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Comparing the Grain Yields and Other Properties of Old and New Wheat Cultivars

Darija Bilandžija [1,*], Željka Zgorelec [1], Marija Galić [1], Mateja Grubor [2], Tajana Krička [2], Zvonimir Zdunić [3] and Nikola Bilandžija [2]

[1] Division of Agroecology, Faculty of Agriculture, University of Zagreb, Svetošimunska cesta 25, 10000 Zagreb, Croatia; zzgorelec@agr.hr (Ž.Z.); mcacic@agr.hr (M.G.)
[2] Division for Agricultural Engineering and Technology, Faculty of Agriculture, University of Zagreb, Svetošimunska cesta 25, 10000 Zagreb, Croatia; mgrubor@agr.hr (M.G.); tkricka@agr.hr (T.K.); nbilandzija@agr.hr (N.B.)
[3] Agricultural Institute Osijek, Južno predgrađe 17, 31000 Osijek, Croatia; zvonimir.zdunic@poljinos.hr
* Correspondence: dbilandzija@agr.hr; Tel.: +385-1-239-4089

Abstract: Selecting cultivars with greater biomass results in higher yields and greater carbon sequestration. Storage of atmospheric carbon in the plant/soil pool contributes not only to food security but also to mitigating climate change and other agroecological benefits. The objective of this study was to determine: (1) grain, residue, and root biomass yields; (2) harvest indexes; (3) residue-to-product ratio; (4) root-to-shoot ratio; (5) biomass carbon and nitrogen contents; and (6) C:N ratios for two new and two old winter wheat cultivars. The greatest yield difference was found between old Srpanjka (the lowest) and new Kraljica (the highest) cultivar where grain, residue, root, and total biomass yield was higher by 38%, 91%, 71%, and 64%, respectively. Total biomass was composed of 40–47% grain, 10–11% roots, 32–36% stems + leaves, 9–11% chaff, and 1–2% spindle. The range of HI was 0.45–0.53, RPR 0.91–1.25, and R:S ratio 0.12–0.13. For all cultivars, positive carbon and negative nitrogen balance within the plant pool was determined. Still, root biomass and rhizodeposition carbon remain open questions for a better understanding of agroecosystems' C dynamics.

Keywords: biological sequestration; above-ground biomass; below-ground biomass; harvest index; residue-to-product ratio; root-to-shoot ratio; carbon balance; nitrogen balance

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1. Introduction

Climate change is affecting the entire world, with extreme weather conditions such as drought, heat waves, heavy rains, floods, landslides, ocean acidification, and loss of biodiversity. Humanity must make enormous efforts to reduce greenhouse gas (GHG) emissions and prevent further warming of the Earth's atmosphere and other negative impacts of climate change. Limiting global warming to 2 °C requires global carbon neutrality by 2070, while a 1.5 °C target requires global carbon neutrality by 2050 [1]. To achieve a net-zero emissions target, every possible solution is important if unprecedented climate change is to be halted. In addition to transitioning to clean energy systems and decarbonizing emissions-intensive practices, methods such as biological carbon sequestration show how we can work with the natural environment to address the climate crisis.

Biological carbon sequestration is the storage of atmospheric carbon in vegetation such as annual and perennial plants, grasslands, or forests, as well as in soils and oceans. Soil, as a potential carbon (C) sink, can be a key factor in addressing climate change [2], as it is the second largest carbon sink, contains twice as much carbon as the atmosphere, three times as much carbon as vegetation, and is also an important sink for atmospheric carbon dioxide (CO_2) [3]. Storing carbon in the plant/soil pool not only achieves the goal of reducing atmospheric CO_2, but also improves soil health, leading to higher yields, nutrient contents, and other agroecological benefits such as reduced soil erosion and soil moisture retention [4].

In addition, nitrogen (N) input from crop residues is an important source of the soil N pool [5], the concentration of which largely determines the rate of residue decomposition. Taken together, C and N from crop residues contribute significantly to the belowground food web [6]. Therefore, precise and accurate estimation of C and N inputs from crop residues is critical for agroecological models and studies assessing nutrient pools, cycles, budgets, and soil quality [7,8] for designing sustainable agricultural food production systems.

Predicting changes in carbon stocks (especially in soils) therefore depends on reliable estimates of net primary productivity (NPP) and the fraction of NPP that is returned to the soil [9–13]. Ref. [14] defined NPP as the increase in plant mass plus losses (such as mortality) summed for above- and belowground fraction per unit area per unit time. Annual NPP in agroecosystems and the distribution of C and N in plant parts are usually calculated from agricultural yield, the most commonly measured plant component. C input from aboveground residues after harvest (i.e., straw) is estimated from grain yields using 'harvest index' (HI) or similar regression relationships, and C input from belowground residues is calculated from root-to-shoot (R:S) ratios [12,15]. These approaches are useful, but better estimates of crop NPP are needed to adequately assess regional and national contributions of agriculture to the global nutrient budget [16].

Therefore, the aim of this study is to determine morphological properties, total annual NPP, biomass distribution, harvest indexes, residue-to-product ratio, root-to-shoot ratio, carbon and nitrogen allocation patterns, and C:N ratio for two old and two new winter wheat cultivars (old: Srpanjka and Renata, new: El Nino and Kraljica) grown in the continental part of Croatia. The results of this study can be used to define future strategies for sustainable field management, breeding programs, decision making and modeling, to estimate changes in soil C and N content in winter wheat agroecosystems of continental Croatia and elsewhere.

2. Materials and Methods

2.1. Experimental Site, Soil Properties, Climate Conditions, Agrotechnical Measures

A study of four different winter wheat cultivars was conducted during the 2020/2021 growing season at experimental site near Osijek city, continental Croatia (φ = 45°31′56.47″ N, λ = 18°44′16.07″ E; 90 m a.s.l).

In 2020, before the beginning of the research, soil samples (0–30 cm) were collected to determine the physical and chemical soil properties. The soil at the experimental site has a silty-loam texture with a content of 2.33% sand, 56% silt, and 41.67% clay. The water holding capacity is 37.7%, air holding capacity is 10.2%, soil porosity is 47.8%, and bulk density is 1.39 g cm^{-3}. The soil pH_{KCl} amount is 7.24, and the soil contains 2.3% of humus, 0.11% of total nitrogen, 1.25% of total carbon, 0.06% of total sulfur, 17.9 mg of P_2O_5, and 15.5 mg of K_2O per 100 g of soil.

The studied area has a continental climate [17]. The multi-year average air temperature (1991–2018) is 11.7 °C, precipitation 707 mm, evapotranspiration 590 mm per year, soil water deficit occurs in the period from July to September, and water surplus in the period from December to March [18]. The climatic analysis of the studied vegetation period is conducted according to climate elements data (mean air temperature and precipitation amount) of the Croatian Meteorological and Hydrological Service, main meteorological station Osijek-Čepin (φ = 45°30′9″ N, λ = 18° 33′41″ E; 89 m a.s.l). Climatic conditions in the 2020/2021 growing season differed from those of the 1991–2018 multiyear average according to [19]. The average air temperature of the 2020/2021 growing season was 10.8 °C, which was 0.9 °C lower than the 1991–2018 average. A difference was also observed in precipitation between the studied growing season and the multi-year average, with 56 mm less precipitation in 2020/2021 compared to the 1991–2018 period. Moreover, evapotranspiration was lower in the studied period and soil water deficit occurred only in

June by 98 mm, while in the recent period 1991–2018 evapotranspiration averaged 415 mm and soil water deficit occurred already in April [19]. For more on climatic conditions in the 2020/2021 growing season, see [19].

The culture on the field before the experiment was establishment was soybean. Agrotechnical measures at the experimental field, i.e., tillage, fertilization, planting/harvesting dates, weed, and pest control, can be found in [19].

2.2. Wheat Cultivars

The experiment includes a control plot and 4 different winter wheat cultivars bred by the Agricultural Institute Osijek. The studied variants were:

- C—control, bare soil—black fallow
- S—winter wheat (*Triticum aestivum* L.) Srpanjka cultivar—old cultivar, very early growing cultivar with average yield of 10 t ha^{-1}, very low habitus (64 cm), plant density 9,110,000 plants ha^{-1}
- R—winter wheat (*Triticum aestivum* L.) Renata cultivar—old cultivar, medium early growing cultivar with average yield of 11 t ha^{-1}, low habitus (65 cm), plant density 11,170,000 plants ha^{-1}
- EN—winter wheat (*Triticum aestivum* L.) El Nino cultivar—new cultivar, early growing cultivar ty with average yield of 11 t ha^{-1}, high habitus (73 cm), plant density 10,670,000 plants ha^{-1}
- K—winter wheat (*Triticum aestivum* L.) Kraljica cultivar—new cultivar, medium early growing cultivar with average yield of 11 t ha^{-1}, high habitus (75 cm), plant density 12,320,000 plants ha^{-1}

More on wheat cultivars can be found at [20].

2.3. Biomass Sampling

NPP includes all plant fractions, so plant biomass was divided into three fractions (gr-grains; res-residues; r-roots), expressed in units of mass per unit area. Biomass sampling was conducted during the wheat harvest in July 2021 by destructively harvesting plant biomass from randomly selected 1 m^2 to a depth of 30 cm in three replicates. Biomass samples of each wheat cultivar (Srpanjka, Renata, El Nino, Kraljica) were stored in sampling bags and transported to the laboratory, where plants were divided into above- and belowground biomass. Aboveground biomass was separated into grains and vegetative aboveground biomass (stem + leaves + chaff + spindle), air-dried and weighed. Belowground biomass was cleaned (washed) from soil particles, air-dried and weighed. Part of the stem and tillers that were beneath the soil surface are considered as part of the belowground biomass in this study and extra-root C was not taken into account (rhizodeposition).

2.4. Harvest Index (HI), Residue-to-Product Ratio (RPR) and Root-to-Shoot Ratio (R:S)

Grain yields of major crops in Croatia are available in the national database [21], but neither their vegetative shoot nor root biomass is available. Prior to 1970, HI was neither measured nor reported in the literature [22]. However, since its introduction for comparing improvements in cereal varieties through plant breeding, HI has been widely estimated for a variety of species, cultivars, and growing conditions. The harvest index, residue-to-product ratio, and root-to-shoot ratio are calculated as follows:

Harvest index (HI):

$$HI = Ygr/Ygr + Yres \quad (1)$$

The residue-to-product ratio (RPR):

$$RPR = Yres/Ygr \quad (2)$$

The root-to-shoot ratio (R:S):

$$R{:}S = Yr/Ygr + Yres \quad (3)$$

where:

Ygr—yield of grain biomass (t/ha)

Yres—yield of aboveground residue biomass (stem + leaves + chaff + spindle—the total aboveground biomass excluding the harvested grain) (t/ha)

Yr—yield of belowground biomass (root) (t/ha)

2.5. Carbon and Nitrogen Balances

The carbon and nitrogen balances represent the difference between the carbon/nitrogen sink and source. The carbon/nitrogen sink represents the amount of carbon/nitrogen that remains in the agroecosystem, and the carbon/nitrogen source represents the amount of carbon/nitrogen that is removed from the agroecosystem. In this analysis, only the grain was considered to be source of carbon i.e., nitrogen, so balances of carbon (CBp) and nitrogen (NBp) within the plant pool were calculated as follows:

$$CBp = (C_{res} + C_r) - C_{gr} \quad (4)$$

$$NBp = (N_{res} + N_r) - N_{gr} \quad (5)$$

2.6. Laboratory Analysis

Total carbon and nitrogen content in above- and belowground biomass were determined simultaneously using the dry combustion method. Samples of biomass were dried in an oven (Nueve, FN 120, Turkey) at 105 °C to a constant weight, weighed (Sartorius CP 64; d = 0.1 mg, Germany), and analyzed using the Vario Macro CHNS analyzer (Elementar, Germany). Total biomass carbon content was determined according to the protocol [23] and total nitrogen content according to the protocol [24]. To obtain carbon and nitrogen yields in t/ha, the dry matter yield of each biomass fraction is multiplied by the carbon and nitrogen concentrations of each fraction.

2.7. Statistical Analysis

Statistical analysis was performed using SAS 9.1 statistical software (SAS Inst. Inc., 2002–2004, Cary, NC, USA). Variability among the studied plant cultivars was analyzed by analysis of variance (ANOVA) and, if necessary, tested with the Fisher post-hoc *t* test. The significance threshold for all analyses was 5%. The quality management system (QM) is in accordance with good laboratory practices and includes internal and external quality controls (QC).

3. Results and Discussion

3.1. Morphological Properties and NPP

Analysis of variance showed that the different wheat cultivars had significantly different morphological characteristics (Table 1). The number of stems per m^2 ranged from 729–945, with an average stem height of 64–73 cm and 6.4–7.6 cm ear height. The greatest difference in the number of stems was found between Srpanjka (old cultivar—the lowest number) and Kraljica (new cultivar—the highest number). The lowest cultivar is Srpanjka and the highest is El Nino, while the lowest ear length was determined for Renata and the highest for El Nino (Table 1). The number of stems is consistent with the plant density of the studied cultivars [20]. The stem height of the studied cultivars is also consistent with [20], with the exception of Kraljica, whose height is expected to be the highest among the other studied cultivars [20].

Table 1. Morphological properties (number of stems per m^2, stem and ear height) of four different wheat cultivars in Osijek, Croatia.

Cultivar	Stem Number (LSD = 213.92)	Stem Height (cm) (LSD = 4.1513)	Ear Length (cm) (LSD = 0.4429)
	$p = 0.0071$	$p = 0.0068$	$p = 0.0019$
Srpanjka	729.1 B	64.6 C	6.9 B
Renata	893.3 AB	67.2 BC	6.4 C
El Nino	853.9 AB	73.2 A	7.6 A
Kraljica	945.0 A	70.6 AB	6.9 B

Average values marked with the same letters are not statistically significantly different at $p \leq 0.05$; LSD—least significant difference.

Analysis of variance showed that average dry matter yields of residues, roots, and total biomass differ statistically significantly for different wheat cultivars while average dry matter grain yield did not (Table 2). Grain, residue, root, and total biomass yields ranged from 6.8–9.4 t/ha, 6.1–11.7 t/ha, 1.5–2.6 t/ha, and 14.4–23.6 t/ha, respectively (Table 2).

Table 2. NPP of different wheat cultivars.

Cultivar	Ygr (t/ha) (LSD = 3.1712)	Yres (t/ha) (LSD = 3.605)	Yr (t/ha) (LSD = 0.9815)	Ytotal (t/ha) (LSD = 7.3219)
	$p = 0.2324$	$p = 0.0451$	$p = 0.0325$	$p = 0.0459$
Srpanjka	6.8 A	6.1 B	1.5 B	14.4 B
Renata	7.8 A	8.6 AB	2.1 AB	18.5 AB
El Nino	9.4 A	9.1 AB	2.2 AB	20.7 AB
Kraljica	9.4 A	11.7 A	2.6 A	23.6 A

Average values marked with the same letters are not statistically significantly different at $p \leq 0.05$; LSD—least significant difference.

Data on crop yields are readily available, while data on residue yields are very limited, because the goal of agricultural production has always been to maximize yields, while total biomass yield has not been considered important. Based on a large data set, Ref. [25] determined a range of 1.4–22.25 t/ha shoot dry matter (n = 1015) and grain yield of 1.9–8.6 t/ha (n = 14,535) for Australian wheat varieties. Ref. [26] determined shoot dry matter of 4.9–6.22 t/ha and root yield of 2.61–3.97 t/ha for Australian wheat cultivars at anthesis. The lower root dry matter values obtained could be partly due to weight loss during storage between collection of roots and weighing or measuring, and washing techniques. Significant differences were found between Srpanjka and Kraljica cultivars in yields of residues, roots, and total biomass, while yields of the other cultivars studied were not significantly different (Table 2). When comparing the yields of Srpanjka (the lowest) and Kraljica (the highest), Kraljica was found to have higher yields of grain, residue, root and in total by 38%, 91%, 71%, and 64%, respectively. In several studies, the yield of modern cultivars was higher than that of older ones [26–28]. In addition to the development of new cultivars, management practices, pest and disease control, and fertilization are the most important factors contributing to increased crop yields [28–30]. Selecting varieties with greater biomass helps mitigate climate change by removing a greater amount of carbon from the atmosphere and sequestering it in the plant biomass, which eventually is stored in the long-term into the soil pool. In addition to biomass yields, specific root characteristics or rhizodeposition processes should be investigated in further research in order to better understand carbon storage dynamics in agroecosystems. In this study, the observed differences in grain, residue, and root biomass yields between old and new wheat cultivars can be attributed solely to genetic factors, since all agrotechnical measures and agroecological conditions were the same for all cultivars studied.

Depending on the wheat cultivar, the proportion of each fraction in the total biomass is 40–47% of the grain, 10–11% of the root, 32–36% of the stem and leaves, 9–11% of the chaff, and 1–2% of the spindle (Figure 1). This similar plant fraction distribution in new and old cultivars differs from the study by [26], who found that old cultivars had a significantly higher proportion of root dry matter in the top 40 cm of soil than new cultivars. Crop partitioning studies of wheat biomass in Canada suggest that the proportion of root, grain, and residue biomass is 19%, 38%, and 44%, respectively, at a dry matter grain yield of 8 t/ha [31,32].

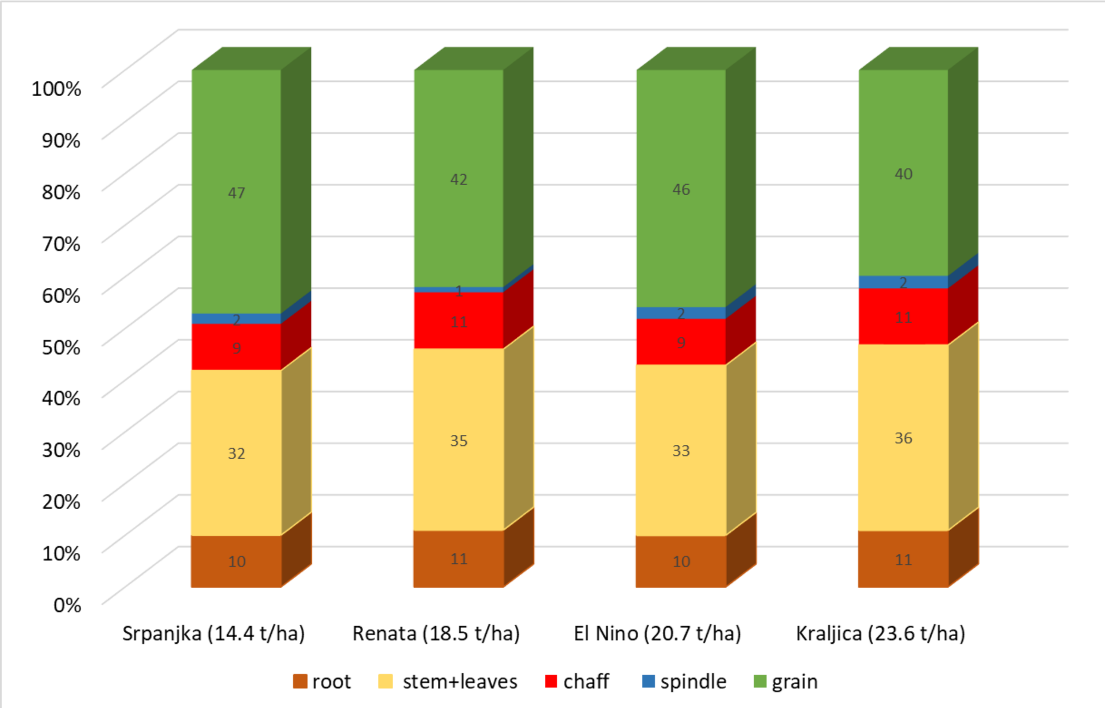

Figure 1. Distribution of plant parts within total biomass of different wheat cultivars.

The greatest uncertainty in deriving NPP may lie in estimating belowground NPP (including inputs from roots, exudates, and other root-derived organic materials from root turnover), one of the most poorly understood properties of terrestrial ecosystems [33]. Quantifying these belowground C inputs, particularly from exudates and other ephemeral root materials, is difficult and remains a focus of research [10,34–36].

3.2. Harvest Index (HI), Residue-to-Product Ratio (RPR) and Root-to-Shoot Ratio (R:S)

Harvest index (HI) and residue-to-product ratio (RPR), as opposed to root-to-shoot ratio (R:S), differed significantly among the studied wheat cultivars (Table 3). The highest HI was determined for Srpanjka (0.53), and the lowest for the Kraljica (0.45). Srpanjka and El Nino have the lowest residue-to-product ratio (0.91 and 0.98, respectively) and Kraljica has the highest one (1.25). Root-to-shoot ratio does not differ significantly among the studied cultivars and ranges from 0.12–0.13.

Globally, HI has increased since the Green Revolution [37] due to genetic improvement through plant breeding [38,39]. Some studies found that the HI increase of various crops was significantly correlated with grain yield [37,40], while other studies showed little or no correlation between residues and grain yield [41]. Recently, ref. [37] found an average increase in HI for cereals from 0.35 in 1951–1955 to 0.45 in 1995–2010 in Germany. The average HI estimated for Australia (n = 1266) ranged from 0.08–0.56 [20]. Although HI has generally increased over time, in this study, the average HI of old cultivars (0.50) is higher than the average of modern cultivars (0.48). This can be attributed to greater plant height of modern cultivars compared to old ones, which have decreased harvest index and increased root size.

Table 3. Harvest index (HI), residue-to-product ratio (RPR) and root-to-shoot ratio (R:S).

Cultivar	HI (LSD = 0.0556)	RPR (LSD = 0.2498)	R:S (LSD = 0.0276)
	p = 0.0498	p = 0.0383	p = 0.8254
Srpanjka	0.53 A	0.91 B	0.12 A
Renata	0.48 AB	1.11 AB	0.12 A
El Nino	0.51 A	0.98 B	0.12 A
Kraljica	0.45 B	1.25 A	0.12 A

Average values marked with the same letters are not statistically significantly different at $p \leq 0.05$; LSD—least significant difference.

The residue-to-product ratio is very specific to the crop type and cultivar. It is very difficult to make a simple estimate of this ratio, because it is influenced by climatic and soil conditions and agricultural practices such as tillage, planting density, fertilization, etc. [42–44]. Available data on RPR have a large scatter as they are reported for different crop cultivars, cropping methods, climatic conditions, etc., and the correlations found vary accordingly. The literature reports a wide range of variation in the RPR from 0.6 to 1.8 [39,42,44–51] and the RPR determined in this study is within this indicated range (average 1.01 for old cultivars and 1.11 for modern ones).

Root growth and R:S ratio in one study in any environment cannot reveal the full extent of genetic variation among crops and cultivars. The R:S ratio at maturity for many cultivars is about 0.10 [52], and the RSR for a soil depth of 0–30 cm for wheat in Canada was 0.157 [32], which is consistent with the results of this study. A study in Western Australia [26] found a higher average R:S ratio (about 0.40) at maturity than reported elsewhere, and the authors suggested that the large soil moisture deficits and high temperatures around anthesis and in the post-anthesis period were the cause.

3.3. Biomass Carbon and Nitrogen

Carbon content in total biomass ranged from 6.1–10.4 t/ha, and a significant difference in total carbon content was found only between Srpanjka and Kraljica (Table 4). Considering the distribution of carbon, all studied cultivars store the smallest amount of carbon in the root system, with a range of 0.6–1 t/ha. The Srpanjka and El Nino store a greater amount of carbon in the grain (2.9 and 4.3 t/ha, respectively) than in the residue (2.6 and 4.1 t/ha, respectively). Conversely, the Renata and Kraljica store less carbon in the grain (3.6 and 4.3 t/ha, respectively) than in the residue (3.9 and 5 t/ha, respectively). The average percentage of carbon in grain is 45.3%, in residue 43.9%, in root 40.5% and in total biomass 43.4%.

Table 4. Carbon content in biomass (% and t/ha).

Cultivar	Cgr		Cres		Cr		Ctotal	
	(%) (LSD = 0.50)	(t/ha) (LSD = 1.45)	(%) (LSD = 1.30)	(t/ha) (LSD = 1.55)	(%) (LSD = 1.90)	(t/ha) (LSD = 0.40)	(%) (LSD = 1.0084)	(t/ha) (LSD = 3.2046)
	p < 0.0001	p = 0.1639	p = 0.0136	p = 0.0426	p = 0.0203	p = 0.1974	p = 0.0105	p = 0.0468
Srpanjka	43.1 C	2.9 A	42.8 B	2.6 B	40.8 AB	0.6 A	42.4 C	6.1 B
Renata	46.6 A	3.6 A	45.0 A	3.9 AB	39.4 B	0.8 A	44.0 AB	8.3 AB
El Nino	45.3 B	4.3 A	44.6 A	4.1 AB	42.4 A	0.9 A	44.1 A	9.3 AB
Kraljica	46.4 A	4.3 A	43.2 B	5.0 A	39.4 B	1.0 A	43.1 BC	10.4 A

Average values marked with the same letters are not statistically significantly different at $p \leq 0.05$; LSD—least significant difference.

Even if total root biomass were accurately measured at maturity, biomass alone would still underestimate the total amount of C derived from roots, because rhizodeposition was not measured. Estimates suggest that 2.5 to 6 times the amount of C taken up into root biomass can be represented as rhizodeposition [53], while [7] estimated that this additional C input represents about 65% of soil biomass for all crops, based on measured roots.

Nitrogen content in total biomass was not significantly different among the studied cultivars and ranged from 0.19 to 0.28 t/ha (Table 5). No differences were also observed in the nitrogen content in the root, which ranged from 0.0013 to 0.0018 t/ha. All studied cultivars had the highest amount of nitrogen in the grain (on average 2.18%), then in root (on average 0.66%), and the lowest amount in residue (on average 0.57%), respectively.

Table 5. Nitrogen content in biomass (% and t/ha).

Cultivar	Ngr		Nres		Nr		Ntotal	
	% (LSD = 0.0111)	(t/ha) (LSD = 0.0003)	% (LSD = 0.0232)	(t/ha) (LSD = 0.02)	% (LSD = 0.1211)	(t/ha) (LSD = 0.0006)	% (LSD = 0.0213)	(t/ha) (LSD = 0.0917)
	$p < 0.0001$	$p = 0.0351$	$p < 0.0001$	$p = 0.0174$	$p = 0.0460$	$p = 0.2777$	$p < 0.0001$	$p = 0.2079$
Srpanjka	2.1 D	0.0007 B	0.6 A	0.0391 B	0.7 AB	0.0013 A	1.0 B	0.1917 A
Renata	2.3 A	0.0010 AB	0.6 A	0.0536 AB	0.7 A	0.0018 A	1.1 A	0.2436 A
El Nino	2.2 C	0.0008 B	0.5 C	0.0436 AB	0.6 AB	0.0016 A	0.9 D	0.2613 A
Kraljica	2.2 B	0.0012 A	0.5 B	0.0621 A	0.661 B	0.0017 A	1.0 C	0.2825 A

Average values marked with the same letters are not statistically significantly different at $p \leq 0.05$; LSD—least significant difference.

Similar to the results of this study, wheat biomass nitrogen concentration studies in Canada estimate that the average N concentration in grain, residue, and root biomass is 2.6% 0.66%, and 1.1%, respectively [31,32]. Similar results were obtained by [54], who found nitrogen concentrations of 2.7% in grain and 0.44% in straw.

The significant difference between the studied cultivars in the C:N ratio was found for all studied plant parts (Table 6). On average, the highest C:N ratio was in, respectively, residue (78:1), root (63:1) and grain (21:1), while average C:N ratio of total biomass is 44:1.

Table 6. C:N ratio in biomass.

Cultivar	C:N gr (LSD = 0.2946)	C:N res (LSD = 3.9947)	C:N r (LSD = 11.724)	C:N Total (LSD = 1.2975)
	$p = 0.0020$	$p < 0.0001$	$p = 0.0468$	$p < 0.0001$
Srpanjka	20.5:1 C	67.0:1 D	63.3:1 AB	41.9:1 C
Renata	20.6:1 BC	72.5:1 C	53.8:1 B	41.6:1 C
El Nino	20.9:1 AB	92.9:1 A	68.5:1 A	47.2:1 A
Kraljica	21.2:1 A	81.4:1 B	64.4:1 AB	44.6:1 B

Average values marked with the same letters are not statistically significantly different at $p \leq 0.05$; LSD—least significant difference.

C:N ratios vary by environment and growth stage. A study shows that tissues with lower C:N ratios decompose relatively faster compared to tissues with higher C:N ratios [55]. Although it is often assumed that a low C:N ratio promotes nutrient release and SOM stabilization, results are contradictory and a study suggests that the formation and stabilization of SOC is more influenced by the quantity of residue input and its interaction with the soil than by the quality of residue input [56]. Root characteristics such as specific root length could be important factors contributing to these conflicting results, as fine roots may lead to greater microbial C-use efficiency and soil organic matter stabilization than coarse roots [57]. Root C:N ratio, which is critical for predicting soil organic matter (SOM) dynamics, also varies by environment and growth stage. Root C:N ratio is the most important indicator of crop residue quality, which influences nutrient availability and SOM stabilization in the short and long term [56–60]. The timing of root measurements is also a very important aspect as postharvest measurements are not accurate, as roots have already undergone some decomposition [61].

The carbon and nitrogen balances that represent difference between the carbon/nitrogen sink (in root and residue biomass) and source (in grain biomass) are presented in Table 7. The carbon balances of the plant pool are positive for all studied wheat cultivars, where the lowest carbon balance is determined for the Srpanjka cultivar (0.3 t/ha) and the highest one for the Kraljica cultivar (1.7 t/ha). Nitrogen balances of all studied wheat cultivars are negative, and are in the range of −0.09 (Srpanjka)–−1.15 t/ha (El Nino).

Table 7. Carbon and nitrogen balances in plant pool.

Cultivar	CBp (t/ha) LSD (0.9195)	NBp (t/ha) LSD (0.0495)
	p = 0.0394	**p = 0.0147**
Srpanjka	0.31 B	−0.0942 A
Renata	1.08 AB	−0.1062 AB
El Nino	0.70 B	−0.1472 B
Kraljica	1.71 A	−0.1269 AB

Average values marked with the same letters are not statistically significantly different at $p \leq 0.05$; LSD—least significant difference.

4. Conclusions

Determined variations within studied wheat cultivars represents important information for selecting genotypes aimed at providing food security, increasing soil carbon and nitrogen stocks, mitigating climate change, and bringing other agroecological benefits. Depending on the wheat cultivar, yields of grain, residue, root and total biomass were in the range of 6.8–9.4 t/ha, 6.1–11.7 t/ha, 1.5–2.6 t/ha and 14.4–23.6 t/ha, respectively. Although harvest indexes of wheat cultivars have increased over the last century, in this study, the average HI of old cultivars (0.50) is higher than the average of new ones (0.48), while root-to-shoot ratios remained the same. The carbon and nitrogen balances within the plant pool showed that, by careful selection of genotypes, higher carbon inputs to the soil or reduced nitrogen losses can be achieved.

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