IMPACT OF SUBSOILING AND SCATTERED SOWING ON SOME SOIL PHYSICAL PROPERTIES AND WHEAT PRODUCTIVITY

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Abstract. The demonstrational on-farm field experiment (three agricultural farms in Vilkaviškis, Pakruojis and Kretinga regions, Lithuania) were carried out in 2010-2012 on light and average loam soils. The aim of the experiment was to evaluate and demonstrate the impact of subsoiling and scattered sowing operations on some soil physical properties and wheat productivity parameters in different regions of Lithuania. Deep soil tillage (subsoiling, Agrisem Combiplow) was performed at 40-45 cm depth before beginning of the experiment. The soil physical properties were tested at the renewal of wheat vegetation in spring. Scattered sowing was performed with Agrisem Disc-O-Sem drill. The results of the experiment showed that subsoiling destroyed hardened deep soil layers, and we found the influence of this operation during the time (3 years) of the experiment. Scattered sowing with shallow disking warranted favourable soil physical properties for wheat germination and development. Structural particles of the researched fields were water resistant. After affecting them with water, about 60 % of the particles remained solid. Unstable (dusty) microstructure made only 0.5-4.6 % and did not exceed the permissible limit. The limit of the soil bulk density (1.4 $g \cdot cm^{-3}$) was not exceeded in any experimental field, too. These affected on high grain (on average about 6 $t \cdot ha^{-1}$) productivity.

Keywords: physical properties, productivity, scattered sowing, subsoiling, wheat.

Introduction

Minimal soil tillage technology has essential positive effect on the soil characteristics. Especially, stability of the soil structural particles gets better; such soil accumulates more moisture, and surplus water penetrates to deeper layers. Characteristics of such soil usually reveal themselves during the 4-5th year [1].

Long-term ploughless soil processing increases endurance, resistance to water and wind erosion of surface soil particles comparing to the traditional soil processing technology [2]. Surface soil erosion is also affected by plants. It was found that winter wheat has a greater effect on prevention of soil erosion in comparison to corn or soy [3]. Liebig *et al* [4] state that applying minimal soil tillage technologies in the surface soil layer (7.5 cm), stability of soil aggregates is about 34 % higher compared to conventional soil tillage. Six *et al.* [5] found that when processing soil minimally, from macroaggregates present in soil more stable microaggregates (compared to soil tilled in a conventional way) are formed. Sowing winter wheat directly or to minimally tilled soil, plant remains reduce water vaporisation; thus the soil surface is moister [6-11]. Ploughless soil processing increases water infiltration [12-13]. Busscher *et al*. [14] determined that soil penetration resistance reduction 1 MPa, on the average, increases wheat harvest from 1.5 to 1.7 $t \cdot ha^{-1}$.

Reduction of soil tillage intensity has various effects on harvest of winter wheat. It depends on the soil and climatic conditions. As it has been determined by the research, in dry climate (annual quantity of precipitation is up to 42 mm) various soil tillage technologies do not affect harvest of winter wheat [15]. Growing winter wheat in moist mulch soil (annual quantity of precipitation is more than 1000 mm), the grain harvest was higher in conventionally tilled soil.

A lot of research has been performed applying the non-tillage soil processing technology; however, modern technique and changing climatic conditions require performing comprehensive experimental and production research. The aims of this paper are to: (1) evaluate the soil physical properties and (2) establish the wheat productivity parameters.

Materials and methods

In 2010-2012, the demonstrational on-farm field experiment was carried out at agricultural farms in three different part of Lithuania: Central (Vilkaviskis reg.), Northern (Pakruojis reg.) and Western (Klaipeda reg.). The experimental soil was light to medium loam. Soil texture:

- Vilkaviškis region – dusty light loam (dp). Sand fraction makes 35 %, dust – 60 %, silt – 5 %;

- Pakruojis region – averagely difficult loam (p_1). Sand fraction makes 35 %, dust – 40 %, silt – 25 %;
- Klaipėda region – sandy light loam (sp). Sand fraction makes – 65 %, dust – 20 %, silt – 15 %.

Experimental winter wheat fields were cultured of even relief, monolithic granular-metric composition and similar soil group, non-widely distributed perennial weeds; non-soaking, optimal quantity background of nutritive materials is made. Preceding crop of winter wheat is winter rapeseed. The technological operations are indicated in Table 1.

Table 1

Technological operations and timing

Technological operation	Timing
1. Soil tillage (subsoiling up to 40 cm depth + disking up to 5-8 cm depth)	After harvest of pre-crop
2. Fertilization (NPK 8:20:30, 150 kg·ha^{-1})	Two weeks later
3. Disking + scattered sowing. Sowing rate – 200 kg·ha^{-1} of seeds, sowing depth – 3-5 cm, variety "Olivin""	After fertilization
4. Fertilization (N_{60}, ammonium nitrate, about 200 kg·ha^{-1} + NPK 8:20:30, 200 kg·ha^{-1})	At the renewal of vegetation in spring
5. Spraying with growth regulators (Kemira CCC, 1 l·ha^{-1}, amount of solution – 200 l·ha^{-1})	From tillering to stem elongation
6. Spraying with herbicides (Granstar 0.008 kg·ha^{-1} + Primus 0.07 l·ha^{-1} + Kemiwett S 0.1 l·ha^{-1}, amount of solution – 200 l·ha^{-1})	Spring, at the time of tillering
7. Fertilization (N_{30}, amonium nitrate, 100 kg·ha^{-1})	Booting
8. Spraying with fungicides (Bumper, 0.5 l·ha^{-1}, amount of solution – 200 l·ha^{-1})	From booting to flowering
9. Spraying with insecticides (Fastac, 0.2 l·ha^{-1}, amount of solution – 200 l·ha^{-1})	At the time of insects attack
10. Spraying with fungicides (Opera, 0.75 l·ha^{-1}, amount of solution – 200 l·ha^{-1})	From ear emergence to flowering
11. Harvest	Ripening

Deep soil tillage (subsoiling, Agrisem Combiplow) was performed at 40-45 cm depth before beginning of the experiments (Fig. 1, a). The soil physical properties were tested at the renewal of wheat vegetation in spring. Scattered sowing was performed with Agrisem Disc-O-Sem drill (Fig. 1, b).

a) b)

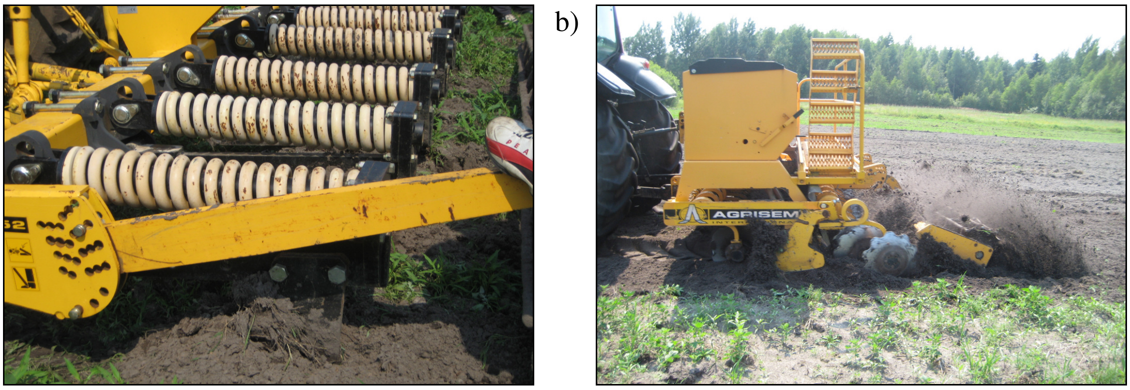

Fig 1. **Tillage and sowing equipment:** a – subsoiler Agrisem Combiplow; b – drill for scattered sowing Agrisem Disc-O-Sem

Samples of soil granulometric composition (texture) were taken by the agrochemical drill not less than in 10 places of the experiment. The explored layer is 0-25 cm. Granulometric composition is evaluated by the organoleptic method by bending soil stick (in field conditions); the results of laboratorial research of the samples are grouped according to graphically expressed Fere triangle [16]. Samples for determination of the soil structure and its stability were taken in not less than 5 places of the experiment. The researched layer is 0-25 cm. Average samples were made. The analysis was performed applying the N. Savinov method using the dry and moist soil sieving method. Using the dry method, a sample is sieved through sieves with holes the diameters of which are 10, 7, 5, 3, 2, 1, 0.5 and 0.25 mm. Moist sieving is performed using sieves with holes the diameter of which is 5-0.25 mm. Moisture and density of soil are determined by a cylinder method. Cylinder volume is 200 cm^3. The samples were taken applying the Nekrasov drill in the depth 0-10 cm not less than in 10 places of the experiment. The samples were dried in 105 ºC temperature till constant mass. According to differences of the moist and dried soil masses, their moisture was determined and density calculated. Penetration resistance was measured by an electronic penetrologger.

Analysing the soil penetration resistance, five measurements in the area of 1.0 m^2 were taken. Measuring soil moisture, additionally the soil moisture sensor was connected. Evaluating wheat productivity, the crop density and biological grain harvest were determined. The research was done in not less than 10 places in the square of 0.06 m^2. Wheat productive stems were calculated, ears were picked and grain was weighted. It is desirable to set average mass of 1000 grains. Mass of 1000 grains was set calculating 3 samples of 1000 grains: they were weighted, and their arithmetical average was calculated. If the difference of the sample mass exceeded 5 %, the fourth sample was calculated and weighted.

2010-2011 weather conditions were not favourable for wheat wintering and in the Northern and Western experiments winter wheat cultivations were under sown with spring wheat. ANOVA was applied for data statistical evaluation.

Results and discussion

Soil structural compositions and water resistance. In 2010, the quantity of mega structure did not correspond to these requirements and reached up to 60 % (Table 2). Model soil structure requirements are valid for physical maturity soil. During the research, the soil was too moist; apart from that, it was flooded during winter and spring. With increase of the mega structure, macro and mezzo structure particles decreased accordingly. As it has been determined by the research, the mega structure on the soil surface should make up to 5 percent. Micro structure was set a little; so, it was possible to predict that crust shall not form on the soil surface when it is moist and later getting dry. Structural particles of the researched fields were water resistant. After affecting them with water, about 60 % of the particles remained solid. It showed that the chosen agrotechnique did not damage the soil structure.

Table 2

Soil physical properties at the renewal of winter wheat vegetation

Site of investigations (part of Lithuania)	Structural composition, particles, %				Water resistance, %	Moisture content 0-5 cm, %	Moisture content 0-10 cm, %	Bulk density, $g \cdot cm^{-3}$
	mega- > 10 mm	macro- 1-10 mm	mezzo- 3-5 mm	micro- < 0.25 mm				
2010								
Central	53.3b	45.7b	9.0b	1.0b	68.2ab	34.1a	26.0a	1.22ab
Northern	42.5c	55.4a	11.2a	2.1a	67.8b	28.6b	20.7b	1.24a
Western	66.8a	32.7c	6.5c	0.5c	70.0a	32.9ab	26.1a	1.17b
2011								
Central	57.7b	40.7a	8.1b	1.6a	74.1a	21.7a	21.8ab	1.25a
Northern	70.9a	28.1b	6.2c	1.0a	77.0a	21.5a	23.5a	1.24a
Western	60.7b	38.6a	9.4a	0.7a	78.8a	21.5a	20.1b	1.20a
2012								
Central	40.5ab	57.0b	14.2a	2.5bc	70.0a	19.6ab	18.4ab	1.20b
Northern	45.4a	52.6c	12.9a	2.0c	57.2c	20.1a	19.7a	1.27ab
Western	31.2b	64.2a	14.1a	4.6a	64.8b	15.0b	14.6b	1.37a

Numbers followed by different letters within the same column are significantly different at $p < 0.05$.

In 2011, the soil of all researched regions was rather structural (Table 2). It contained sufficient quantity of macro and mezzostructure needed for development of plants. The microstructure was from 0.7 to 1.6 % (maximal permissible quantity is 5 %). Such soil is resistant to wind erosion. After strong rain, the surface of such soil does not soften, and later when the soil dries, crust does not form on the soil surface. The soils of farms of all regions are characterised by high soil structure endurance to water impact. Endurance of the researched soil reached 79 %.

In 2012, it was determined that in the soil of Vilkaviškis and Pakruojis regions in spring macrostructure favourable for plant growth prevails; also, there is a lot of water resistant mezzostructure (Table 2). Unstable (dusty) microstructure made only 2-2.5 % and did not exceed the permissible limit. In the soil of farm of Klaipėda region, dusty particles were twice more than in other regions. However, the permissible 5 % limit was not exceeded. Water resistance of the structure in all tests in all regions was high. Only in Pakruojis region is was the lowest. It could be influenced by the fact that the soil samples were taken from moister soil conditions.

Soil moisture content and bulk density. In 2010, due to high quantity of precipitation, moisture of the soil surface during the tests was high (0-5 cm soil layer). In the field of Vilkaviškis region, moisture reached 34 %, and in Klaipėds region it reached 33 % (Table 2). Under such conditions, water gets into the soil, pushes out the air and speeds up washing of nutritive materials. More optimal moisture conditions were determined having researched a thicker soil layer – from 0 to 10 cm. The research showed that excessive water did not infilter to deeper soil layers. Under such conditions, bogs may form on the soil surface, and if they stay longer, the crop may die. Marginal soil density for springing and development of the majority of cultural plants is 1.60 $g \cdot cm^{-3}$. In 2010, in all the researched experimental fields the soil density in the depth of 0-10 cm did not reach 1.30 $g \cdot cm^{-3}$, and it was optimal for growth of winter wheat.

In 2011, it was determined that there was enough moisture for development of summer wheat (Table 2). Its quantity in 0-10 cm soil layer was similar in all the researched regions. Similar tendencies were determined after research of the upper soil layer (0-5 cm depth). A bit more moisture in the soil surface was determined in the Pakruojis region summer wheat field since it rained in this region not long ago. Soil density also varied only little and met the requirements for quick development of summer wheat crop. Least subside soil was in Klaipėda region where its density reached 1.20 $g \cdot cm^{-3}$.

In 2012, after the research of soil moisture in Vilkaviškis and Pakruojis regions, its favourable meanings were determined. In Klaipėda region, moisture was the smallest and reached the limit of dry development environment (Table 2). Marginal soil density for development of the majority roots of agricultural plants is 1.40 $g \cdot cm^{-3}$. According to the research data, this limit was not exceeded in any experimental field. A bit higher density was noticed in the Klaipėda region farm; however, it is natural because more resistant to penetration soil prevailed there.

Soil penetration resistance. In 2010, the most favourable soil penetration resistance conditions were set in the farm of Vilkaviškis region. Up to the depth of 20 cm, the soil penetration resistance did not exceed 1 MPa. It started to increase in the depth of 30 cm and remained in the same level till deeper layers (Fig. 2). In the experimental field of Pakruojis region, in the depth of 30-40 cm the soil penetration resistance was noticed, which could be influenced by usage of hard agricultural technique. In Klaipėda region, significant penetration resistance variations were not noticed. The soil penetration resistance started to evenly increase from the depth of 20 cm.

In spring 2011, in the farm of Vilkaviškis region, the soil penetration resistance of summer wheat crop within the entire measuring depth varied rather evenly (Fig. 2). In the depth of 25-30 cm, the soil penetration resistance was up to 3 MPa, *i.e.* according to the soil penetration resistance classification, the soil was rather penetration resistant. In deeper layers, the soil penetration resistance increased more quickly; the soil was hard and very hard. In Pakruojis region summer wheat crop, soil penetration resistance in the upper layer up to 10 cm was up to 1.0 MPa, up to 30 cm – up to 2.0 MPa. In deeper layers, the soil was rather hard; however, very hard soil (> 5.0 MPa), as in other regions, was not determined. In Klaipėda region farm spring wheat crop, the soil penetration resistance up to 50 cm deep increased very evenly. Significant soil penetration resistance deviations were not noticed. Despite this, increase was rather even; however, it is worth noticing that it was rather quick since in the depth of 40 cm and deeper soil layers the penetration resistance was rather high.

In spring 2012, having measured penetration resistance (Fig. 2) in crop of winter wheat in the farm of Vilkaviškis region, it was determined that the resistance increased significantly from the surface of soil to the depth of 20 cm. In deeper layers, soil hardness got stable, and from 26 cm, it started to reduce. According to the penetration resistance qualification, in the upper surface to 8 cm depth the soil was loose; deeper, the soil was harder, and in some places it was hard. In the Pakruojis region farm, the penetration resistance of winter wheat crop in the upper layer till 10 cm depth was up to 2.0 MPa (according to the soil hardness qualification – loose), till 46 cm, it reached 3.0 MPa (rather hard). In deeper layers, the soil was hard. In the Klaipėda region farm, the penetration resistance of winter wheat crop till 12 cm depth was loose. From 12 to 40 cm depth – rather hard, deeper – hard.

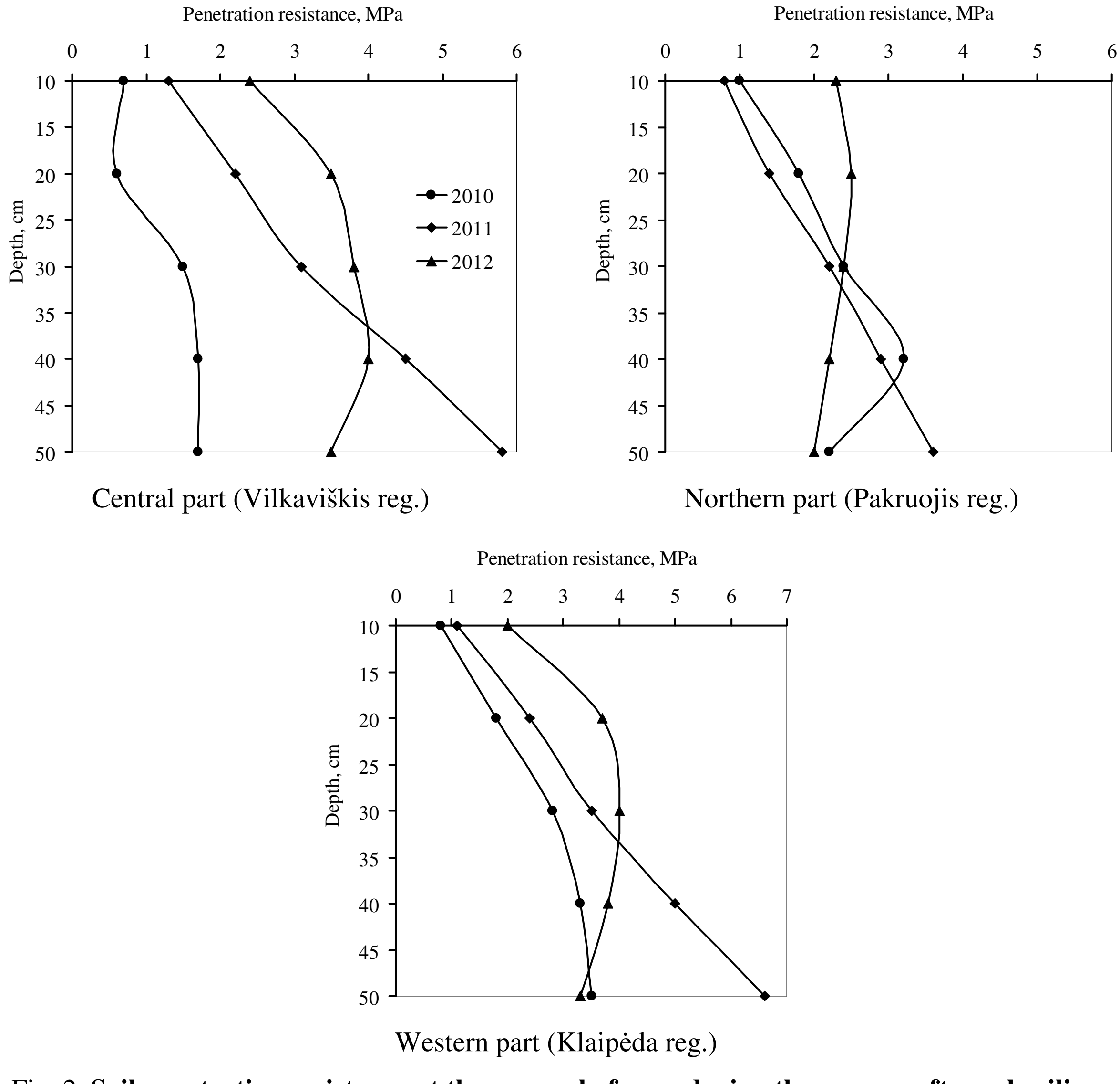

Fig. 2. **Soil penetration resistance at the renewal of crop during three years after subsoiling**

Wheat productivity parameters. In 2010, the crop got a bit sparse during the vegetation period due to very high quantity of precipitation and influence of spreading plant diseases. Despite this, the crop was sufficiently dense. Wheat grown by the farmer of Klaipėda region was the densest (Table 3). On the average, 381 plants were found in one square meter; the general quantity of stems reached 528 pcs, and the quantity of productive stems was 511 pcs. Similar quantity of productive stems was found in the wheat field of Pakruojis region farmer. A bit less productive stems were formed in Vilkaviškis region. High level agrotechnics and favourable phytosanitary conditions of crop conditioned high winter wheat harvest in Pakruojis and Klaipėda regions farms. Grain harvest in

Pakruojis region was more than 6 t·ha^{-1}, and in Klaipėda region it was more than 7 t·ha^{-1} (Table 3). The biggest grain was grown in Klaipėda region. Due to minimal crop fertilisation and the non-balanced plant protection system, wheat of Vilkaviškis region farmer was smaller, and its harvest did not reach 4 t·ha^{-1}.

Due to unfavourable winter conditions in 2010/2011, the crop of winter wheat froze; so, in spring, spring wheat was sown. In Vilkaviškis and Pakruojis regions, spring wheat got well bushed; so, the general number of stems reached more than 600, and the number of productive stems reached about 600 pcs·m^{-2}. It is an optimal index. In Klaipėda region, due to dry wheat tillering conditions, the crop was rather rare; however, the general quantity of stems reached 480.6, and the quantity of productive stems was 456.2 pcs·m^{-2}. Under such conditions, 1-1.5 t·ha^{-1} less yield of grain was reached; however, grains were bigger (Table 3).

Table 3

Winter wheat productivity parameters

Site of investigations (part of Lithuania)	Total number of stems per m^2	Number of productive stems per m^2	Yield of grain, t·ha^{-1}	Mass of 1000 grain, g
2010				
Central	484b	461b	3.73b	27.6c
Northern	531a	531a	6.10a	33.4b
Western	528a	511a	7.09a	44.0a
2011				
Central	690a	597a	5.80a	43.60a
Northern*	687a	637a	5.39a	42.13a
Western*	481b	456b	4.25b	45.24a
2012				
Central	588a	583a	9.05a	53.10a
Northern	596a	596a	6.01b	40.34c
Western	450b	446b	5.58b	46.87b

* – under sown spring wheat. Numbers followed by different letters within the same column are significantly different at $p < 0.05$.

In 2012, during the entire vegetation of winter wheat, the best crop was in Vilkaviškis region farm; so, the highest grain harvest was evaluated there – it reached 9 t·ha^{-1} (Table 3). In other farms, the grain harvest was smaller; however, it reached about 6 tons. A higher grain harvest in Vilkaviškis region was conditioned by higher grain mass which reached 53 grams. Due to high density of crop in the first part of vegetation in Pakruojis region, smaller grains were formed; so, the harvest potential was not fully used. It was also influenced by higher dispersion of plant diseases.

Conclusions

1. Subsoiling destroyed hardened deep soil layers (hardpans). This operation influenced on soil compaction properties during 3 years of the experiment.
2. The soil particles of the researched fields were water resistant. After affecting them with water, about 60 % of the particles remained solid. Unstable (dusty) microstructure made only 0.5-4.6 % and did not exceed the permissible limit. The limit of the soil bulk density (1.4 g·cm^{-3}) was not exceeded in any experimental field, too.
3. The wheat productivity parameters varied during 3 years of investigations. Grain productivity was on average about 6 t ha^{-1}, mass 1000 grain – 42 g.
4. The wheat growing technology supported by environment friendly scattered shallow hoeing and deep subsoil hoeing, application of scattered sowing and balanced fertilisation and plant protection secures not only optimal maintenance of the soil characteristics, but also perfect state of crop and high productivity of wheat grain.

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