A multi-criteria evaluation of the efficiency of winter oilseed rape production under different tillage systems

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Abstract

This dissertation presents the results of a study investigating the agronomic, economic and energy efficiency of winter oilseed rape production under different tillage and seeding systems. A field experiment was conducted during three growing seasons (2016/2017, 2017/2018 and 2018/2019) in the Agricultural Experiment Station in Bałcyny (53°35'46.4'' N, 19°51'19.5'' E) owned by the University of Warmia and Mazury in Olsztyn, located in north-eastern Poland. The experiment, established each year, had the 3^{5-1} fractional factorial design with two replications. Five fixed factors (A, B, C, D, E) were tested simultaneously at three levels (0, 1, and 2). The experimental factors were as follows: **A. tillage and seeding:** (A0) strip-till, (A1) no-till, (A2) plowing. **B. weed control**: (B0) pre-emergence herbicide treatment, (B1) foliar herbicide treatment, (B2) sequential herbicide treatment. **C. application of plant growth regulators (PGRs)**: (C0) no PGRs, (C1) in the fall, (C2) in the fall and spring. **D. spring fertilization with nitrogen (N)**: (D0) 160, (D1) 200, (D2) 240 kg ha^{-1}. **E. spring fertilization with sulfur (S)**: (E0) 0, (E1) 40, (E2) 80 kg ha^{-1}.

The following criteria were used in a multi-criteria evaluation of the efficiency of winter oilseed rape production: (i) agronomic analysis: soil chemism, plant growth and development in the fall and spring, stand weed infestation, yield components, seed yield and straw yield, harvest index; (ii) qualitative analysis: crude fat content, fatty acid profile, total protein content, fiber fractions (acid detergent fiber - ADF, neutral detergent fiber - NDF), quantitative and qualitative composition of glucosinolates - GLS; (iii) economic analysis: production costs based on structure and agronomic operations, money equivalent of seed yield, farm income and economic efficiency of the production process (unit cost and profitability ratio); (iv) energy efficiency analysis: energy inputs based on energy fluxes and agronomic operations, unit energy value of seeds (heating value), volume of energy accumulated in seed yield, energy gain and energy efficiency of seed production.

Tillage and seeding systems exerted significant effects on plant growth and development in the fall. The highest number of leaves per rosette, the largest root collar diameter, the maximum height of the apical bud and the longest taproot were noted in the strip-till system. In the plowing and no-till systems, root collar diameter was 14% smaller, and the epicotyl (o 8%) and taproot were shorter (by 8% and 11%, respectively). The weight of aboveground and underground plant parts was 29% and 26% higher, respectively, in the strip-till system than in the remaining tillage systems. Epicotyl length was significantly affected by weed control strategies, and it was approximately 15% higher when herbicides were applied before seedling emergence, compared with foliar and sequential herbicide treatments. Foliar and sequential herbicide treatments significantly (by approx. 18%) inhibited the development of rosette biomass. A PGR applied in the fall stimulated taproot growth (3% increase in length).

The seed yield of winter oilseed rape was highest (5.95 Mg ha^{-1}) in the strip-till system. Plowing and no-till systems resulted in a minor, but statistically significant decrease in seed yield (by 0.05 and 0.14 Mg ha^{-1}, respectively). Foliar herbicide application was most effective in the strip-till system, pre-emergence and sequential herbicide treatments were most effective in the no-till system, whereas pre-emergence herbicide treatment was most effective in the plowing system. An increase in N fertilizer rate to 200 kg ha^{-1} had a positive influence on seed yield. The highest N fertilizer rate (240 kg ha^{-1}) was justified only when S fertilizer was applied in early spring. An important role was played by S fertilization, which increased seed yield by 11% on average.

A comparison of the analyzed production technologies revealed that the highest seed yield of winter oilseed rape (6.66 Mg ha^{-1}) was achieved in the no-till system, when herbicides were applied before seedling emergence, PGRs were applied in the fall, and N and S were applied at the highest rates

(240 kg and 80 kg ha^{-1}, respectively). The lowest seed yield (4.95 Mg ha^{-1}) was noted in the plowing system, when herbicides were applied to the leaves, PGRs were applied in the fall, N was applied at the highest rate (240 kg ha^{-1}) and S was not applied.

The seeds of winter oilseed rape had the highest crude fat content (498 g kg^{-1} DM) in the strip-till system. The crude fat content of seeds was 2-3% lower in the no-till and plowing systems. The seeds of winter oilseed rape in the strip-till and no-till systems had higher oleic acid concentration but lower linolenic acid concentration, compared with the plowing system. Winter oilseed rape plants fertilized with 160 and 200 kg N ha^{-1} in the spring accumulated similar amounts of fat in seeds (495 and 494 g kg^{-1} DM). The crude fat content of seeds decreased significantly (484 g kg^{-1} DM) in response to the highest rate of N fertilizer (240 kg ha^{-1}). The seeds of winter oilseed rape had the highest total protein content (196 g kg^{-1} DM) in the no-till and plowing systems. The total protein content of seeds was considerably lower (189 g kg^{-1} DM) in the strip-till system. The total protein content of seeds increased with increasing N fertilizer rates – from 191 (160 kg N ha^{-1}) to 199 g kg^{-1} DM (240 kg N ha^{-1}). Among the analyzed agronomic factors, S fertilization exerted the greatest effect on GLS synthesis in the seeds of winter oilseed rape. The total GLS content of seeds increased by 35% on average when the rate of S fertilizer was increased from 0 to 80 kg ha^{-1}, mostly due to the increased accumulation of alkenyl GLS (gluconapin – increase of 51%, glucobrassicanapin – increase of 75%, progoitrin – increase of 40%).

Production costs were highest in the conventional tillage system (PLN 3 300 -3 600 ha^{-1}). In the plowless systems, the costs associated with labor, the operation of tractors and machines, and energy carriers decreased from PLN 227 (no-till system) to PLN 341 ha^{-1} (strip-till system). The value of seed yield, revenue and profitability were highest in the strip-till system, followed by the no-till system and the plowing system. In the strip-till system, profitability was highest (324%) in the technology involving sequential herbicide treatment, PGR application in the fall, and spring fertilization with 240 kg N ha^{-1} and 40 kg S ha^{-1}. In the no-till system, profitability was highest (301%) when herbicides were applied before seedling emergence, PGRs were applied in the fall, N was applied at 240 kg ha^{-1} and S was applied at 80 kg ha^{-1} in the spring. In the conventional tillage system, profitability was highest (294%) in response to foliar herbicide treatment and the application of 200 kg N ha^{-1} and 80 kg S ha^{-1}.

Energy consumption was highest in the plowing system (25.9-28.8 GJ ha^{-1}), and 3% and 9% lower in the strip-till and no-till systems, respectively. In the strip-till system, seed yield had the highest energy value (72.5 GJ ha^{-1}). The volume of energy accumulated in seed yield, energy gain per ha and the energy efficiency ratio were highest in the strip-till system, followed by the no-till system and the plowing system. In the strip-till system, the most desirable energy efficiency ratio (3.17-3.20) was achieved when (i) herbicides were applied before seedling emergence and N was applied at 160 kg ha^{-1} or (ii) herbicides were applied sequentially, PGRs were applied in the fall and N was applied at 160 kg ha^{-1}. In the no-till system, the energy efficiency ratio was highest (2.90) in the technology involving foliar herbicide treatment, PGR application in the fall and the application of 160 kg N ha^{-1}. In the plowing system, the energy efficiency ratio was highest (2.90) when herbicides were applied to the leaves, and N and S fertilizers were applied at 200 kg ha^{-1} and 80 kg ha^{-1}, respectively, in the spring.