, decreases the soil-water consumption in the root zone [5], decreases the irrigation water consumption and plant vegetation period [6 - 8], increases the temperature of the root layer, decreases the weediness of fields in absence of herbicides and, as a consequence, eliminates the environmental pollution by toxic substances [9, 10]. The mulching material catalyses the biological processes occurring in soil as it provides better excess of the feeding components to the plants [11, 12]. As a result, it increases the plants development and the harvest amount [11 - 13].

The main role in the ecosystem «water-soil-plant» is played by the moisture as it is the linking part of the nutrients supply from the soil to the plants. The quality of the individual soil processing operations depends largely on its physical, mechanical, physicochemical and technological properties, the type and the parameters of the machines and the aggregates used [14]. All the properties of the soil, with exception of its mechanical properties, undergo significant changes due to the weather conditions, the crop change, the crop rotation, the fertilization, and the methods of the previous treatment. This statement is of a particular importance for Kazakhstan, which is located in the zone of a sufficient risk in respect to the precipitation moisture. This is typical for the countries of Central Asia. However, there is practically no reliable information on the effect of film mulching materials on the transformation and accumulation of mineral salts and nutrients in the water-soil-plant ecosystem in view of the local natural climatic conditions.

EXPERIMENTAL

Object description

An experimental field of the stock-farm Aksai of Almaty region (Kazakhstan) was selected as an object of research. It is part of the Zailiyskiy Alatau (N $43^0$13'37.16'', E $76^0$46'34.24''). The experiment lasted from May, 20 to September 10. The field experiment was carried out in three variants in fourfold repetition: the first one served as a control (without a film); the second used a transparent polyethylene film (0.2 mm thick), while the third used a black film of the same thickness. The length of the beds was 50 m, the width was 0.8 m, while the width of the film was 0.9 m. Cucumbers of "Konkurent" sort were chosen. The prepared seeds were planted in cross-shaped (10 cm x10 cm) openings of a film of pre-moistened bedrock soil at a distance of 30 cm - 40 cm from each other. The care in respect to the plants consisted in fertilization, irrigation, two machine weedings of the soil between the rows, stalks pinching, and treatment of the plants aiming to protect them from powdery mildew. The watering was carried out locally. The soil samples were taken for a chemical analysis 7 days - 10 days after fertilization.

Meteorological data

The climate of the territory is continental. The total solar radiation is high. The climate of the Trans-Ili Alatau is formed under the influence of the winter invasion of the Siberian pressure maximum and the summer Central Asian minimum. The absolute height and the relief features of the northern slope of the Trans-Ili Alatau determine the air temperature and the annual sum of the precipitation, the surface runoff of the moisture, the magnitude of the total radiation and, therefore, are of decisive importance for the soil-forming process.

The July temperature at the foothills and the foothill plain is 20.3^{o}C - 24.7^{o}C, while in January it is 5.6^{o}C - 12.7^{o}C. In April, the temperature rises relative to that in March and amounts to 5.7 ^{o}C - 11.5^{o}C. May can be considered a summer month.

The spring is characterized by an average seasonal temperature of 0^{o}C - 4^{o}C. The snow melt is fast due to the greater number of warm days, the intensively increasing influx of solar energy and the arrival of warm air from Central Asia.

A stock of snow water on the slope of the ridge prior to the beginning of the spring snowmelt varies from 80 mm to 180 mm. The meltwater is completely absorbed by the soil and partly drained. The summers are hot, with an average seasonal temperature of 21^{o}C - 22^{o}C. All this causes a strong evaporation of moisture and drying of the soil. The autumn is warm and dry, with an average daily temperature of 7.7^{o}C - 8.6^{o}C. The average daily temperature changes within 10 degrees. Precipitation and freezing are possible.

Soil analysis prior to the experiment

The studies were carried out on light chestnut soils. The content of the total humus in the investigated soils was from 0.14 % to 2.72 %. It decreased with the depth [15]. It contained a relatively high percentage of nitrogen, while the ratio of carbon to nitrogen in the topsoil was 6.0 - 8.5 (Table 1). The content of CO_2 in the upper horizons ranged from 2.73 % to 9.30 %.

Water-physical properties of the soil were characterized by the following indicators (Table 2). The specific weight (γ) varied in the range of 2.61 g cm^{-3} - 2.75 g cm^{-3}, while the bulk weight (BW) which was slightly increasing with the depth amounted to 1.17 g cm^{-3} - 1.48 g cm^{-3}. The total porosity of the investigated area soil varied between 47 % - 55 %. The lowest value was found at a depth of one meter. The wilting point (WP) of the soil profile varied within 7.9 % - 8.6 %, while the field capacity (θ_{fc}) was equal to 20.1 % - 23.6 %. The moisture reserve at the lowest moisture capacity found in the layer at the depth of one meter amounted to 319 mm. It included 226 mm of productive moisture. The maximum hygroscopicity (MH) value of the soil under study varied between 4.65 % - 5.75 %. It decreased

Table 1. Chemical and physicochemical properties of light chestnut carbonate soils.

depth of sample, cm	humus, %	total nitrogen, %	C:N	CO_2,%	Absorbed cations, mg eq per 100 g of soils				pH of aqueous extract
					Ca	Mg	Na	total	
0-6	2.72	0.19	8.2	2.73	12.61	1.49	0.5	14.60	8.1
10-20	1.90	0.15	6.7	3.65	11.71	2.44	0.3	14.45	8.2
25-35	1.22	0.11	7.1	6.32	11.20	0.49	0.2	11.80	8.2
42-52	1.17	0.08	8.5	8.08	10.24	1.95	0.2	12.39	8.2
75-85	0.70	-	-	9.30	8.78	2.44	0.2	11.42	8.5
88-98	0.14	-	-	6.45	-	-	-	-	8.8

Table 2. Water-physical properties of light-chestnut carbonate soils.

Depth, cm	γ, g cm^{-3}	BW, g cm^{-3}	total porosity, %	MH, %		WP, %		θ_{fc}, %	
				by weight	by volume	by weight	by volume	by weight	by volume
0-6	2.61	1.17	55	5.75	6.8	8.6	10.4	23.5	28.0
10-20	2.66	1.32	51	5.55	6.9	8.3	10.4	23.2	29.0
25-35	2.68	1.28	54	5.40	6.5	8.1	9.8	23.6	28.6
42-52	2.70	1.30	52	5.25	6.3	8.2	9.3	21.3	25.8
75-85	2.74	1.37	49	4.90	6.4	7.9	10.3	20.1	26.3
88-98	2.75	1.48	47	4.65	6.9	7.9	10.0	20.4	26.5

gradually with the depth. It is worthy adding that the value of the maximum hygroscopicity of the sandy soils varied within the limits of 0.1% - 1 %, while the humus reached 10 %- 15 % in clay [16].

The observations of the water regime of the investigated soils showed that they belonged to the non-wash type. The maximum depth of the spring soaking of the soil profile reached 1.5 m - 2.0 m. The productive moisture reserves were completely depleted by the end of June, while the upper layers (0 cm- 50 cm) dried out to moisture which was lower than that of the plants stable wilting.

The soil used in the experiments was sampled in beds in absence and presence of films at a depth of 0 cm - 30 cm. Each sample was analyzed 3 times.

Films

Two types of films (transparent and black) of a width of 90 cm were investigated. Their presence resulted in decrease of the water evaporation from the soil surface and its temperature in hot days. The films lead also to decrease of weeds viability.

The transparent film improved the temperature regime of the soil due to accumulation of daytime heat. It could be explained with the different air-soil temperatures, which lead to condensate formation.

The black film absorbs the sunrays and could be heated up to 57°C. But soil in this case was heated less than in presence of a transparent film.

Preparation of an aqueous extract

The pre-air-dried soil samples were crushed and sieved through a 1 mm sieve. The air dried soil (50 g) was treated with 250 ml of distilled water. The mixture was shook during 3 min and filtered several times to obtain a transparent solution [17].

Determination of some soluble components of the soil

The determination of the hydrocarbonate-ions in the aqueous extract was done by titration using 0.01 N or 0.02 N solution of H_2SO_4 in presence of 1 drop - 2 drops of methyl orange. The determination of the chloride-ions was done by titration with 0.02 N solution of $AgNO_3$ in presence of 1 ml of 10 % solution of K_2CrO_4. The determination of the sulphate-ions was done by titration using 0.02 N solution of $BaCl_2$ in presence of $C_{22}H_{14}N_6O_{18}S_4$. The sample was initially passed through a cation exchanger and acidified by adding 0.1 N solution of HCl. This was done aiming the elimination of calcium-ions presence.

The determination of the calcium- and magnesium-ions was done using a single aliquot. The first calcium-ions were determined by titration with 0.01 M solution of EDTA in presence of murexide. The later magnesium-ions were determined by titration with 0.01 M solution of EDTA in presence of chromogen black. The determination of the potassium- and sodium-ions was done with the application of the flame photometric method.

Irrigation water and plants

The irrigation water during the period from May to September had good irrigation qualities: the temperature was 11°C - 15°C, mineralization was 189.1 mg l^{-1}- 260.3 mg l^{-1}, the pH values were 7.15 - 7.45, the total hardness was 1.45 mg eql^{-1} - 2.34 mg eql^{-1}. HCO_3^- (123.9 mg l^{-1} - 172.1 mg l^{-1}) and Ca^{2+} (22.2 mg l^{-1} - 32.3 mg l^{-1}) prevailed among the ions studied.

Samples of the irrigation water (Aksai river) and the plants vegetative mass were taken once a month. Generally accepted methods of measurement were applied [18 - 19] with a percentage of errors did not exceeding the permissible values. All water and plants samples were analyzed at least 3 - 4 times.

RESULTS AND DISCUSSION

The evaluation of the mulching procedure is based on one of the most common vegetables of the region – the cucumber. Three different conditions are realized: in presence of a transparent and a black film and in absence of any film. The soil sampling is done at different stages of the cucumber development, i.e. those of planting, young growth, tillering, flowering, and fruiting.

The temperature in the root layer of the soil (0 cm-30 cm) with a mulched transparent film is, on average, 6.4°C - 18.2°C higher than that of the open area, with the highest values occurring in daytime (Table 3). A decrease of the soil temperature during the tillering period is noted due to the shading of the film by the vegetative mass of plant. The droplet moisture condensate formed on the surface of the film facing the soil, under the influence of the temperature difference between the soil and air above it, contributes to the preservation of the heat in the soil accumulated in the course of the day.

It is well recognized that an air layer forms between the film and the ground in presence of a film since the surface of the soil is rough. It depends on the optical parameters of the film material and hence can assert a different effect. Most of the sun's rays fall into the visible region of the spectrum. Therefore, when applying a coating of a transparent film, the energy of the sun is accumulated by the surface of the ground, while the

Table 3. Average values of humidity and soil temperature (0-30 cm) under transparent mulch and in control areas.

Index		planting	young growth	tillering	flowering	fruiting
Moisture,%	mulch	17.63	18.20	18.01	17.64	17.31
	control	17.50	17.62	17.22	16.83	16.41
Temperature,^{0}C	mulch	20.6	36.5	30.1	25.3	23.5
	control	14.2	18.3	17.8	17.1	16.7

Table 4. Dynamics of pH and Eh*100 mV in the soil during the vegetation period of cucumbers depending on the method of mulching the soil with film.

Type	Index	planting	young growth	tillering	flowering	fruiting
control	pH Eh*100 mV	7.86 2.22	7.97 2.11	8.15 2.00	8.21 1.20	8.32 1.15
transparent film	pH Eh*100 mV	7.86 2.22	7.90 1.79	8.04 2.03	8.13 1.40	8.27 0.96
black film	pH Eh*100 mV	7.86 2.22	7.92 2.00	8.16 2.10	8.24 1.18	8.30 0.88

air layer protects it from cooling. This results in heat increase [9, 20].

During the vegetation period, the soil moisture under the mulch varies within the range of 17.31 % - 18.20 %, which is with 3.3 % - 5.5 % more than that of the open soil.

A gradual increase of pH values is observed in all variants of the experiment. The control sample pH increases with 0.06 - 0.18, while the change observed in the period from planting to fruiting amounts to 0.46. The corresponding pH variations in presence of a transparent film refer to 0.04 - 0.16 and to 0.41. Those recorded in presence of a black film are found equal to 0.06 - 0.24 and 0.44, correspondingly (Table 4). This pH increase in all variants of the experiment indicates some alkalization of the soil. The redox potential Eh is an indicator of the degree of oxidation or reduction of the variable-valence components of the chemical composition of the soils and the natural waters. It also serves as a quantitative measure of the ability of the ecosystem elements to oxidize and reduce such components. Positive values of Eh are found. They indicate that, in comparison with the standard hydrogen system, this system is more oxidized, i.e. a normal hydrogen system will reduce the system of Eh > 0.

In the soil samples under study, A gradual decrease of the values of Eh and an increase of pH values are noted in case they are juxtaposed with those of the control soil without a film. This verifies the conclusion referring to the gradual process of soil alkalization. Besides, the changes of pH and Eh are more noticeable and in presence of a black film.

The values of Eh reported in ref. [17] vary from 750 mV in well-aerated soils with an oxidation regime to 150 mV in over-moistened soils under reducing conditions.

The behaviour of the main ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-} and CO_3^{2-}, SO_4^{2-}, Cl^{-}) in the aqueous extract of the investigated soil during the vegetation period is illustrated in Figs. 1 - 6.

Figs. 1 and 2 show that the concentrations of calcium and magnesium ions decreases during cucumbers growing following the line: a transparent film > a black

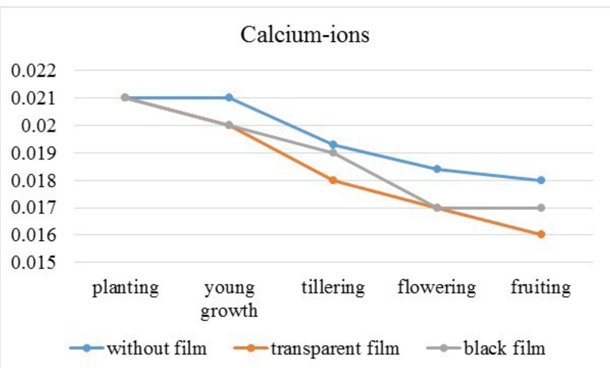

Fig. 1. A concentration of calcium-ions, %.

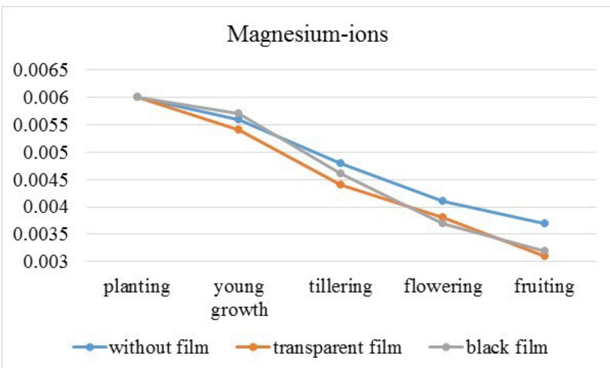

Fig. 2. A concentration of magnesium-ions, %.

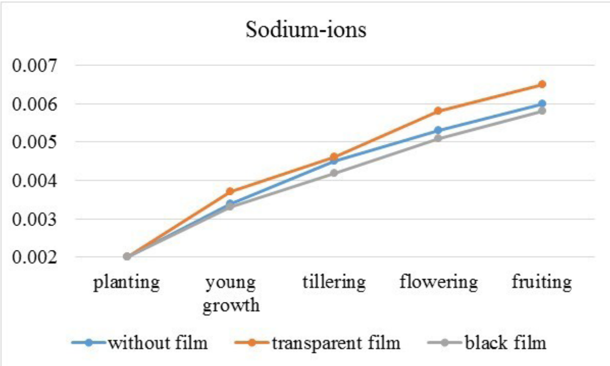

Fig. 3. A concentration of sodium-ions, %.

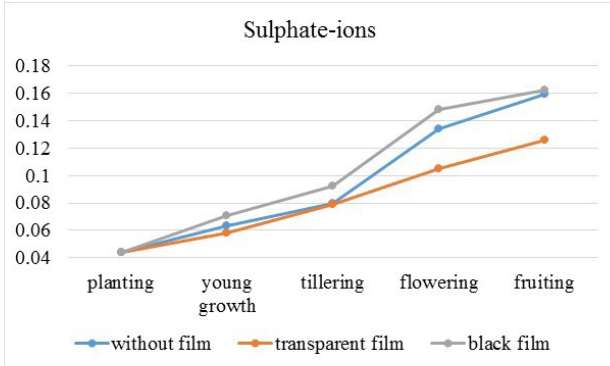

Fig. 5. A concentration of sulphate-ions, %.

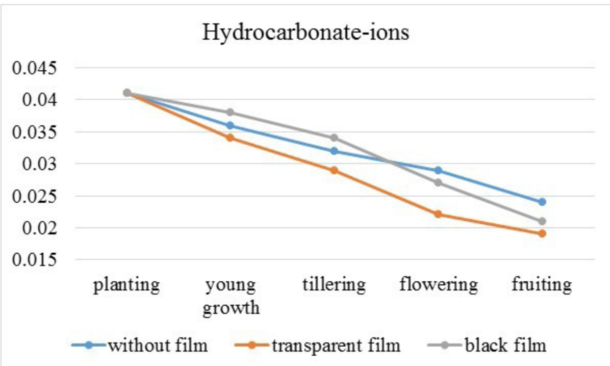

Fig. 4. A concentration of hydrocarbonate-ions, %.

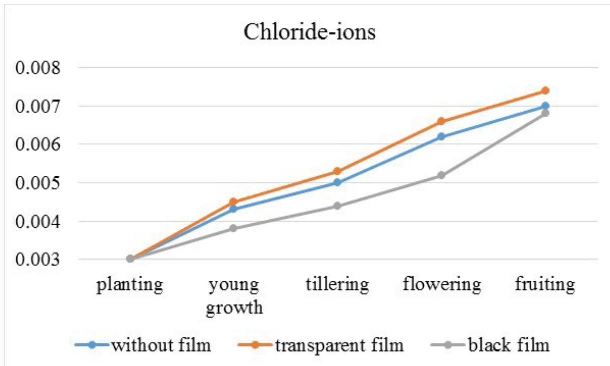

Fig. 6. A concentration of chloride-ions, %.

film > an absence of a film. This fact can be explained with their accumulation by the plants in the process of growing. The accumulation proceeds faster in presence of the films. The best result is obtained in case of a transparent film. The behaviour of the sodium-ions is completely opposite. As calcium and magnesium ions are extracted from the soil, they are substituted by sodium-ions. Thus, an accumulation of sodium-ions is observed in soil. The concentration of potassium-ions is equal to 0.001 % for all investigated samples, so no dependence on cucumbers vegetation is observed.

Hydrocarbonate-ions are also accumulated by the plants, i.e. their content in the soil decreases. The best results are obtained in case of a transparent film. The hydrocarbonate-ions can be converted to carbonate one. The latter reacting with calcium-ions can form chemogenic calcium carbonate. Carbonate-ions are not found in the samples investigated. Sulphate- and chloride-ions are not accumulated by the cucumbers, but are concentrated in the soil instead. The dependence observed follows the line: a transparent film > no film > a black film. The pattern followed in case of chloride-ions is as follows: a black film > no film > a transparent film. It is evident that the effect of the different types of the films has a different mechanism. The chemical composition of the tops and the pulp of the cucumbers are studied in June, July and August. The tops of cucumbers grown on soils with no mulch contain phosphorus (in the form of P_2O_5) 0.2 - 3.0 times more than in case of mulch presence (0.12 % - 0.18 % of dry matter). The tendencies of the gradual accumulation of phosphorus in the plants during their vegetation period can not be identified. The content of potassium in the cucumbers tops is directly dependent on its content in the soil. A tendency of its concentration decrease from 3.00 % to 2.20 % is found in the tops grown in mulch presence by the end of their vegetation. This difference is observed in respect to the control sample. The total nitrogen content in the tops of the cucumbers decreases gradually from 4.65 % to 2.84 % on mulch soil. The cucumbers pulp in case of mulch using contains also higher concentrations of phosphorus, 1.4 - 3.6 times greater than that of the control sample (0.04 % - 0.07 %). The highest values are obtained in case of the black film. A similar pattern is also observed for the potassium ions: the pulp of the cucumbers grown on soil in presence of a film contains potassium ions 2.1 - 5.4 times more than the control sample. The total nitrogen content of the pulp of the cucumbers fluctuates between 3.50 % and 4.43 % of the dry matter. A smaller amount is accumulated in presence of a transparent film. The total nitrogen content of the cucumbers of the control sample does not depend on the presence of any film.

CONCLUSIONS

During the vegetation period, the soil moisture under the mulch varies within the limits of 17.31 % - 18.20 %, while the temperature is equal to 20.6°C - 36.5°C. These changes are greater by 3.3 % - 5.5 % and 6.4°C - 18.2°C, correspondingly, when compared to those of in absence of any film.

The concentrations of calcium and magnesium ions decrease during the cucumbers growing due to their accumulation by the plants. As calcium and magnesium ions are extracted from the soil, sodium-ions substitute them leading to their accumulation. The concentration of the potassium-ions is identical for all investigated samples. Hydrocarbonate-anions are accumulated by the plants. The best results in this respect are obtained in presence of a transparent film. Sulphate- and chloride-anions are not accumulated by the cucumbers. They are concentrated in the soil instead.

The pulp of the cucumbers grown on a soil under mulch contains also higher concentrations of phosphorus. It is 1.4 - 3.6 times greater than that of the control sample (0.04 % - 0.07 %). The highest values are observed in presence of a black film.

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