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WinFOLIA flag leaf analysis of winter wheat (Triticum aestivum L.) and evaluation of grain quality indicators

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Abstract.** **Winter wheat (**Triticum aestivum **L.) is one of the most widespread and economically beneficial crops in Latvia. Wheat grain yield and quality are strongly related to the growing conditions of crop that are possible to improve agronomically by carrying out an appropriate soil tillage and growing it in a well-planned crop sequence. The aim of the study to determine soil tillage system and precrop influence to winter wheat flag leaf parameters and grain yield quality indicators. A two-factor field trials was set up in the Latvia University of Life Sciences and Technologies training and research farm "Peterlauki" in 2022/2023: 1. soil tillage system and 2. precrop. The basic indicators of flag leaf length, width (cm) and flag leaf area (cm2) of a winter wheat were detected using a scanner STD4800 and the specialized computer program WinFOLIA Regent Instruments Software were determined from 10 plants in each variant. Three samples from each variant were taken for yield determination and structural elements of crops. Winter wheat 1000 grain weight and grain quality indicators were determined in Grain and Seed study and research laboratory of LBTU. Winter wheat precrop did not significantly affect (p>0.05) grain yield in the trial year, but the lowest yield was obtained in the conventional soil tillage system where wheat was grown in repeated sowings (5.1 t ha-1), and the highest yield in the minimal soil tillage system where precrop was field beans (7.0 t ha-1). The larger winter wheat flag leaf area was determined in both soil tillage systems, if the winter wheat precrop was field beans, the relationships are not significant (p>0.05).

***Keywords:** grain quality, precrop, soil tillage, WinFOLIA, winter wheat, yield.*

I. INTRODUCTION

Wheat belongs to the family *Poaceae* and is an important cereal crop for the vast majority of people around the world [1] and it is also an annual staple food crop, with an average planting area of more than 23 million hectares in the European Union, with an average yield of 5.5 t ha^{-1} dry weight [2]. Literature also indicates that the main bread wheat is grown in various parts of the world, including Europe and Latvia [3], [4]. Research in scientific articles shows that wheat contains rich ingredients such as carbohydrates, vitamins (especially B vitamins), gluten proteins and phytochemicals that are essential for human health. In fact, the unique properties of the gluten protein fraction allow the processing of wheat into bread, pasta, pastries, noodles and the production of a wide range of functional ingredients [5], [6], [7], supplying a fifth of global food calories and protein [8], [9]. Furthermore, scientists from Uman National University of Horticulture, Ukraine Hospodarenko and Liubych [7] reported crop productivity is the most variable and significant indicator of their vitality, this increases their genetic potential, soil fertility, weather and aspects of the cultivation method. According to research findings from Latvia, the process of cereals' maturation and harvesting is possible during the rainy season, this is often attributed to a low quality of the grain and even grain sprouting in ears [10]. Indeed, just a few studies have noted that the sudden weather changes, floods, strong winds, heavy rains and storms, hail,

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droughts, which lead to significant environmental and economic damage around the world and affect the yield of most crops, especially cereals [11], is anticipated to have a marked negative impact on crop production [12].

Scientist from Kalam Technical University Lucknow, India [13] evaluated the most recent scientific studies that have been published, and concluded that the leaf is a reflection of the plant's health and the area of the leaf is one of the most important parameters in tracking the plant's growth. As a result, the greater amount of data is available to get about the leaf – the better quality of decision making is expected. Researchers Pandey and Singh [14] has accepted that the area of the leaf is estimated in studies of plant nutrition, competition, water relations, protection, respiration, light reflectance, and heat transfer in plants. Because of this, it's an important component of the understanding of photosynthesis, light interception, water and nutrient utilization, and the potential for crop growth and yield. In turn by University of Göttingen, Germany scientists study leaf traits are among the most important traits as they describe key dimensions of a plant's life history strategy. Further they emphasizes that leaf area is a key parameter with relevance for other traits such as specific leaf area, which in turn correlates with leaf chemical composition, photosynthetic rate, leaf longevity, and carbon investment. Measuring leaf area usually involves the use of scanners and commercial software and can be difficult under field conditions [15]. Scientists have proven in their research that the measuring leaf area can be difficult under field conditions as standard protocols require a scanner, computer, and digital image processing by sophisticated and often expensive software to obtain accurate and reliable results, e.g., WinFOLIA (Regent Instruments Canada Inc.), [15]. WinFOLIA is a computer image analysis system that accurately do morphological measurements on broad leaves. It comprises hardware for image acquisition (scanner or digital camera and accessories) and a computer program, WinFOLIA, specifically designed for leaf analysis (area, morphology and disease analysis) [16]. Studies revealed that knowledge of leaf parameters is necessary for numerous calculations in agronomy. It is critical for an understanding of crop production, crop growth, weed control, crop–weed competition as a area of leaves impacted by plant diseases and pests [17], [18].

The aim of the study to determine soil tillage system and precrop influence to winter wheat flag leaf parameters and grain yield quality indicators.

II. Materials and Methods

Study fields. A two-factor field trials with winter wheat cultivar 'Zeppelin' (Latvia) was set up in the Latvia University of Life Sciences and Technologies training and research farm "Peterlauki" (56°30.658′ N and 23°41.580′ E) in 2022/2023: 1. soil tillage system and 2. precrop. Latvian Seed Breeder's Association 'Zeppelin' describes: type of use for food grain production, an early, winter-hardy winter wheat variety that stands out with stable, high yields (https://www.syngenta.lv/product/seed/zeppelin). Soil tillage systems were applied for each precrop: a conventional soil tillage system with ploughing at a depth of 22 to 23 cm and minimal soil tillage system with disc harrowing at a depth to 10 to 12 cm. The field trial was arranged in split-plot design two blocks. Each blocks was split forming six field trials (0.25 ha each) with different precrop.

Three different variants of precrop were examined: wheat after field beans (W–FB); wheat after wheat (W–W); wheat in repeated sowings (W–W–W). The field trial was arranged in a two-factorial split–plot design in two blocks.

Winter wheat was sown in 25 September 2022, seeding rate from winter wheat variety was 420 seeds per m^{-2}, start of vegetation period in 12 April 2023. Winter wheat was harvested on 15 August. Harvesting, three sample sheaf's (each from 0.1 m^2) were taken from every plot, which was later used to calculate the grain yield, by uprooting the plant.

The basic indicators of flag leaf length, width (cm) and flag leaf area (cm^2) at wheat tillering growth stage BBCH 44 of a winter wheat were detected using a scanner STD4800 and the specialized computer program WinFOLIA Regent Instruments Software (Figure 1). The winter wheat flag leaves were taken in each field places, in each place in 10 repetitions according to the principle of randomization.

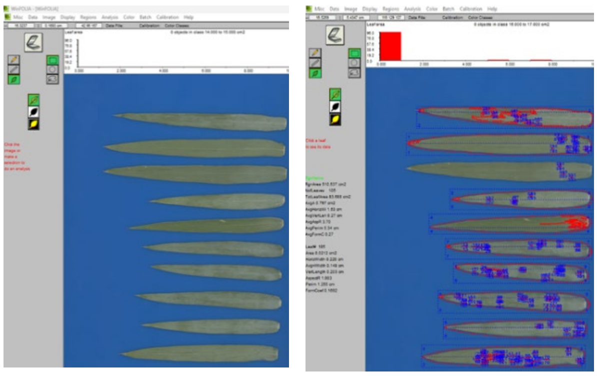


Fig. 1. Winter wheat flags leaves placed in the scanner (A) and the analysis process (B).

Sample sheafs for winter wheat were taken before the yield harvesting at BBCH 87 for analysis of crop yield components from 0.1 m^{-2} area at three locations randomly selected in each replication. The following yield components were detected: number of ears per m^{-2}, grain number per ear, 1000 grain weight (g). After harvesting the whole plots, yield's data was calculated to standard moisture (14%) and 100% purity [19].

The evaluated yield structural elements were: number of winter wheat spikes, pcs. per m^{-2} (counted from (20×50 cm) 0.1 m^2 frame (sample sheaf) and recalculated per m^{-2}), root mass, kg; number of productive stems, pcs.; mass of spikes, kg; mass of straw, kg; grain weight of sample sheaf, kg.

Wheat grain qualities. The winter wheat grains analysed at the Latvia University of Life Sciences and Technologies in Grain and Seeds research laboratory.

The plots were combine-harvested at grain ripeness BBCH 89. Winter wheat grain quality indicators – *crude protein content* (CP, %); *starch content* (SC, %); *gluten content* (GC, %) and *Zeleny index* (ZI, %) were detected by the Near Infrared Spectroscopy (NIRS) method (analyser InfratecTM NOVA (FOSS, Hillerød, Denmark)). *The thousand grain weight* (TGW, g) was determined according to the standard ISO 520:2010.

Meteorological conditions according to Latvian Environment, Geology and Meteorology data. April 2023 with an average air temperature of +7.4 °C (1.3 °C above normal). May was cooler than normal, with an average air temperature of +11.3 °C (0.1 °C below normal), which influenced plant growth and development. June as a whole, with an average air temperature of +16.6 °C (1.4 °C warmer than the monthly norm). On August 15, a week-long heat wave of +34.4 °C began, and until the end of August, daily average air temperatures remained above normal. The summer started with a great drought. In June, the total amount of precipitation was 22.9 mm, which is 67% below the monthly norm (70.1 mm). In contrast to a dry June, August became the 4th wettest on record, with a total of 144.7 mm of precipitation, 88% above the monthly normal (76.8 mm). The data sets generated during and analyzed during the current study are available in the repository of LEGMC Latvian Environment, Geology and Meteorology Centre, *https://www.meteo.lv/meteorologija.*

Statistical analysis. Analyse of variance were used for data statistical processing, whereas the significance of differences between mean values was evaluated with p-value.

III. RESULTS AND DISCUSSION

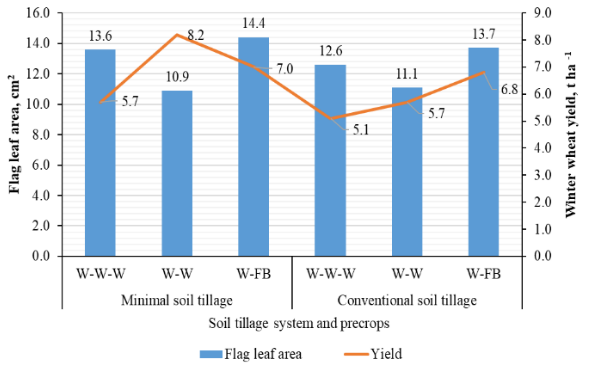
Article summarizes the research findings on the soil tillage system and precrop influence to winter wheat flag leaf parameters and grain yield quality indicators. Literature from different scientific journals all around the world has been used. It includes information from studies conducted in Latvia, Poland, Bulgaria, Switzerland, Ukraine, Uzbekistan and other countries.

The flag leaf area, are the main source of carbohydrates production. At least 50% of photosynthetic products for grain are provided by flag leaf, the most important organ for photosynthesis. Some traits, such as size and shape of flag leaf, affect photosynthesis to a certain extent, thereby influencing production [20].

In the trial year, a higher yield of winter wheat was obtained in the minimal soil tillage system, when the precrop was wheat (8.2 t ha^{-1}), but in the conventional soil tillage, when the precrop was field beans (6.8 t ha^{-1}), the relationships are not significant ($p>0.05$) (Figure 2). The larger winter wheat flag leaf area was determined in both tillage systems, if the winter wheat precrop was field beans (MT 14.4 cm^2 and CT 13.7 cm^2), the relationships are not significant ($p>0.05$).

In turn scientific studies in Latvia [21], [22] determined that the area of flag leaf had significant $p<0.05$ effect to winter wheat grain yield. Therefore, it was reasonable that wider crop flag leaf may increase photosynthetic area, so that the source supply was enhanced, and thereby crops yield improved [20].

Weather conditions in 2023 were with heat wave und with a great drought of Latvia (in provided in Materials and methods). This means that winter wheat plants were in stress conditions, which affected the formation of fewer productive stems, grain mass and others winter wheat yield structural elements. Table 1 shows results evidenced the remarkable influence of the environmental conditions that occurred during the study on same the winter wheat agronomic traits evaluated. The winter wheat root weights of conventional soil tillage (CT) and minimal soil tillage (MT) treatments were not significantly ($p>0.05$) different in all investigated factors, except at MT W–FB had the highest root dry weight (0.18 kg m^{-2}) of sample sheaf compared to W–W–W (0.09 kg m^{-2}) of sample sheaf, it was not statistically significant. The difference in root distribution can be attributable in part to the slower preliminary growth of plants in minimal soil tillage systems due to competition of weeds. In addition, scientists emphasize that the shoot: root ratio is generally affected by nutrient status of soil, climatic conditions [23].



W–FB wheat after field beans; W–W wheat after wheat; W–W–W wheat in repeated sowings.

Fig. 2. Winter wheat flag leaf area and yield analysis.

The higher biomass not only helps crop plants compete better with weeds, thus reducing herbicide applications, but also enhances the quality of degraded rainfed soils, clearly being advantageous for sustainable agroecosystems [24]. Scientists from Spain [24] reported the increased root biomass contribute to improve wheat plant's ability to capture resources and can lead to a greater ground cover, reducing soil temperature and water lost by evaporation.

Despite the fact that winter wheat number of spikes (490 to 710 pcs. m^{-2} of sample sheaf) was higher by minimal soil tillage system but it was the lowest (420 to 535 pcs. m^{-2} of sample sheaf) by minimal soil tillage system it was not significantly ($p>0.05$) affected by soil tillage systems in all field trial variants (provided in Table 1).

Significant spikes mass, kg straw mass and grain weight, kg difference was not found ($p>0.05$), whether the precrop was W–FB, W–W, W–W–W. Significant differences ($p<0.05$) of spikes mass, kg straw mass and grain weight, kg were observed depending on soil tillage systems.

Gluten content (GC). Soil tillage systems affected the gluten content not significantly ($p>0.05$) are in provided in Table 2. Under conventional soil tillage system the gluten content was higher (22.90%) than minimal soil tillage system (19.22%). Precrop also affected the gluten content in grain not significantly ($p>0.05$). Higher average gluten content was observed when wheat was grown after field beans. Scientists from Uman National University of Horticulture, Ukraine Hospodarenko and Liubych [7] reported that the protein and gluten content are most dependent on weather conditions during grain maturation and the use of nitrogen fertilizers [7].

TABLE 1. WINTER WHEAT STRUCTURAL ELEMENTS OF THE SAMPLE SHEAF M^{-2} DEPENDING ON INVESTIGATED FACTORS

Factors	Root mass, kg p=0.68	Spikes, pcs. p=0.23	Spikes mass, kg p=0.71	Straw mass, kg p=0.83	Grain weight, kg p=0.72
Precrop / Soil tillage system					
W–FB	0.18	560	1.20	0.58	0.99
W–W	0.12	710	0.91	0.49	0.74
W–W–W	0.09	490	0.80	0.38	0.66
MT	0.13	587	0.97*	0.48*	0.80*
Precrop / Soil tillage system					
W–FB	0.13	535	1.25	0.59	1.00
W–W	0.13	497	1.02	0.42	0.83
W–W–W	0.09	420	0.84	0.38	0.71
CT	0.12	484	1.04*	0.46*	0.85*
MT/CT	p=0.11	p=0.39	p=0.01	p=0.01	p=0.01

W–FB wheat after field beans; W–W wheat after wheat; W–W–W wheat in repeated sowings; MT – minimal soil tillage system; CT – conventional soil tillage system; significant at p<0.05.

Starch content (SC) is not among the traditionally evaluated indicators for food wheat grain quality. It is should be evaluated in cases when wheat grain is intended for the production of ethanol [25]. Results of our trial show that the average starch content in wheat grain was 68.93 to 71.23%. In our study, soil tillage system (p>0.05), precrop (p<0.05) had a significant impact on starch content.

TABLE 2. WINTER WHEAT GRAIN QUALITY INDICATORS DEPENDING ON INVESTIGATED FACTORS

Factors	GC, % p=0.07	SC, % p=0.01	ZI, % p=0.08	CP, % p=0.05	TGW, g p=0.79
Precrop / Soil tillage system					
W–FB	20.95	70.57	37.99	11.53	50.35
W–W	20.17	70.50	34.36	11.10	45.86
W–W–W	16.53	71.23*	29.69	10.07	46.88
MT	19.22	70.77	34.01	10.90	47.70*
Precrop / Soil tillage system					
W–FB	24.00	68.93*	42.36	12.43	50.90
W–W	22.77	69.17	39.92	12.17	45.64
W–W–W	21.93	69.23	38.35	11.93	48.26
CT	22.90	69.11	40.21	12.18	48.27*
MT/CT	p=0.55	p=0.92	p=0.49	p=0.63	p=0.01

GC – gluten content; SC – starch content; ZI – Zeleny index; CP – crude protein; TGW – 1000 grain weight; W–FB wheat after field beans; W–W wheat after wheat; W–W–W wheat in repeated sowings; MT – minimal soil tillage system; CT – conventional soil tillage system; significant at p<0.05.

Zeleny index (ZI) determines quantity and quality of gluten proteins [26]. In addition, soil tillage system had a not significant (p>0.05) effect on Zeleny index. Conventional soil tillage system Zeleny index was higher (40.21%) than minimal soil tillage system (34.01%). Zeleny index was affected not significantly (p>0.05) by the precrop. Higher results were observed when wheat was grown after field beans. An opposite effect was found in field trial in Latvia, where higher Zeleny index was gained in minimal soil tillage system [27].

Grain crude protein (CP) content is the most important indicator of wheat grain quality [4]. Results show that the soil tillage did not significantly affect (p>0.05) the CP content in grain. Under minimal soil tillage system (10.07 to 11.53%) the protein content of winter wheat was lower than conventional soil tillage system (11.93 to 12.43%) in all field trial variants are in provided in Table 2. The highest protein content was established when the conventional soil tillage system were used and by precrop wheat after field beans and the next significant increase was observed by precrop wheat after wheat (https://www.syngenta.lv/product/ seed/zeppelin). An opposite effect was found in field trial in Latvia, where higher protein content was gained in minimal soil tillage system [27]. Scientists from Ukraine Hospodarenko and Liubych [7] reported that moisture deficiency and high temperature during the growth stage BBCH 73 in contributed to higher protein and gluten content in grain.

Winter wheat thousand grain weight (TGW) characterizes the size of seed and is used as one of the parameters for assessing the quality of grain. Grains with higher TGW have better milling quality and ensure better emergence [28]. Our results showed that the soil tillage system had a significant (p<0.05) impact on TGW. Data in our experiment suggest that the average TGW depending on soil tillage system was 47.70 to 48.27 g. Data mathematical processing showed influence were small effect of precrop on the TGW. Average TGW increased when wheat was grown after field beans if compared with growing wheat after wheat, such a relationship has also been reported by Latvian scientists [27].

IV. CONCLUSIONS

In our trial year scientific study did not prove that any of the soil tillage systems could be the most suitable to obtain a higher grain yield of winter wheat. Significant differences were not found in winter wheat structural elements of the sample sheaf m^{-2} and winter wheat grain quality depending on soil tillage system and precrop in our study, only in some cases it was higher or lower depending on affected by soil tillage system and precrop. The minimal soil tillage system and conventional soil tillage system can be considered as an appropriate tillage systems for winter wheat production in the Latvian region. This is one year trial study, that this indicates the need to continue research under various soil tillage systems and climatic conditions, including research on the long-term effects on tillage on winter grain quality.

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