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Growth and yield of winter oilseed rape under strip-tillage compared to conventional tillage

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Abstract: Three-year field trials were conducted to compare the effect of three tillage systems: strip-tillage (ST), strip-tillage after mouldboard ploughing (STmp) and conventional tillage (CT) on growth and yield of winter oilseed rape at the experimental station in Červený Újezd, Czech Republic. Compared to CT, the growth of roots and aboveground biomass was slower (significantly thinner root necks, shorter roots and leaves) under ST at the beginning of vegetation (BBCH 14–18). Plants under ST still had significantly thinner root necks, and a lower number of leaves than plants from CT before winter (BBCH 21) but the differences were no longer statistically significant in spring (BBCH 30). Despite a slower start, the ST variant with an average yield of 5.47 t/ha significantly exceeded the CT variant with the yield being 5.06 t/ha. Conversely, plants grown under STmp had significantly longer leaves than those under CT in BBCH 14–18 and with the highest values of all parameters, tended to faster growth of biomass, although the other differences were not statistically significant. No differences were observed between STmp and CT in BBCH 21 and 30. The STmp variant achieved the highest yield 5.53 t/ha, and significantly exceeded the CT variant.

Keywords: *Brassica napus* L.; tillage practices; strip-tillage technology; root biomass; leaf biomass

Rapeseed is the European Union (EU)'s most important oilseed and the world's third most important oilseed in terms of oil production, following oil palm and soybeans. The tillage system by ploughing and subsequent use of the seed drill is the most reliable way to establish rapeseed stands in the current soil-climatic conditions of EU countries. In recent years, areas with winter oilseed rape sown to unploughed soils have been growing, mainly due to frequent drought during tillage and sowing, but also thanks to new legislative requirements for anti-erosion tillage at sloping lands (Růžek et al. 2016). In order to optimise growing technologies, new methods have been sought worldwide to ensure higher energy and economic efficiency. Additionally, the emphasis has been placed on the elimination of soil degradation processes, especially erosion, increasing of soil infiltration capacity, reducing compaction and sustaining the soil structure (Holland 2004, Kertész and Madarász 2014, Brant et al. 2016). On the other hand, many Western and Central European countries have been facing drought for several years. Recently, especially in 2015, 2018 and 2019, Central Europe has suffered from droughts. According to the Czech Hydrometeorological Institute, temperatures in Europe will continue to rise. Along with an increase of temperature, a change of the precipitation regime will be the main cause of more frequent floods or droughts (Huang et al. 2014, Schwarzak et al. 2015, Hänsel et al. 2019). Strip-till technology is one of the ways to save soil moisture whilst simultaneously representing an anti-erosion measure that reduces surface runoff and soil loss in comparison to intensive tillage (Laufer et al. 2016). Cost savings resulting from decreased fuel consumption as well as shortening of work time are the other reasons to spread this technology (Holland 2004, Jabro et al. 2014).

The principle of strip-tillage technology is the combination of no-till and full tillage in narrow strips for the sowing of the next crop with the possibility of targeted application of nutrients (Brant et al. 2016). Loosened soil in strips has a positive effect on root development and water infiltration into the soil (Brant et al. 2016, Jaskulska and Jaskulski 2020), and the removal of post-harvest residues from loosened strips contributes to better soil heating (Tabatabaeekoloor 2011). On the other hand, the presence of post-harvest residues in untreated inter-rows reduces the risk of water erosion and eliminates soil evaporation, this is important for maintaining water in this part of the soil profile and creating a zone for water intake by roots (Brant et al. 2016). Untreated soil in the inter-row ensures water rising and its availability for plants (Tabatabaeekoloor 2011).

Strip-till technologies are mainly used for wide-row crops. In European climates, strip-till technology is applied especially on maize (Licht and Al-Kaisi 2005, Trevini et al. 2013, Herout et al. 2018), but also on sugar beet (Morris et al. 2007, Laufer and Koch 2017), soybeans (Potratz et al. 2020) or sunflower (Celik et al. 2013). However, there are few research results for crops grown in narrow rows, such as cereals (Cociu and Alionte 2011, Jaskulska et al. 2019) and rapeseed (Jaskulska et al. 2018). In the case of rapeseed, the use of strip tillage is primarily about ensuring optimal conditions for the development of the taproot due to deeper loosening of the soil in the sowing line (Bednář et al. 2013, Brant et al. 2016).

The aim of this work was to verify the possibility of establishing a crop stand of winter oilseed rape using strip-tillage and to compare the response of plants to this tillage system with those under conventional tillage.

MATERIAL AND METHODS

Field trial. Field experiments were carried out in 2014/15–2016/17 at the experimental station of the Czech University of Life Sciences Prague, located in Červený Újezd, Czech Republic (geographical coordinates: 50.0772189N, 14.1744758E), at an altitude of 405 m a.s.l. The prevailing soil type is Haplic Luvisol, the average annual temperature is 8.4 °C, and the normal annual precipitation reaches 502 mm at the site.

Three types of tillage practices were tested: conventional tillage (CT); strip-tillage after mouldboard ploughing (STmp) and strip-tillage (ST). After harvest of the pre-crop (spring barley), mouldboard ploughing to a depth of 22 cm was carried out for the CT and STmp variants, whereas stubble tillage to a depth of 10 cm was carried out for ST. The non-residual seeder Oyord, designed for small plots sowing, was used for CT variant, and a Farmet Falcon 6 seed drill (working width 6 m) with deep loosening in strip lines was used for both ST and STmp. The experimental variants were established in strips next to each other. The width of each strip was 6 m, and the length 120 m. The strips were divided into experimental plots (4 × 72 m^2). The variants were separated on both sides by zero plots. The line spacing was 25 cm for all variants. The giant, medium-early hybrid of winter oilseed rape Marcopolos was used as a model cultivar. The seed rate was 60 seeds per m^2, and the real average stand densities were 43, 49 and 41 plants per m^2 at CT, STmp and ST, respectively, in the three-year average. The fertilisation and treatment of the experimental variants were identical. Pre-emergence herbicides were applied, followed with post-emergence graminicides and in the autumn, as needed, 1–2× growth regulator. Autumn nitrogen fertilisation was performed at a dose of 46 kg/ha with stable urea fertiliser. Spring nitrogen fertilisation (180 kg N/ha in total) was split into four doses, ammonium sulphate nitrate (26% N, 13% S) and calcium ammonium nitrate (27% N) were used. Phosphorus and potassium were not applied. According to the current state, insecticides were applied 2–3 times, and fungicide was applied once.

Plant sampling. The growth dynamics of above-ground and underground biomass were monitored in each variant during the vegetation period. Plants were sampled at three times: (*i*) after the formation of the leaf rosette (BBCH 14–18, i.e., 4–8 leaves unfolded); (*ii*) before winter (BBCH 21, i.e., the beginning of ramification development), and (*iii*) after overwintering (BBCH 30, i.e., the beginning of prolonged growth). For each variant, 40 plants were sampled (10 plants in 4 repetitions), taken in a row always min. 1.5 m from the edge of the plot. The depth of underground biomass sampling was 30 cm. The number of leaves (pcs.), length of the longest leaf (cm), root neck thickness (mm), length of the roots (cm), weight of the above-ground biomass (g) and weight of the roots (g) were determined for the sampled plants. The experiment was harvested with a small-plot harvesting machine Wintersteiger. The seed yield was determined from the weight of the harvested seeds, sample purity and moisture. The seed yield was calculated to the moisture content of 8%.

Weather. The average air temperatures and total precipitation at the site (Table 1) were compared with the standard climatological normal at the nearest hydrometeorological station in Prague-Ruzyně (1981–2010) according to the WMO methodology (Kožnarová and Klabzuba 2002). The agrometeorological years 2014/15 and 2015/16 were extraordinary above normal in temperature with extraordinary warm winters, and the year 2016/17 was above normal in temperature. The first year of the experiment 2014/15 was very below normal in terms of precipitation. Especially the summer of 2015 was very warm and dry. The following agrometeorological years, 2015/16 and 2016/17, were normal in precipitation (Table 1).

Statistical analysis. The obtained data were statistically analysed by using two-factor (year and tillage system) analysis of variance in the SAS program (version 9.4, SAS Institute, Cary, USA) at the level of significance P = 0.05. The differences between means were evaluated by using Tukey's *HSD* (honestly significant difference) test at a 95% confidence level.

Abbreviations. The BBCH scale, used in the text, is a uniform decimal code for phenological identification of growth stages of agricultural crops and weeds (Lancashire et al. 1991).

RESULTS AND DISCUSSION

Effect of tillage practice on roots and aboveground biomass growth. Roots and aboveground biomass parameters of winter oilseed rape grown under strip-tillage, strip-tillage after mouldboard ploughing and conventional tillage.

Strip-tillage. The three-year results of field experiments showed that rapeseed plants had a slower initial growth of roots and aboveground biomass when using ST compared to CT. In the first autumn sampling (BBCH 14–18), the plants from the ST variant had a significantly thinner root neck (Figure 1B), shorter leaves (Figure 1C) and shorter roots (Figure 1D) than the plants of the CT variant. The other parameters, such as the number of leaves (Figure 1A), the weight of aboveground biomass (Figure 1E) and the weight of root (Figure 1F), were also lower in the ST variant than in the CT variant, but the differences were not statistically significant. Conversely, Jaskulska et al. (2018) found that the number of leaves, the dry mass of the above-ground part of

Table 1. Average monthly temperatures and sums of precipitation in experimental years in Červený Újezd

Month	Normal (°C)	Average temperature (°C)				Normal (mm)	Σ of precipitation (mm)			
		2014	2015	2016	2017		2014	2015	2016	2017
I	–1.4	0.47	1.78	–0.42	–5.13	22	19.7	19.1	28.4	13.8
II	–0.3	3.04	0.70	3.29	1.90	20	1.7	1.6	41.7	13.9
III	3.6	7.55	5.48	4.42	7.19	28	35.3	32.6	21.9	33.4
IV	8.5	11.21	8.96	8.74	7.75	28	28.3	30.0	19.6	51.3
V	13.5	12.89	13.65	14.18	14.70	70	91.5	44.7	90.8	16.5
VI	16.2	16.69	16.19	17.93	18.69	67	25.0	37.0	58.8	85.8
VII	18.3	20.13	20.82	19.57	19.79	78	155.5	29.4	58.6	84.1
VIII	17.9	16.81	21.93	18.48	19.46	66	57.0	54.7	34.6	55.5
IX	13.5	16.12	14.58	17.64	12.78	38	76.7	11.5	23.7	25.0
X	8.5	10.72	8.18	8.45	10.64	27	54.1	53.2	56.9	61.6
XI	3.1	5.77	6.68	2.68	4.44	30	24.1	52.3	23.0	29.1
XII	–0.3	2.28	4.75	0.67	1.31	28	31.6	11.3	16.5	22.0
			2014/15	2015/16	2016/17			2014/15	2015/16	2016/17
X–III	2.2		4.5 ean	4.5 ean	2.6 n	155		163 n	209 van	158 n
IV–IX	14.7		16.0 an	16.1 an	15.5 n	347		207 bn	286 n	318 n
X–IX	8.4		10.2 ean	10.3 ean	9.1 an	502		370 vbn	495 n	476 n

Normal – Prague Ruzyně (1981–2010); evaluation of air temperature and precipitation normality of half-years (X–III, IV–IX) and years (X–IX) according to Kožnarová and Klabzuba (2002): vbn – very below normal; bn – below normal; n – normal; an – above normal; van – very above normal; ean – extraordinary above normal

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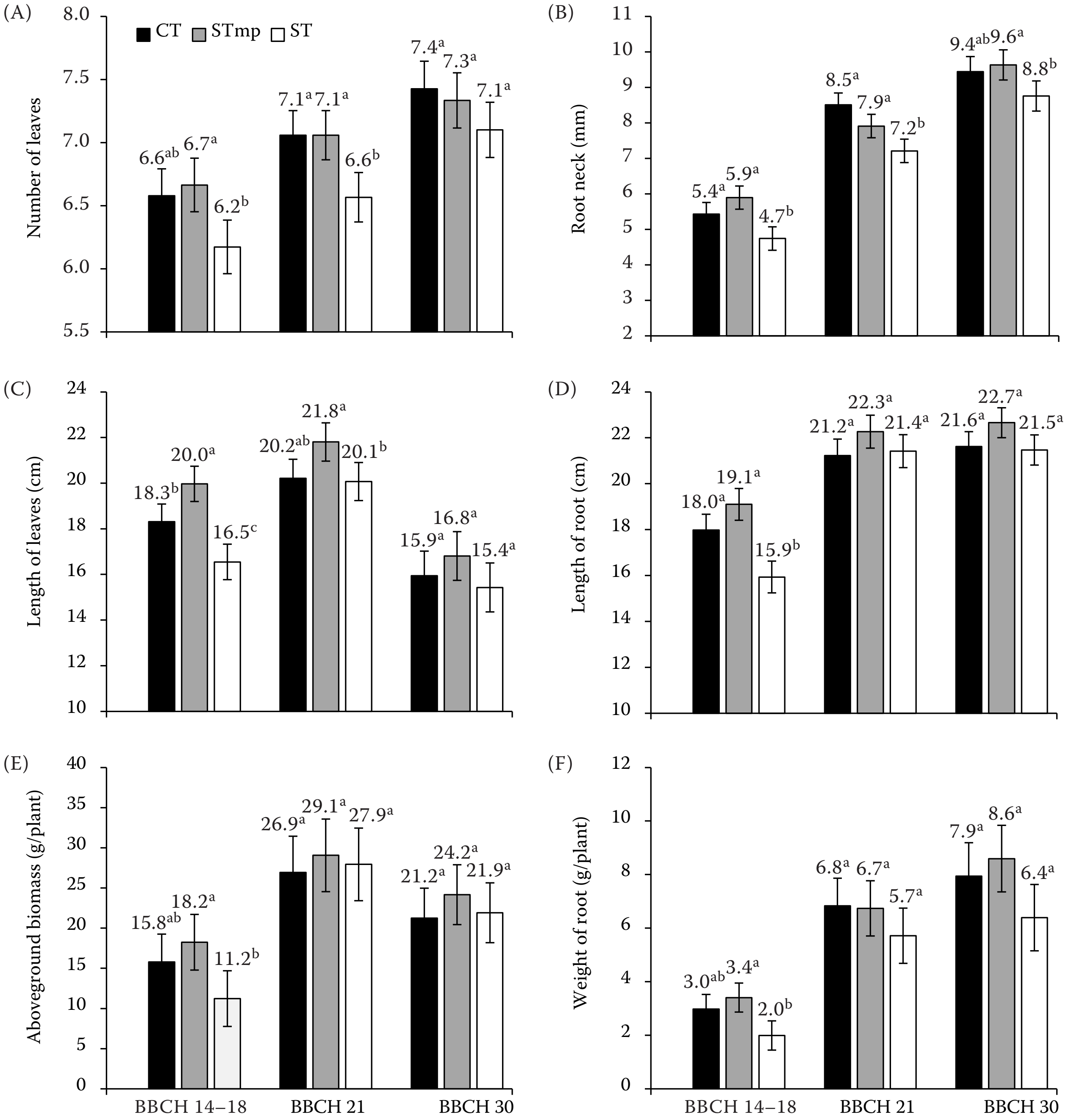

Figure 1. Effect of tillage system on above-ground biomass and roots of winter oilseed rape in three growth phases (BBCH 14–18, 21 and 30), three-year average (2014/15–2016/17). Different letters indicate statistically significant differences between tillage systems in individual growth phases (Tukey's *HSD* (honestly significant difference) test; $P < 0.05$). (A) number of leaves; (B) root neck thickness; (C) length of leaves; (D) root length; (E) weight of aboveground biomass, and (F) root weight. CT – conventional tillage; STmp – strip-tillage after mouldboard ploughing; ST – strip-tillage

winter oilseed rape plants and the thickness of the root neck were higher and more uniform for the ST technology than for the CT system during sampling at the end of October. However, Laufer and Koch (2017) found a similar tendency for slower plant emergence and growth of sugar beet under strip-tillage compared to intensive tillage with annual mouldboard ploughing (IT) and reduced tillage (RT): the field emergence period under ST was prolonged by 5–7 days; leaf area index and plant dry matter yield in June tended to be lower compared to IT and RT, however, differences were not significant.

Before winter (BBCH 21), the plants on ST still had a significantly lower number of leaves (Figure 1A) and thinner root necks (Figure 1B) than on CT. The root weight was also slightly lower but not significantly (Figure 1F). The values of other parameters on ST were identical to CT (Figures 1C–E).

Although slightly lower values were also found in the ST variant during spring sampling (BBCH 30) – the lower number of leaves (Figure 1A), thinner root neck (Figure 1B) and lower root weight (Figure 1F) than in CT, these differences were no longer statistically significant (Figures 1A–F). The values of other parameters on ST were again identical with CT (Figures 1C–E).

Strip-tillage after mouldboard ploughing. On the other hand, the growth of roots and aboveground biomass was slightly faster when using STmp than CT (Figures 1A–F) at the beginning of vegetation (BBCH 14–18). The plants had higher values in all parameters at STmp than at CT, but the differences between these variants were small and only for leaf length were found to be statistically significant (Figure 1C). There were statistically significant differences in all parameters between two strip-till variants, ST and STmp, in this rapeseed growth phase (BBCH 14–18). STmp had the highest values of all parameters, ST on the contrary; it had the lowest values of all parameters (Figures 1A–F). Brant et al. (2016) also state that the modified strip-tillage for winter rapeseed also finds its place in ploughed fields, where it contributes to increasing the homogeneity of the soil environment at the site of the root system development and consequently reduces heterogeneity between plants.

Before winter, the values of the monitored parameters of rapeseed plants (BBCH 21) were identical for STmp and CT variants (Figures 1A–F). Also, in the spring sampling (BBCH 30), the differences between STmp and CT were small and statistically not significant. Although the differences were not significant, the rapeseed plants grown under STmp tended to have longer leaves and roots also in these growth phases (BBCH 21 and 30), which is evident in the graphs (Figures 1C, D).

Effect of tillage practice on seed yield. The strip-tillage after mouldboard ploughing variant, which showed a tendency for faster growth of both rapeseed roots and aboveground biomass, also achieved the highest yield. On a three-year average, the STmp variant had a yield of 5.53 t/ha (109% compared to CT), and the yield was significantly higher for STmp than CT. Only in the first year of experiments, this variant did not reach the first place in seed yield (Table 2).

The second highest yield was achieved by the strip-tillage variant with an average yield of 5.47 t/ha (108% compared to CT). Although this variant had a slower start, it had comparable or significantly better yields than CT in individual years. On a three-year average, the yield of rapeseed at ST was significantly higher than the yield at CT (Table 2).

The conventional tillage variant achieved the lowest yield (5.06 t/ha, 100%) in a three-year average. In individual experimental years, the rapeseed yields were the same or significantly higher at ST and STmp than the yields at CT. Jaskulska and Jaskulski (2020) also achieved a significantly higher yield of winter oilseed rape at ST (4.16 t/ha) than in CT (3.81 t/ha).

For other field crops, e.g., Übelhör et al. (2014) consider strip-tillage, with all of the advantages in terms of soil protection, to be a suitable alternative for growing cauliflower, as they reached almost the same yield as in a tillage system with mouldboard ploughing. Also, for sunflower, the differences between conventional tillage and four reduced tillage technologies (RT 1–4) were not statistically significant in experiments of Sessiz et al. (2008). Despite the statistical insignificance,

Table 2. Winter oilseed rape yield (t/ha) under three tillage systems (2014/15–2016/17)

Tillage system	2014/2015	2015/2016	2016/2017	3-year average	(%)
CT	4.91^{a}	5.22^{b}	5.05^{ab}	5.06^{b}	100
STmp	5.15^{a}	6.02^{a}	5.41^{a}	5.53^{a}	109
ST	5.66^{a}	5.86^{a}	4.89^{b}	5.47^{a}	108
$HSD_{0.05}$	0.777	0.514	0.366	0.311	

Different letters indicate statistically significant differences between the tillage systems in individual years (Tukey's *HSD* (honestly significant difference) test; $P < 0.05$). CT – conventional tillage; STmp – strip-till after mouldboard ploughing; ST – strip-till

RT 2 technology using strip-tiller had the highest yield of all technologies in both experimental years. Jabro et al. (2014) state that sugar beet yields at ST are comparable to CT or even greater in areas that are prone to wind damage to sugar beet seedlings. Conversely, Laufer and Koch (2017) report that sugar beet dry matter yield and white sugar yield under ST on silty loam soil was decreased by approximately 7% in comparison to intensive tillage (annual mouldboard ploughing) and reduced tillage. With maize, studies comparing strip-till and no-till found that ST increased grain yield compared to NT (Trevini et al. 2013, Potratz et al. 2020). Herout et al. (2018) achieved a similar grain yield of maize for NT, ST and disk cultivation. Potratz et al. (2020) also compared ST and NT for soybeans, but yields in ST were generally equivalent to NT and yield benefits associated with strip-till were dependent on other management factors.

Through summarising the final results, ST technology can be concluded as an appropriate alternative to the CT system for winter oilseed rape because it achieves comparable or better yields than CT. The use of STmp contributes to improving conditions for rapeseed plants, which resulted in an annual yield increase. The ST and STmp technologies applied in the growing of winter oilseed rape are perspective in the context of advancing climate changes in Europe as they reduce the unfavourable effects of periodical soil moisture shortages occurrence on plants.

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