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ORIGINAL PAPER

Main soil tillage types and their effect on the agronomic response of common bean (*Phaseolus vulgaris* L.)

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Abstract

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This study was carried out at the trial field of DAI from 2014 to 2016. The influence of seven main soil tillage systems (MSTS) on the yield and the physical properties of dry bean seeds were investigated. Four of these MSTS were applied independently and annually in crop rotation: 1. CP-conventional plowing; 2. D–disking; 3. C–cutting; 4. NT-nil tillage. The other three MSTS systems included: 5. Plowing (for spring crops) – Direct sowing (of wheat); 6. Cutting-Disking and 7. Plowing-Disking. A significant differentiation in the productivity of dry bean was found depending on the tested MSTS systems. Lowest mean yields were obtained at the annual use of systems 2 (D) and 4 (NT) – 1110.4 kg/ha and 1137.2 kg/ha, respectively. Among the annually applied systems, constant plowing (1st MSTS) and cutting (3rd MSTS) were the most favorable for expression of the crop's production potential. The systems involving annual alternation of tillage types with and without turning of the plow layer exceeded with 499.5 kg/ha (37.81%) the same systems, which were applied independently. The alternation of plowing for root crops with direct sowing of wheat and plowing for root crops with disking of wheat were most efficient from an agronomic point of view. In comparison to annual plowing, the increase of productivity was with 473.0 (32.96%) and with 510.1 kg/ha (35.54%) respectively. The values of the physical properties of seeds were also highly differentiated according to MSTS. The mean value of the correlation coefficient between the yield and the test weight (0.644**) was higher than the correlation coefficient of the yield with 1000 seeds weight (-0.526**).

Key words: Common bean, Tillage systems, Yield, 1000 kernel weight

Introduction

Legumes have played a crucial role in agricultural production throughout history all over the world. Common bean (*Phaseolus vulgaris* L.) is grown world wide in a range of environments, production systems (PS), soil types, and input levels, and suffers from numerous abiotic and biotic constraints (Singh 1992, 2007; Singh et al. 2007; Terarn et al. 2009; Urrea et al. 2009). According to Onder and Babaoglu (2001) a lower yield due to climatic and soil inconvenience and various fungal diseases, may result in dramatic yield losses.

The capacity to fix nitrogen association with rhizobia by using solar energy collected through plant photosynthesis is very important charecteristic (Kurasu et al., 2011). This crop possesses high content of starch, protein and dietary fiber and is an excellent source of potassium, selenium, molybdenum, thiamine, vitamin B_6, and folic acid (Maiti and Singh, 2007).

Dry bean or common bean has been an important leguminous food grown in Bulgaria for human nutrition for thousands of years. However production and yield are not sufficiently enough yet. Dry seeds and green pods are food with high biological value and are used for human consummation, while straw has high protein content and is a valuable fodder for animals (Milev, 1995).

Bean productivity is strongly affected by the soil. The soil tillage system is a part of the agronomy practice for field bean production. The tillage purpose is to provide favorable conditions to seed germination, emergence of seedlings and development of the crops (Zerbato et al., 2013, Birkás et al., 2014). The applied soil tillage has to ensure good thermal regime, good aeration and accumulation of high autumn and winter moisture reserves in soil. It is a prerequisite for development of a powerful root system and higher microbiological activity, especially of the tuber bacteria which form symbiosis with the bean plant (Yankov, 2010). For Dobrudzha region, Klochkov et al. (1988), Georgiev et al. (1998) and Milev et al. (2016) recommended differentiation of the mail soil tillage depths according to the soil type and the degree of occurrence of weeds, varying from 23-25 cm to 28-30 cm. The various effects of different type of soil tillages lead to improving or deterioration of the soil's major characteristics, which are of crucial importance for plant development. They are best manifested on yield size.

Therefore, the objectives of this study were to assess which tillage techniques and main soil tillage systems could be considered as adaptation to climate change scenarios. The objectives were: (i) to investigate the seasonal variability in common bean yield as influenced by the tillage systems; (ii) to investigate the variability in the physical properties of seeds and (iii) to evaluate the correlations between the seeds yield and their physical properties.

Materials and Methods

This study was carried out at the trial field of Dobrudzha Agricultural Institute-General Toshevo from 2014 to 2016. The influence of seven main soil tillage systems (MSTS) on the yield and the physical properties of common bean were investigated. Four of these MSTS were applied independently and annually in crop rotation: 1. CP - conventional plowing (24-26 cm); 2. D – disking (10-12 cm) 3. C – cutting (24-26 cm); 4. NT- nil tillage (direct sowing). The other three MSTS systems included: 5. Plowing (for spring crops) – Direct sowing (of wheat); 6. Cutting (for spring crops) - Disking (for wheat) and 7. Plowing (for spring crops) - Disking (for wheat). The mineral fertilization (kg/ha) in the crop rotation was as follows: Common bean – $N_{60}P_{60}K_{60}$; Wheat – $N_{120}P_{120}K_{60}$; Sunflower - $N_{60}P_{120}K_{120}$ and Maize – $N_{120}P_{60}K_{60}$. Mineral fertilization was done with common ammonium nitrate NH_4NO_3 (34% N), triple superphosphate (46% P_2O_5) and potassium chloride (60 % K_2O). Phosphorus and potassium were introduced before main soil tillage, and nitrogen – before sowing. The bean was planted with seeders for direct sowing "Bettison 3D". The variety used was Dobrudzhanski ran, and the sowing norm was 45 germinating seeds/m^2. The cultivar is early maturing, with vegetative growth of 82 – 88 days. It has large seeds (450-500 g), test weight of 70 kg/100 l, rich is in antioxidants and is excellent in taste. The plant is semi-climbing and is suitable for two-stage harvesting.

Weeds were controlled with soil herbicides according to the following scheme: pre-sowing treatment with incorporation of grass herbicide and treatment after sowing with deciduous herbicide before emergence. In direct sowing a total herbicide was applied (glifosat 360 g/l).

The resulted data were statistically processed using variance analysis, F test and LSD (Least Significant Difference) test, which are commonly utilized in the multi-criterial statistical analysis. We used the SPSS version 16.0 statistical package. Significance of the treatments' effect was considered at 0.05 probability level. After performing the analysis of variance, we compared the means for each treatmen, using the Waller-Duncan's Multiple Range Test. Finally, Pearson correlation coefficients ("R coefficients") were computed and tested for significance.

Results and discussion

The variances of the productivity, averaged for the investigated period, revealed high statistical significance of the independent and combined interaction of the factors *Year* and *Main soil tillage systems* (MSTS) (Table 1). The independent action of MSTS influenced significantly the dry bean productivity in all investigated years.

The productivity of the cultivars varied significantly depending on the meteorological conditions during the vegetative growth and the type of the main soil tillage system (Table 2).Lowest mean yield was obtained in 2015 – 553.2 kg/ha, and highest in 2016 – 2833.7 kg/ha. The different systems of main soil tillage caused stronger differentiation in the productivity during 2014 and 2015 in comparison to 2016. During the first two years of the investigation, the system plowing-disking had the most favorable effect on the productivity of the crop. The exceeding according to the constant plowing in the crop rotation was with 65.5% (2014) and 70.5% (2015), respectively.

Table 1. Analysis of the variances of productivity during 2014-2016 and by years

Source	Dependent Variable	df	Mean Square	F	Sig.
Years (1)	Yields 2014-2016	2	385107,666	4878,055	,000
MSTS (2)	Yields 2014-2016	6	13313,926	168,644	,000
1 X 2	Yields 2014-2016	12	5537,697	70,145	,000
By years	Yield - 2014	6	17937,686	188,821	,000
	Yield - 2015	6	85691,676	1238,587	,000
	Yield - 2016	6	3132,159	43,108	,000

In 2016, the differentiation between the tested MSTS was lower in comparison to the previous two years. Best results were obtained under constant use of cutting in the crop rotation and under alternation of plowing with direct sowing. The exceeding according to constant plowing in the crop rotation was with 31.5% and 32.1%, respectively.

Table 2. Effect of the soil tillage system on the productivity of common bean over years, kg/ha

No	Soil tillage system	2014 Sig 0.000	2015 Sig 0.000	2016 Sig 0.000
1	Plowing - Plowing	1263.3 b	622.5 c	2419.6 a
2	Disking - Disking	371.8 a	227.5 a	2731.8 b
3	Cutting - Cutting	1266.6 b	354.4 b	**3182.1 d**
4	Direct sowing – Direct sowing	296.1 a	381.9 b	2733.8 b
5	Plowing – Direct sowing	1754.2 d	774.7 d	**3195.5 d**
6	Cutting - Disking	1484.8 c	774.7 d	2889.3 c
7	Plowing - Disking	**2090.5 e**	**1061.6 e**	2683.4 b
	Average	***1218.2 b***	***553.2 a***	***2833.7 c***

These results demonstrated the extremely high effect of the meteorological elements on the development and the productivity of the crop. All three years were characterized with a sum of autumn-and-winter rainfalls above the climatic norm (1953-2013), which was a prerequisite for good moisture reserves in soil.

During the vegetative growth of common bean, there were extreme meteorological situations in all three years, which were at the basis of the differentiated response of the cultivar under the same soil tillage system used in the crop rotation (Figure 1).

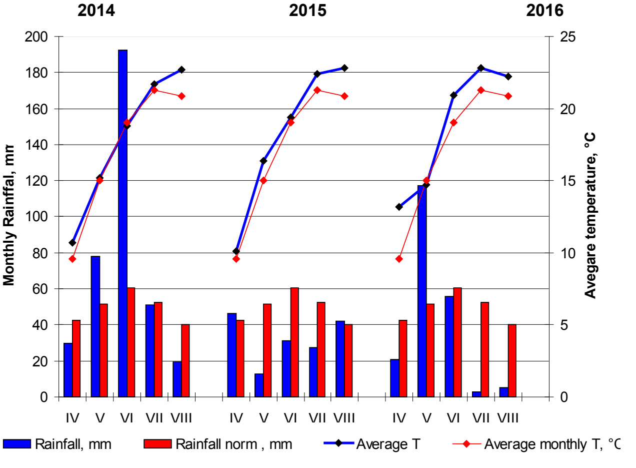


Figure 1. Dynamics of precipitation and temperature values over months during the vegetative growth, and mean long-term norm for 1953-2013

In all three years the mean monthly temperatures during the vegetative growth were above the climatic norm, especially in 2015 and 2016. In 2014 and 2016, the temperature regime was comparatively favorable for the conditions of intensive growth also during flowering, pollination and fertilization, while in 2015 the temperature conditions were extremely unfavorable. They were characterized with high temperatures exceeding 32-35^{0}C during the periods 7th – 9th July, 25th – 30th July and 12th – 15th August.

Year 2014 was with highest amount of vegetation rainfalls, strongly exceeding the mean long-term value with 69.66 %. Regardless of the abundant rainfalls in June, some of which were accompanied with strong winds causing partial lodging in the bean crops, year 2014 can be described as having good conditions for the crop development. In 2015 the vegetation rainfalls were 50-60 % from the climatic norm. The high temperatures in July – August, accompanied with severe soil drought, had unfavorable effect on the productivity of dry bean. In 2016, long periods of extreme high temperatures exceeding 32^{0}C and critical levels of relative air humidity did not occur, and the vegetation rainfalls were 94.88 % from the climatic norm. This year can be determined as having very good conditions for the development of the crop, in comparison to the other years of the investigation.

Averaged for the investigated period, considering the constant and independent soil tillage types, bean was with the highest productivity under systematic cutting in the crop rotation – 1601.0 kg/ha (Fig. 2).

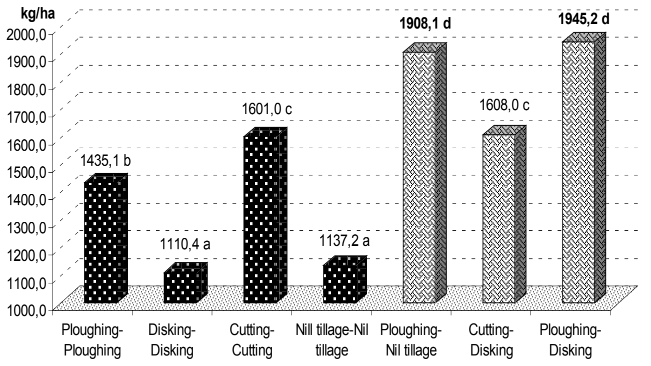


Figure 2. Mean productivity of dry bean according to MSTS

This tillage type exceeded constant plowing with 11.6 % (of with 165.9 kg/ha). The system with constant plowing in the crop rotation comes next by positive effect on productivity (1435.1 kg/ha). The other two constant and independent soil tillage systems (disking and direct sowing) were totally unsuitable for common bean, mainly in the years with unfavorable conditions during intensive growth, flowering and pod filling.

All three systems involving alternation of the of the tested soil tillage types lead to lower productivity of the crop in comparison to constant plowing. Highest mean yields in the experiment were obtained after applying the systems Plowing – Nil Tillage and Plowing – Disking. The system Plowing – Plowing was with 33.0% (473.0 kg/ha) and 35.5% (510.1 kg/ ha), respectively.

The obtained results clearly show that the meteorological conditions were the main factor determining yield. The strength of its effect in this experiment during the period of investigation was calculated to 84.03 % (Fig. 3).The analysis on the variances of the grain's physical properties (1000 kernel weight and test weight) demonstrated the high effect of the tested factors on their values, averaged for the investigated period (Table 3). Maximum level of significance of the MSTS on the values of these indices was found over years, as well.

During the investigated period, the factor *year* had greater strength of effect on the values of the obtained results in comparison to *MSTS* and their interaction (Figure 4). The effect of the meteorological factor was much stronger on the values of test weight than on the values of 1000 seed weight.

The largest and plumpest seeds were produced in 2014 - 411.41 g (Table 4). The mean values of 1000 seed weight in 2015 and 2016 were lower. Averaged for the investigated period, the independent long-term types of soil tillage contributed to the formation of seeds with a mean value of the absolute weight of 377.45 g. Their alternation in the crop rotation, however, had a slightly negative effect on the value of the index, decreasing it to 375.81 g. The values of 1000 seed weight in 2014 and 2015 were less differentiated according to MSTS in comparison to the differentiation determined in 2016. Within the same soil tillage system in the crop rotation, the weight of the seeds varied significantly depending on the meteorological conditions during the period of vegetative growth. In 2014, 1000 seed weight varied from 396.60 g under the system Plowing – Disking to 432.70 g under Cutting - Disking.

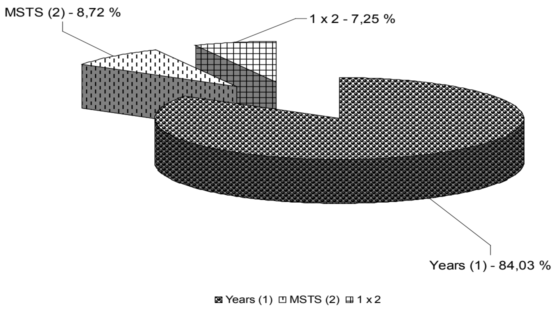


Figure 3. Strength of effect of the factors on yields, averaged for 2014 – 2016

Table 3. Analysis of the variances of the physical seeds properties during 2014-2016 and by years

Source		Dependent Variable	df	Mean Square	F	Sig.
Years (1)		1000 seed weight	2	33036,172	311,863	,000
		Test weight	2	15409,787	21935,640	,000
MSTS (2)		1000 seed weight	6	831,456	7,849	,000
		Test weight	6	10,483	14,923	,000
1 X 2		1000 seed weight	12	1746,047	16,483	,000
		Test weight	12	7,713	10,979	,000
By years	2014	1000 seed weight	6	979,259	8,364	,000
		Test weight	6	,856	23,262	,000
	2015	1000 seed weight	6	2379,238	12,007	,000
		Test weight	6	23,656	12,063	,000
	2016	1000 seed weight	6	3132,159	43,108	,000
		Test weight	6	965,053	376,966	,000

Under the extremely unfavorable conditions for vegetative growth of dry bean in 2015, the variation in the values of the index was from 355.50 g under the system Cutting-Disking to 414.50 g under the use of constant plowing in the crop rotation. In spite of the significantly lower mean values of seed weight in 2016, their variations according to the tested MSTS were highest. The Waller-Duncan test redistributed their values in 5 groups of sameness, similarities and differences – from 316.80 g (Plowing-disking) to 363.10 g (Cutting-Disking).

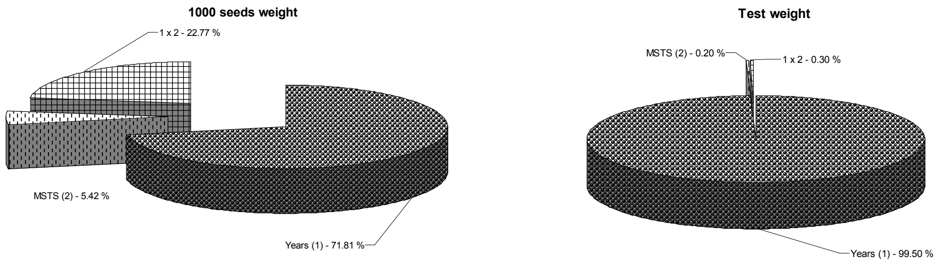


Figure 4. Strength of effect of the factors on seed's physical properties, averaged for 2014 – 2016

Test weight was with the highest mean values again in 2014 - 79.21 kg (Table 4). The values of this index were very well differentiated by years in comparison to the index 1000 seeds weight.

Table 4. Effect of the soil tillage system on the 1000 seeds weight of common bean over years, g

No	Soil tillage system	2014 Sig 0.000	2015 Sig 0.000	2016 Sig 0.000
1	Plowing - Plowing	396,0 a	414,50 c	346,88 c
2	Disking - Disking	425,7 c	363,75 a	346,41 c
3	Cutting - Cutting	408,5 ab	349,75 a	334,32 b
4	Direct sowing – Direct sowing	423,3 bc	363,50 a	356,81 d
5	Plowing – Direct sowing	396,6 a	400,00 bc	334,69 b
6	Cutting - Disking	432,7 c	355,50 a	363,10 e
7	Plowing - Disking	397,1 a	385,75 b	316,88 a
	Average	***411.41 c***	***376.11 b***	***342.73 a***

They once again confirmed the fact that year 2014 was the least favorable for formation of the seeds physical properties according to a complex of meteorological conditions. The seeds were with highest weight after using the system Plowing–Disking. Under the extremely unfavorable conditions for vegetative growth of common bean (2015), best results were obtained after the systems which involved plowing. In 2016, common bean seeds with highest weight were produced using the system Plowing–Direct Sowing.

Averaged for the period of investigation, the obtained results outlined a tendency of most favorable effect of MSTS on the physical properties of the seeds from cultivar Dobrudzhanski ran after systematic use of plowing in the crop rotation (Fig. 4). The involvement of plowing in the systems with alternation of the tillage types had a favorable effect on the values of test weight, even increasing them in comparison to systematic use of plowing in the crop rotation.

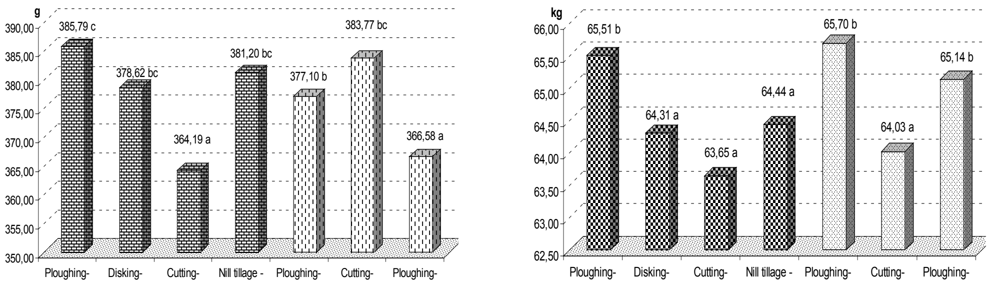
Test weight was with the highest mean values again in 2014 - 79.21 kg (Table 5). The values of this index were very well differentiated by years in comparison to the index 1000 seeds weight. They once again confirmed the fact that year 2014 was the least favorable for formation of the seeds's physical properties according to a complex of meteorological conditions. The seeds were with highest weight after using the system Plowing–Disking. Under the extremely unfavorable conditions for vegetative growth of common bean (2015), best results were obtained after the systems which involved plowing. In 2016, common bean seeds with highest weight were produced using the system Plowing–Direct Sowing.

Averaged for the period of investigation, the obtained results outlined a tendency of most favorable effect of MSTS on the physical properties of the seeds from cultivar Dobrudzhanski ran after systematic use of plowing in the crop rotation (Fig. 5). The involvement of plowing in the systems with alternation of the tillage types had a favorable effect on the values of test weight, even increasing them in comparison to systematic use of plowing in the crop rotation.

Table 5. Effect of the soil tillage system on the test weight of common bean over years, g

No	Soil tillage system	2014 Sig 0.000	2015 Sig 0.000	2016 Sig 0.000
1	Plowing - Plowing	78,70 a	41,45 c	76,85 ab
2	Disking - Disking	79,25 c	36,38 a	76,38 a
3	Cutting - Cutting	78,98 b	34,98 a	77,18 bc
4	Direct sowing – Direct sowing	78,73 ab	36,35 a	77,30 bc
5	Plowing – Direct sowing	79,53 d	40,00 bc	78,25 d
6	Cutting - Disking	79,30 cd	35,60 a	77,00 b
7	Plowing - Disking	80,00 e	38,58 b	77,58 c
	Average	***79.21 c***	***37.62 a***	***77.22 b***

Yankov's experiment data (2010) showed that with the reduction of the number and depth of the soil tillage operations in the common bean crop (cv. Abritus), the number of pods per plant, number of seeds per pod, seed weight per plant and 1000 seed weight decreased.



1000 seed weight, g Test weight, kg

Figure 5. Values of the physical properties of seeds according to the tested MSTS (2014-2016)

Regardless of the meteorological conditions during the growing of the crop, a high positive correlation was found between the productivity and the test weight of the common bean seeds (Table 6). Averaged for the period, the correlation between the seed yield and 1000 seed weight was negative at a high level of statistical significance. It is interesting to mention the fact, however, that in years with extreme droughts during flowering and pod formation and filling (2015), the values of these correlations were positive and high.

Table 6. Correlations between seed yield indices, 1000 seed weight and test weight (Pearson Correlation)

Indices	2014	2015	2016	2014-2016
1000 seed weight	-0.494(**)	0.533(**)	-0.152	-0.526(**)
Test weight	0.624(**)	0.532(**)	0.418(*)	0.644(**)

Conclusions

A significant differentiation in the productivity of common bean was found depending on the tested MSTS systems. Lowest mean yields were obtained at the annual use of constant disking and nil tillage – 1110.4 kg/ha and 1137.2 kg/ha, respectively. Among the annually applied deep MSTS, constant plowing and cutting were the most favorable for expression of the crop's production potential.

The systems involving annual alternation of tillage types with and without turning of the plow layer exceeded with 499.5 kg/ha (37.81%) the same systems, which were applied independently. The alternation of plowing for root crops with direct sowing of wheat and plowing for root crops with disking of wheat were most efficient from an agronomic point of view. In comparison to annual plowing, the increase of productivity was with 473.0 kg/ha (32.96%) and with 510.1 kg/ha (35.54%) respectively.

The values of the physical properties of seeds were also highly differentiated according to MSTS. The constant application of plowing in the crop rotation contributed to the production of seeds with the best physical indices – 1000 seed weight 408.33 g and test weight 65.51 kg. The constant use of the cutting in crop rotation was with the highest negative effect on the physical properties of the seeds.

Averaged for the period, the correlation between the seed yield and the physical indices of seeds was with high significance. The mean value of the correlation coefficient between the yield and the test weight was strong and positive (0.644^{**}) and with test weight – strong and negative (-0.526^{**})

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