Experimental results of a combined machine for soil preparation and plastic film laying in melon crop production

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Abstract. Analyzed the current state of melon crop cultivation on rainfed lands of Uzbekistan with the application of plastic film mulching technology. Investigated the influence of combining soil tillage, seedbed preparation, and plastic film laying operations on the technological process of watermelon cultivation. Identified that the use of combined machines enables a reduction in the number of field passes during soil preparation. Studied the structural design of a combined machine incorporating chisel-type working tools, rippers, leveling–compacting units, and a film-laying mechanism. Determined the functional purpose and interaction of the main working units ensuring the execution of multiple operations in a single pass. Established the compliance of the operational performance indicators of the prototype combined machine with agrotechnological requirements. Substantiated the application of the developed structural scheme for soil preparation and simultaneous plastic film laying on rainfed lands. Presented the results of field tests of the combined machine prototype conducted according to developed and standard testing methodologies.

1 Introduction

Worldwide, the cultivation of melon and vegetable crops in open fields and obtaining early yields largely depends on the development and application of energy- and resource-efficient soil preparation machines with high operational productivity. Considering that the global area cultivated with melon and vegetable crops amounts to approximately 1.6 billion hectares, the development of combined machines capable of ensuring high-quality operation, high productivity, and energy-resource efficiency in soil preparation for planting has become one of the important tasks of modern agricultural engineering. In particular, considerable attention is being paid to the development and application of combined machines capable of performing several technological operations in a single field pass, including strip primary tillage, preparation of soil for planting, laying irrigation hoses, and covering the soil with plastic film.

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Melon crops are among the most valuable agricultural products worldwide, including in Uzbekistan. Uzbekistan is well known for its high-quality watermelons and melons. Plastic film mulching technology is widely applied in the country for the cultivation of early-maturing watermelon varieties. More than 750 thousand hectares of agricultural land in Uzbekistan are classified as non-irrigated (rainfed) areas, which are mainly used for growing early watermelon and melon crops under plastic film due to limited water resources and climatic conditions. In 2025, melon crops, including watermelons, were cultivated in Uzbekistan on more than 72.2 thousand hectares of sown area. The volume of watermelon production in Uzbekistan accounts for approximately 2% of global watermelon production.

Existing technologies for soil preparation for melon crop cultivation under the conditions of Uzbekistan consist of a sequence of agro technical operations performed by separate machine units, including plowing, field surface leveling, chiseling, harrowing, rolling, as well as manual opening of furrows for burying the film edges, film laying, and covering the film edges with soil. This leads to increased time, labor, energy, and fuel consumption, soil moisture losses, deterioration of soil structure, excessive compaction, and delays in preparing the soil for melon planting under plastic film. Therefore, high-quality soil preparation and reliable film laying for melon cultivation remain an urgent task in modern agriculture.

Currently, soil preparation technologies for melon production under plastic film are implemented using single-operation machines in several passes, which causes excessive soil compaction, reduced labor productivity, increased labor and financial costs, prolonged field preparation periods, and intensive soil drying, resulting in yield reduction. The problems of soil preparation for melon crop cultivation under plastic film have been widely discussed in numerous scientific studies. Research aimed at improving soil preparation technologies, developing machinery for melon production, and substantiating the design and parameters of working tools in the CIS countries has been carried out by A.A.G. Al-Shammary, Y.A. Othman, S. Bandopadhyay, G. Amare, M.A. Kader, A. Sorze, Y.N. Syromyatnikov, C.W. Wyenandt, F. Lamont Jr., D.L. Karlen, R.C. Ebel and others. In particular, substantiated and developed working tools for pre-sowing soil tillage and sowing of melon crops. However, these studies are mainly focused on improving technologies and technical means for soil preparation in open fields and cannot be directly applied to integrated operations involving soil preparation.

2 Materials and methods

Based on the results of the conducted theoretical and experimental studies, the initial requirements and technical specifications were developed for a machine designed for simultaneous soil preparation and plastic film laying for melon crop planting (conditionally designated as KMP-P-1.4). A prototype of the machine was manufactured (Figure 1), and field and farm tests were carried out on farms in the Kukdala district of the Kashkadarya region.



Fig. 1. The machine aggregated with an MTZ-80 tractor.



Fig. 2. Operating process of the machine aggregated with an MTZ-80 tractor.

The developed machine consists of a frame, a three-point hitch system, a chisel-type tine, an inclined shank ripper, a leveling–compacting unit, a flat disc furrow former, a rubber film-laying roller, and spherical discs for burying the film edges. The machine is aggregated with an MTZ-80 tractor. The overall working width of the machine is 1.4 m. Table 1 presents the parameters of the working elements of the machine designed for simultaneous soil preparation and plastic film laying for melon crop planting, while Table 2 provides its technical specifications.

Table 1. Parameters of the developed machine.

No.	**Diameter of the flat disc forming a furrow for film covering, m**	D_{td}	**0.38**
1	Installation angle of the flat disc relative to the direction of travel, degrees	α_t	22
2	Diameter of the spherical disc for burying the film, m	D_{sd}	0.44
3	Installation angle of the spherical disc relative to the direction of travel, degrees	α_s	25

Table 2. Technical specifications of the machine for simultaneous soil preparation and plastic film laying for melon crop planting.

No.	Indicator name	Unit of measurement	Value of the indicator
1.	Type	-	Mounted
2.	Tractor class	-	2-3
3.	Operating speed	km/h	4-5
4.	Working width	m	1.4
5.	Number of chisel-type tines	pieces	2
7.	Number of inclined shank working tools	pieces	4
9.	Number of leveling-compacting units	pieces	1
10.	Number of furrow-forming flat discs	pieces	2
11.	Number of rollers for laying the film edges	pieces	2
12.	Number of spherical discs for burying the film	pieces	2
14.	Mass	kg	630±5
15.	Longitudinal distance from the arrow-shaped sweep to the inclined-shank working body, m	L_o	0.45
16.	Working width of the inclined-shank working body, m	$B_{c.h}$	0.35
17.	Length of the chisel of the inclined-shank working body, m	L_u	0.22
18.	Width of the chisel of the inclined-shank working body, m	b_u	0.05
19.	Transverse distance between the inclined-shank working bodies, m	B	0.45
20.	Longitudinal distance between the inclined-shank working bodies, m	L	0.55
21.	Height of the upper compaction part of the leveler–compactor, m	H_m	0.18
22.	Length of the blade, cm	l_p	9
23.	Installation angle of the lower part of the leveler relative to the horizontal, degrees	α_{1z}	25
24.	Angle of installation of the upper part of the leveler relative to the lower compaction part, degrees	α_2	155
25.	Length of the lower compaction part of the leveler–compactor, cm	l_o	10

3 Results and Discussion

During a single pass of the machine designed for simultaneous soil preparation and plastic film laying for melon crop planting, the following performance indicators were determined: tillage depth, soil crumbling quality, and fuel consumption. The quality indicators of the machine were evaluated in accordance with TSt 63.04:2001 “Testing of Agricultural Machinery. Machines and Implements for Deep Tillage. Test Program and Methods” and TSt 63.03:2001 “Testing of Agricultural Machinery. Methods for Energy Evaluation of Machines”.

The tillage depth was determined by inserting a ruler with a cross-sectional area of 1 cm² (1×1 cm) into the soil down to the bottom of the tilled layer. Measurements were performed with an accuracy of 0.1 cm. At both operating speeds, four replications were conducted with 25 measurements in each replication.

To evaluate the soil crumbling quality of the loosened layer, soil samples were taken from a 1 m² plot at the working depth in five replications. The collected soil samples were sieved using sieves with mesh diameters of 50, 25, and 10 mm. The mass of soil aggregates retained on each sieve and those passing through the final sieve was measured using a

LIBOR "EL-600" balance. The proportion of soil fractions larger than 50 mm, 50-25 mm, 25-10 mm, and smaller than 10 mm was determined as a percentage. During sieving, the samples were passed sequentially from larger mesh sieves to smaller ones. The measurement accuracy for each fraction was 10 g.

The main physical and mechanical properties of the soil during the sowing period were determined in accordance with GOST 20915-2011.

To determine soil moisture content and bulk density, soil samples were collected along the field diagonal at five locations using a cylinder with a volume of 503 cm^3. Samples were taken in five replications from four soil layers at depths of 0-5, 5-10, 10-15, and 15-20 cm. The cylinder was inserted vertically into the soil, excess soil was carefully removed with a knife, and the mass of the soil in the cylinder was measured in the field using an electronic balance. The measured values were recorded in the field logbook. Subsequently, soil samples from each layer were transferred onto paper sheets, thoroughly mixed, and subsamples of 30–40 g were placed into aluminum containers (weighing boxes), tightly sealed with lids, and weighed with an accuracy of ±0.01 g using an MN-390 electronic balance. The container numbers and masses were recorded. In the laboratory, the containers were opened and placed in a drying oven at a temperature of 105-107 °C for 8 hours. After drying, the samples were cooled for 30 minutes and reweighed.

Soil penetration resistance (hardness) was measured at depths of 0-5, 5-10, 10-15, and 15-20 cm using a measuring device equipped with a conical tip having a base area of 1 cm^2 and a sharpening angle of 22°30′. Prior to testing, the device was calibrated and the calibration coefficient was determined.

The soil moisture content in the 0-10, 10-20, and 20-30 cm layers was 16.7%, 17.3%, and 18.4%, respectively, while soil hardness was 1.92, 1.34, and 1.86 MPa.

Field tests of the machine for simultaneous soil preparation and plastic film laying for melon crop planting were conducted in February on farm fields in the Kukdala district of the Kashkadarya region. During the tests, the machine was aggregated with an MTZ-80 tractor (Fig.3). The field soil type was typical gray soil, and its mechanical composition was classified as medium loam.

Table 3 presents the test conditions of the machine, while Table 4 shows the experimental results. The tests were carried out in early spring during the period of soil preparation for planting melon crops under plastic film.

Table 3. Test results of the machine for simultaneous soil preparation and plastic film laying for melon crop planting.

No. t/r	Names of indicators	Names of indicators	According to the test results
1.	Operating speed, km/h	4-5	4.8
2.	Plowing depth of the planting zone, cm: M_{ave} $\pm\sigma$ v; %	 30 cm ±2 <10	 31.9 1.82 7.6
3.	Content of soil fractions of the following size ranges in the area treated by the inclined shank working tools, % > 100 mm 100-50 mm < 25 mm	 < 10 - > 80	 7.2 9.12 87.82
4.	Fuel consumption, kg/ha	-	18.7

During the conducted tests, the target tillage depth was set at 30 cm, while the actual average value reached 31.9 cm. The proportion of soil fractions smaller than 25 mm averaged 89.6%.

When the diameter of the spherical disk working body is D_{sd} = 500 mm, the tillage depth is greater compared to spherical disk working bodies with diameters of D_{sd} = 440, 380, and 320 mm**.** Experimental results showed an increase in the proportion of soil aggregates larger than 25 mm. This can be explained by the larger diameter of the spherical disk working body.

The soil throwing distance and the height of soil covering over the plastic film were also higher than those observed for smaller-diameter spherical disk working bodies. This is attributed to the increased volume of soil interacting with the larger disk.

At the same time, the draft resistance of the spherical disk working body with a diameter of 500 mm was higher than that of disks with diameters of 440, 380, and 320 mm by 25.5%, 30.6%, and 45.9%, respectively.

During the experiments, when the disk diameter was 500 mm, the increased tillage depth caused excessive soil displacement, leading to soil being thrown onto the laid plastic film and covering the planting furrows intended for melon crops. This resulted in damage to the plastic mulch.

In addition, the draft resistance of the spherical disk working body at D_{sd} = 500 mm was relatively high, reaching 98.0 N.

When the diameter of the spherical disk working body is D_{sd} = 440 mm, the tillage depth reached 12.2 cm. The soil throwing distance and soil covering height were 25.6 cm and 11.8 cm, respectively, which are higher compared to spherical disk working bodies with diameters of 380 mm and 320 mm by 26.5% and 33.1%, and 51.1% and 50.8%, respectively. These parameters meet the agro technical requirements.

Experimental observations showed that soil clods did not fall into the planting furrows intended for melon seedlings, and the laid plastic film remained undamaged. The draft resistance of the spherical disk working body with a diameter of 440 mm was 25.5% lower than that of the disk with a diameter of 500 mm. Thus, the spherical disk working body with a diameter of 440 mm demonstrated high-quality operational performance and acceptable energy efficiency indicators.

In contrast, when the diameter of the spherical disk working body was D_{sd} = 380 mm and 320 mm, the agro technical requirements for soil preparation for melon planting were not adequately satisfied. Specifically, the tillage depth, soil throwing distance, and soil covering height were 9.3 cm, 18.8 cm, and 7.9 cm, and 7.2 cm, 12.5 cm, and 5.8 cm, respectively. These values do not meet the required agro technical standards.

Furthermore, the soil covering height and soil volume necessary for properly burying the edges of the plastic film were insufficient. As a result, the technological process of soil preparation for melon planting was not performed at the required quality level.

Therefore, based on the results of the conducted research on selecting the spherical disk working body, it was established that when the diameter is D_{sd} = 440 mm, the technological process of covering the edges of the laid plastic film during soil preparation for melon crops is performed effectively. Consequently, further studies were continued using the spherical disk working body with a diameter of D_{sd} = 440 mm.

As shown by the data presented in Table 4, the operational performance of the machine for simultaneous soil preparation and plastic film laying for melon crop planting complies with agro technical requirements. During the tests, the developed machine reliably performed the specified technological operations, and no significant deficiencies were observed.

According to the performed calculations, the application of the machine for simultaneous soil preparation and plastic film laying reduces fuel and lubricant consumption by 42% and operating costs by 45%.

4 Conclusion

During the tests, the developed prototype machine for soil preparation and simultaneous plastic film laying for melon crop planting reliably performed the technological process, and its operational indicators fully complied with the specified requirements.

Application of the developed machine allows reducing fuel and lubricant consumption by 37-43%, labor input by 41-45%, and operating costs by 47-52% compared with existing technical solutions.

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