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Productivity, quality and economics of four spring wheat (*Triticum aestivum* L.) cultivars as affected by three cultivation technologies

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Abstract. Managing farming inputs in wheat production technologies is an issue of paramount importance to attain optimum profitable production. To examine how varying the farming inputs affects the nutrients uptake and productivity of spring wheat (*Triticum aestivum* L.) cultivars and to determine the economic efficiency of various cultivation technologies, three-year field experiments were laid out at the Russian Research Institute of Agriculture, during the 2015–2017 growing seasons. Experiments were conducted once a year using randomized complete block arranged in a split plot experimental design with three replications, with the cultivation technology treatments (basic, intensive and high intensive technology) as the main plots, and spring wheat cultivars (Zelata, Lubova, Liza and Ester) as the sub-main plots. The highest grain yield (10.8 t ha^{-1}), harvest index (42.9%), gluten content (39.45%) and gluten index (71.17%) observed for spring wheat cultivar Lubova with the moderate application of farming inputs as an intensive cultivation technology. Highest protein content (18.02%) was attained for both intensive and high intensive cultivation technology with the cultivar Lubova, and the highest 1,000 grains weight (46.32 g) was recorded by cultivar Lubova in basic cultivation technology. Applying moderate amount of inputs as an intensive cultivation technology resulted in highest wheat yield and net income.

Key words: spring wheat, cultivars, cultivation technology, economic efficiency.

INTRODUCTION

Wheat is one of the most important cereal crops across the globe with the widest distribution and is also the main cereal which provides proteins and energy to the most of the world population (Hurkman et al., 2013; Wan et al., 2014).

World population is forecasted to reach its maximum (~10 billion people) by the year 2050, which will raise the demand for food. The intensive farming systems developed during the Green Revolution employ a macro-level, large-scale mono-crop production that utilizes field-level, uniform input applications of chemicals. These systems have been integral to response enhancing agricultural production demands during the past half century (Tilman et al., 2001; Weekley et al., 2012).

Advanced farming system is fundamentally based on cultivars bred for high performance under high input farming approach, which generally do not perform well under low-input agricultural technologies (Tiffany et al., 2011). In developed countries, modern cropping is fundamentally based on high input farming, which is not sustainable given resource limitations foreseen to occur in the near future (Phillips & Wolfe, 2005). As resources diminish and world population grows, high-input cropping systems become less sustainable. A paradigm shifts of research subjects and crop science objectives from high-input farming systems to those with a developed justification between yield and energy input is needed. Crop management concentrated more on nutrient economy will help reduce energy demands for agricultural production while still providing adequate amounts of high quality food as global resources decline and population is increasing (Sthapit et al., 2008).

Low-input farming relies on the improved resources management, ultimately resulting in a sustainable agroecosystem, due to low dependence on resources (Murphy et al., 2005). Low input systems have reduced usage of chemicals including fertilizers and pesticides, but not eliminating them (Abay & Bjornstad, 2009). Low-external input farming system in developed world may resemble farming in marginal environments of developing countries (Desclaux, 2005; Dawson et al., 2008; Zargar et al., 2017). Crop cultivars adapted to low-input cultivation systems are essential in both developed and developing countries.

In developed agricultural systems, the use of high yielding modern cultivars is the norm. Using off-farm inputs involving fertilizer and pesticides makes the growing conditions similar from farm to farm and region to region (Sperling et al., 2001; Dawson et al., 2008). Hence, there is concern over the rising cost of inputs and growing interest in sustainable cropping systems. Low-external-input farmers choose to limit their inputs for the reasons such as economic and environmental concerns (Murphy et al., 2005; Tiffany et al., 2011).

The need to reduce inputs in cropping systems throughout the globe is a challenge for both plant breeders and producers. Diminishing inputs can benefit producers in marginal environments developed and developing countries, and also those farmers who are seeking to lower their synthetic inputs for economic reasons (Dawson et al., 2008). The objectives of the study were to assess the effict of various cultivation technologies such as basic, intensive and high intensive cultivation technologies with varying fertilizers and pesticides use on the the uptake of nutrients and yields of four spring soft wheat cultivars and on the economic efficiency.

MATERIALS AND METHODS

Site Description and Soil

Three field experiments were performed during 2015–2017 in the Russian Research Institute of Agriculture, Moscow region, Russia. The site is located at 54° 45′ N, 37°38′ E and 200 m altitude. In order to test the soil, the samples were randomly collected from the depth of 0–30 cm and different parts of the land recording the initial characteristics of the experimental soil. The soil type was a loamy with 1.6% organic matter and a pH of 5.8. The experimental field was ploughed before sowing seeds, and the field was prepared by roller harrowing. Dolomitic powder 4.5 t ha^{-1} was applied to the seedbed so as to raise the soil pH.

Climatic Condition

Growing season of 2015 and 2016 were moderate in the amount of rainfall precipitation and also with high mean daily air and soil temperatures; moisture deficiency was achieved in the middle of vegetation season (Fig. 1). Weather condition of winter 2017 was almost non typical in comparison with average for Moscow region, soil was frozen up to 36 cm; snow level was high up to 38 cm. Growing stage of spring wheat began 01.06.2017 because of low temperature condition for a long period of time.

During experimental years, meteorological data regarding temperature and rainfall was achieved from Russian Research Institute of Agriculture.

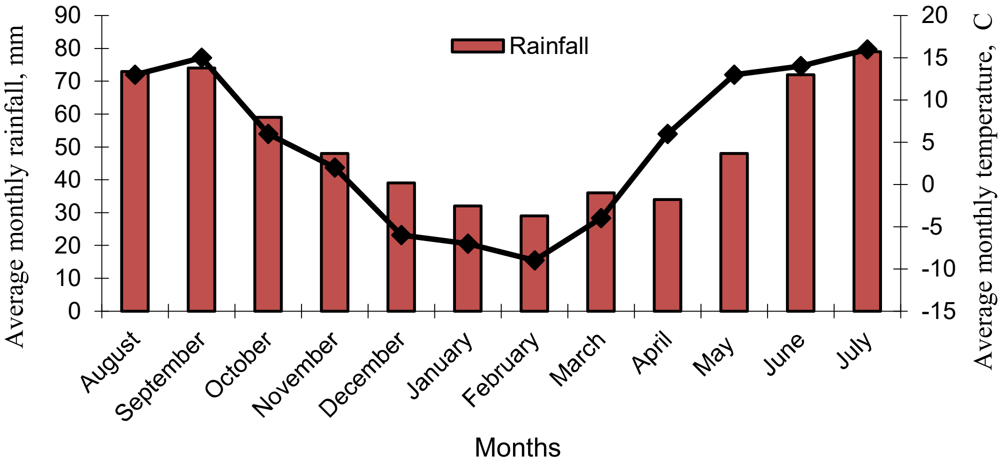

Figure 1. Average monthly rainfall and temperature during 2015–2017, Moscow region.

Experimental Design and Treatments

Field experiments were laid out once in each of the year during three-year of study. Randomized complete block arranged in a split plot experimental design with three replicates was used. Three cultivation technology treatments (basic tech, intensive tech and high intensive tech) were the main plots, and wheat varieties (Zelata, Lubova, Liza and Ester) were in the sub-main plots.

The soil was sampled from various surface layers of the fields (in depths 0 to 30 centimeters), prior to the experimentation. Sowing was done (seeder SN 16 PM) at the beginning of May maintaining plant densities of five million viable seeds per hectare.

The experiments were carried out in the field where crop rotation is adopted using different cultivation technologies and alternating crops, for instance: busy steam (vetch + oats), winter cereals, potatoes, spring cereals, and legumes. The predecessor crop to the experiment was potatoes.

Basic cropping system or (extensive farming) is an agricultural production system that uses lesser inputs of labor, fertilizers and pesticides. Basic cropping system most commonly refers to traditional farming in areas with low productivity, but can also refer to large scale of wheat cultivation. Intensive cropping system is a production system characterized by the high use of inputs involving: labor, pesticides and fertilizers. The details of the input used in three tested technologies of the experiment are given in Table 1.

Table 1. Inputs used in different cultivation technologies

Cultivation Technology	Fertilizers (kg ha^{-1})	Crop protection details
1. Basic	Basal application N_{45} P_{60} K_{90}	vincite forte 'seed treatment' (seed treat) (1.25 L t^{-1}) + picus (L t^{-1}); lintur (150 g ha^{-1}) + dietox 1 L ha^{-1}) + retardant (perfect) (0.3 L ha^{-1})
2. Intensive	Basal application N_{45} K_{60} P_{120} Top dressing, at the start of stem elongation Tillering stage N_{30}	vincite forte (1.25 L t^{-1}) + picus (1 L t^{-1}); accurate extra (25 g ha^{-1}); + dietox (1 L ha^{-1}) + alto super (0.5 L ha^{-1}); retardants perfect (0.3 L ha^{-1}) (phase GS 21–22) + retardant (perfect) (0.3 L ha^{-1}) (phase 31–32, according to the forecast)
3. High-intensive	Basal application N_{45} K_{90} P_{150} Top dressing Tillering stage N_{30} and through the tube N_{30}	vincite forte (1.25 L t^{-1}) + picus (1 L t^{-1}); accurat extera (35 g ha^{-1}) or aton (20 g ha^{-1}) + danadim power (0.6 L ha^{-1}) + alto super (0.5 L ha^{-1}); consul (0.7 L ha^{-1}), retardants perfect (0.3 L ha^{-1}) (phase GS 21–22) + supress (0.3 L ha^{-1}) (phase 31–32) + impact super (0.75 L ha^{-1}) + vantex (60 mL ha^{-1})

Data Recording

Agrophysical, agrochemical and biological observations in experiments were performed during the growing season according to the accepted methods Evans (Evans, 1993).

Statistical Analysis

Pooled data were subjected to analyses by M-STAT C (Russell, 1991, while Duncan's multiple range test was used to verify the significant differences between treatments means as described by Duncan (Duncan, 1955).

RESULTS AND DISCUSSION

Quality and productivity of four spring wheat varieties

Crop yield is the main determinative factor in the selection of a specific cultivation technology. In this study, efficacy of three cultivation technologies including intensive and high intensive technology I on spring wheat varieties was assessed. Grain yield of Lubova significantly enhanced over the three years of study ($P < 0.05$) with intensive cultivation technology, with a low coefficient of variation (3.12 to 6.33%). The highest wheat yield (10.81 t ha^{-1}) was observed with the variety Lubova under intensive technology (Table 2). Higher yields may be due to increased nutrient availability and superior growing conditions (FAO, 2012), which enhance the physiological development of wheat.

Zelata (10.46 t ha^{-1}) and Liza (10.48 t ha^{-1}) varieties also performed desirably under high intensive and basic cultivation technologies (Table 2). Managing nutrition inputs in wheat production systems is important in order to achieve maximum profitable production, and minimum negative environmental impact (Mandic et al., 2014). Le Gouis et al. (2000) found that some modern wheat varieties performed well in conditions where nutrients were comparatively low.

Table 2. Interaction effects of cultivation technology and variety on wheat yield

Interaction CT x V	Wheat yield (t ha^{-1}) 2015	Wheat yield (t ha^{-1}) 2016	Wheat yield (t ha^{-1}) 2017	Average wheat yield (t ha^{-1}) (2015–2017)	+/- % to the base
CT1 x V1	8.23 d	8.17 c	8.54 c	8.31	-
CT1 x V2	8.65 d	10.25 a	9.30 b	9.75	1.44 / 17
CT1 x V3	10.80 b	10.28 a	10.36 a	10.48	2.17 / 26
CT1 x V4	8.35 d	8.18 c	8.75 c	8.42	-
CT2 x V1	9.67 c	9.92 b	9.87 b	9.82	1.40 / 16
CT2 x V2	11.10 a	10.69 a	10.66 a	10.81	2.39 /28
CT2 x V3	8.36 d	8.42 c	8.13 d	8.30	-
CT2 x V4	9.70 c	8.64 c	9.12 bc	9.15	1.02 / 12
CT3 x V1	10.50 b	10.57 a	10.32 a	10.46	2.16 / 26
CT3 x V2	7.68 a	7.05 d	8.05 d	7.59	-
CT3 x V3	8.91 d	8.01 cd	9.38 b	8.76	1.17 / 15
CT3 x V4	9.43 c	10.40 a	9.49 b	9.88	2.29 / 30
LSD (0.05)	0.19	0.24	0.20		
CV%	3.12	6.33	5.89		

Means in columns followed by the same letter are not significantly different at P = 0.05; Abbreviations: V1, V2, V3, V4 = Varieties: Zelata, Lubova, Lisa and Esther, respectively; CT1, CT2 and CT3 = Basic, intensive and high intensive cultivation technology, respectively; CV = Coefficient of variation.

Most studies show mineral fertilization to have a positive effect on wheat productivity, with this effect being greatest in the case of nitrogen fertilization (Gevrek & Atasoy, 2012; Harasim et al., 2016). Duan et al. (2014) determined that the grain yield of wheat with 150 kg N ha^{-1} increased from 51.4 to 66.6% compared with control. In our study, intensive cultivation technology, involving the increase in the fertilizers rate of NPK, resulted in a significant effect in grain yield.

Wheat is an essential part of the diet of the world population therefore its quality traits are most critical. The interaction of experimental treatments of this study significantly affected the yield contributing traits of the spring wheat. The highest nature of the wheat grain value attained in intensive technology with Zelata (818.1 g L) and Liza (818 g L). Zelata in high intensive technology also had the high (817 g L) nature of grain. The lowest grain nature value (807.5 g L) was obtained in high intensive technology for wheat variety Liza (Table 3).

The highest gluten content (39.45%) was obtained under intensive technology with the Lubova variety. The lowest gluten percentage (35.85%) was attained in high intensive technology with Lisa. The treatment CT1 x V4 (basic technology with the Ester variety) had the lowest gluten index (58.00%). The highest gluten index (71.17%) was achieved for CT2 x V2 (intensive technology with the Lubova variety) (Table 3). Plants require three major mineral macronutrients NPK and a host of other essential micronutrients in order to develop properly (Tiffany et al., 2011) and stimulating efficacy of fertilization intensity on the growth of crops was reported earlier (Ellaminn, 2001; Fageria et al., 2008; Zargar & Pakina, 2014).

The important index to evaluate quality of wheat is grain protein (Sun et al., 2013; Ahmed & Hassan, 2015). The significant effect of fertilization on grain chemical composition was investigated earlier (Mohammed et al., 2013). The analysis of variance for protein content revealed that it was significantly influenced by level of technology applied and the variety cultivated. The highest protein content (18.02%) was obtained by both CT2 and CT3 (intensive and high technologies) with Lubova variey. Lowest protein content (16.08%) was attained by CT1 (basic technology) with Esther variety (Table 3). In this study, intensity of cultivation technology significantly affected all the investigated components of spring wheat. An increase in NPK fertilizers rate resulted in enhancement of grain protein content by an average of 18.02% for high intensive cultivation technology system (Table 3). In a similar study, Varga et al. (2003) declared that the use of an intensive production technology compared to an extensive technology significantly enhanced protein content (16.9%), gluten (59.7%), falling number (7.8%), drough resistance (138.1%).

Table 3. Interaction effects of cultivation technology and variety on grain quality traits, 1,000 grain weight and harvest index of wheat (2015–2017)

Interaction CT x V*	Nature of the grain (g L)	Gluten content (%)	Gluten index (%)	Protein content (%)	1,000 grain weight (g)	Harvest index (%)
CT1 x V1	811.2 ab	37.02 bc	68.33 a	17.04 b	45.65 ab	42.80 a
CT1 x V2	811.0 ab	38.35 ab	66.00 ab	17.31 b	46.32 a	42.77 a
CT1 x V3	814.3 ab	38.20 ab	67.33 a	17.60 b	44.3 b	41.01 b
CT1 x V4	812.7 ab	38.10 ab	58.00 b	16.08 c	43.37 c	38.59 c
CT2 x V1	818.1 a	37.00 bc	68.22 a	17.28 b	45.5 ab	41.40 b
CT2 x V2	814.0 ab	39.45 a	71.17 a	18.02 a	46.2 a	42.90 a
CT2 x V3	818.0 a	38.20 ab	58.10 b	16.80 c	45.5 ab	42.44 a
CT2 x V4	812.1 ab	37.45 abc	66.02 ab	16.76 c	44.3 b	41.00 b
CT3 x V1	817.0 a	37.55 abc	68.20 a	17.28 b	45.5 ab	41.40 b
CT3 x V2	812.0 ab	36.70 bc	68.00 a	18.02 a	46.2 a	42.80 a
CT3 x V3	807.5 b	35.85 c	69.51 a	16.80 c	45.5 ab	42.44 a
CT3 x V4	813.0 ab	37.10 bc	70.03 a	16.76 c	44.3 b	38.59 c
LSD (0.05)	8.91	2.17	8.59	1.92	2.88	0.95
CV%	2.88	3.58	7.88	4.40	4.79	6.03

Means in columns followed by the same letter are not significantly different at P = 0.05; *Abbreviations: V1, V2, V3, V4 = Wheat varieties: Zelata, Lubova, Lisa and Esther, respectively; CT1, CT2 and CT3 = Basic, intensive and high intensive cultivation technology, respectively; CV = Coefficient of variation.

There was a significant difference ($P < 0.05$) between treatments in 1,000 grain weight. The highest 1,000 grain weight (46.32 g) was with basic technology using Lubova variety, which was statistically similar to that of CT2 (intensive technology) with Lubova and CT3 (high intensive technology) with Lubova (46.2 g). Hence, the variety Lubova was the best performed spring wheat cultivar under all three levels of technology having consistent and highest 1,000 grain weight. The 1,000 grain weight of variety Esther (43.37 g) in CT1 (basic technology) was the lowest. However, the grain weight of the Esther variety significantly improved as the level of technology intensity increased from 43.37 g basic technology(43.37 g) to both intensive and high intensive technology (44.3 g) (Table 3).

Wheat yields improved greatly over the last 50 years. Phillips & Wolfe (2005) opined that much of this improvement has been due to adjusting the harvest index in favour of grain yield. The highest harvest index (42.90%) was attained in CT2 x V2 (intensive technology x Lubova variety) and was statistically similar to that CT1 x V1 (42.80%), CT1 x V2 (42.77%), CT2 x V3 (42.44%), CT3 x V2 (42.80%) and CT3 x V3 (42.44%). These findings were in agreement with those of Varga et al. (2001). The lowest (38.59%) harvest index was observed in both CT1 x V4 and CT3 x V4 (basic technology x Esther and high intensive technology x Esther).

Baking quality of wheat flour

The whole grain products consumption can be illustrated by improving their perceived attractiveness (Boz & Karaoglu, 2013). The vitality of gluten is generally assessed by its ability of enhancing the volume and improving the crumb structure of bread baked from standard flour fortified with gluten (Esteller et al., 2005). The effect of three different cultivation systems (basic, intensive and high intensive technology) on four wheat varieties such as Zelata, Lubova, Lisa and Esther were assessed for the bread quality parameters like crumb color, general score and volume output. The specific volume of bread significantly improved with intensive cultivation technology use in wheat variety Lisa (Table 4).

Table 4. Processing bread quality attributes of spring wheat grain as affected by treatments (2015–2017)

Interaction	Standard baking		
CT x V	Volume output, cm^3	Crumb color	General score
CT1 x V1	1,009.01 cd	4.81	4.60
CT1 x V2	998.10 d	4.88	4.85
CT1 x V3	1,010.00 cd	4.80	4.91
CT1 x V4	973.09 e	4.51	4.74
CT2 x V1	1,007.16 cd	4.55	4.65
CT2 x V2	1,017.21 c	4.61	4.72
CT2 x V3	1,151.19 a	4.29	4.88
CT2 x V4	962.00 e	4.38	4.89
CT3 x V1	1,014.28 c	4.48	4.64
CT3 x V2	1,037.07 b	4.44	4.75
CT3 x V3	902.50 g	4.50	4.61
CT3 x V4	924.51 f	4.47	4.80
LSD (0.05)	14.69	NS	NS
CV%	6.09	2.69	2.39

Means in columns followed by the same letter are not significantly different at P = 0.05. *Abbreviations: V1, V2, V3, V4 = Wheat varieties: Zelata, Lubova, Lisa and Esther, respectively; CT1, CT2 and CT3 = Basic, intensive and high intensive cultivation technology, respectively; NS = Not significant; CV = Coefficient of variation.

It was concluded that intensive cultivation technology (CT2) had a greater effect than basic and high intensive technologies in increasing the volume output to 1,151.19 cm^3 with variety Liza. The lowest specific volume (902.5 cm^3) was obtained with wheat variety Liza when high intensive technology (CT3) was used. Color of the crumb and overall score of the bread were not significantly affected by tested three cultivation technologies and four wheat varieties (Table 4). Intensive cultivation system, specially more intensive nitrogen fertilization, had a significant effect on wheat grain composition (Johanson, 2002). Pushman & Bingham (1976) declared that intensified wheat resulted in better milling and baking quality through enhanced, grain protein content, flour water absorption and bread volume. Varga et al. (2001) also demonstrated that intensive application of fertilizers specially nitrogen significantly improved flour properties and baking quality as a consequence of bread volume.

Interrelationship between grain yield attributes and yield

Correlation coefficient of genotypic and phenotypic are important in determining the degree to which different yield contributing characters are related. Correlation coefficients of various wheat traits indicated positively and significant correlations between nature of grains with volume output ($r = 0.380$, $p < 0.05$) and crumb color ($r = 0.704$, $p < 0.01$), but negatively with harvest index ($r = 0.125$, $p < 0.05$) (Table 5). Gluten content had significantly high correlation with volume output ($r = 0.205$, $p < 0.05$) and protein content ($r = 0.150$, $p < 0.05$). The correlation of gluten index with 1,000 grains weight ($r = 0.940$, $p < 0.01$) and protein content ($r = 0.787$, $p < 0.01$) were positive and significant (Table 5).

Table 5. Correlation coefficients of wheat yield and yields components

	GY	NG	GC	GI	PC	GW	HI	VO	CC
NG	00.41								
GC	0.090	0.003							
GI	-0.009	0.044	-0.097						
PC	0.042	-0.043	0.150*	0.787**					
GW	0.039	0.085	-0.152	0.940**	0.876**				
HI	0.151	-0.125*	0.153	0.224	0.241	0.320			
VO	0.080	0.380*	0.205*	-0.074	0.108*	0.153	0.502*		
CC	0.111	0.704**	0.172	-0.111	-0.239	-0.128	-0.235	0.125	
GS	0.116	-0.289	-0.047	-0.093	0.104	-0.044	-0.009	-0.139	0.030

*and **: significant at 0.05 and 0.01 probability levels; GY: grain yield; NG: nature of the grain; GC: gluten content; GI: gluten index; PC: protein content; 1,000 grains weight; HI: harvest index; VO: volume output; CC: crumb color; GS: general score.

Protein content was the most important effective secondary trait, which had a positive and significant genotypic correlation with 1,000 grains weight ($r = 0.876$, $p < 0.01$) and volume output ($r = 0.108$, $p < 0.05$). Volume output had the highest correlation with harvest index ($r = 0.502$, $p < 0.05$) (Table 5). The yield stability depends on yield components and other factors (Kang, 1998). Parihar et al. (2016) have reported that various wheat yield and yield components could have positive and negative correlation.

Economic efficiency of tested treatments

Most of the available research studies have focused on the production of high grain yields of wheat and have neglected significance of economic efficiency. The economic efficiency of fertilization depends on the optimization of the input norms and the ratios between the nutrients, the soil fertility, the meteorological conditions, the level of the applied technologies for crops cultivation.

The highest income was achieved with intensive cultivation technology in variety Lubova, when net income was 58,955 RUB ha^{-1} and payback 2.66 RUB RUB (Table 6).

The most profitable cultivation strategy was intensive cultivation adoption with the variety Lubova as it had the highest payback 2.66 RUB RUB, which was simpler to that obtained with basic cultivation technology using variety Liza (2.65 RUB RUB). However, the lowest profitability (1.5 RUB RUB) was observed when high intensive technology was used with a huge amount of inputs inclusive of labor, chemical fertilizers and pesticides. Jat et al. (2014) have also reported that the diversified cropping systems affected the net returns due to higher yields and differential cost of production.

Table 6. Economic efficiency of four wheat cultivars as affected by three cultivation technologies in spring wheat (average for 2015–2017)

Cultivation technology	Yield (t ha^{-1})	Gross income (RUB ha^{-1})	Cultivation cost (RUB ha^{-1})	Net income (RUB ha^{-1})	Cost: Benefit Ratio (Pay back, RUB RUB)
	Variety: Zelata				
Basic Technology	8.31	62,325	21,512	40,813	1.89
Intensive Technology	9.82	73,650	22,120	51,530	2.32
High intensive Technology	10.46	78,450	22,785	55,665	2.44
Variety: Lubova					
Basic Technology	9.75	73,125	21,512	51,613	2.39
Intensive Technology	10.81	81,075	22,120	58,955	2.66
High intensive Technology	7.59	56,925	22,785	34,140	1.50
Variety: Liza					
Basic Technology	10.48	78,600	21,512	57,088	2.65
Intensive Technology	8.30	62,250	22,120	40,130	1.81
High intensive Technology	8.76	65,700	22,785	42,915	1.88
Variety: Ester					
Basic Technology	8.42	63,150	21,988	41,162	1.87
Intensive Technology	9.15	68,625	22,702	45,923	2.02
High intensive Techology	9.88	74,100	23,029	51,071	2.21

CONCLUSIONS

The ‘*intensive farming technology*’ (moderate application of farming inputs) significantly enhanced grain yield (10.8 t ha^{-1}), harvest index (42.9%), gluten content (39.45%) and gluten index (71.17%) of spring wheat cultivar Lubova. The highest protein content (18.02%) was observed with ‘*intensive and high intensive farming technologies*’ with the cultivar Lubova, while the highest 1,000 grains weight (46.32 g) was recorded with cultivar Lubova in ‘*basic cultivation technology*’.

Applying moderate amount of agricultural inputs as an '*intensive farming technology'* resulted in highest spring wheat yield and net income (58,955 rub. ha^{-1}) and cost: benefit ratio (2.66 rub. rub payback). Hence, producers should be advised not to use large amounts of farming inputs as in '*high intensive farming technology*', since it increases production costs and reduces the economic benefits.

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