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Evaluation of the Effect of the Tillage System and Weed Control on the Yield of Flax Fibre and Its Quality

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Abstract
Fibrous flax, despite its many different uses, is currently growing within a relatively small area, mainly because of the low production margin. This study shows possible approaches to the reduce production costs of flax fibre by 424 PLN per hectare as a result of no-tillage cultivation and direct sowing. No such research on flax fibre production has been conducted so far. The study (carried in 2011-2012) covered highly differentiated temperature and precipitation conditions. The yields of homomorphic fibre in a dry year were higher than in a year with optimum precipitation in the no-till system comparing to conventional tillage. The application of Chisel 75WG increased the yield of fibre regardless of the weather and cultivation system and was the result of both straw yield and fibre content increase. Tillage systems and herbicides differentiated the length and linear density of homomorphic fibre and impurity content, whereas the elongation at break and tenacity did not depend on the cultivation method.

Key words: *dflax, homomorphic fibre, tillage systems, herbicides, flax fibre, fibre quality.*

Introduction

Fibre flax is a crop of versatile uses. It can be utilized in the textile, pharmaceutical, pulp and paper and food industry to produce polymers and biocomposites while a linseed oil can be used as adjuvant increasing pesticide efficacy [1, 2]. As a non-food crop it can be used for the reclamation of heavy metal-polluted land around metal smelters or coking plants [3, 4].

The advantages of flax fibre are the result mainly of its high strength, tensile strength, characteristic silky shine and relatively low tendency to pilling. Flax fibre is also well known for its highly positive effect on human physiology, like the pleasant cool touch and good thermal conditions resulting from the hygroscopic, thermal and electrostatic properties of these fibres [5]. The advantages of flax mentioned above have no influence on the increase of its cultivation area. The low interest in flax cultivation results from the low profitability of production. Increasing the production margin of this crop can be achieved by both yield growth and a reduction in cultivation and processing costs [6 - 9].

A factor that can influence the increase in flax fibre production profitability is the reduction of expenditure on crop production by simplifying production technology. The most far-reaching simplification used in the cultivation is the no-tillage planting method instead of plough tillage, which is the most energy and time consuming treatment in plant production [10 - 14]. The no-tillage system along with the reduction of energy and production costs contributes to a decrease in soil erosion and the soil organic matter mineralisation rate, the improvement of the upper layer soil structure, an increase in soil moisture content, and its biological activity enrichment [15 - 18]. A lower mineralisation rate also reduces CO_2 emissions to the atmosphere, contributing to a lower greenhouse effect [19]. The reduction of CO_2 emissions is also a result of lower fuel consumption in the no-tillage system compared to the traditional one.

The effect of different tillage systems on the yields of different crops has been reported by numerous authors with ambiguous results [2, 20 - 24]. Analysis of the results indicates that different crop species react in various ways to tillage systems. The methods of tillage differentiate not only crop yield but also its quality. This leads to the conducting of the research with crops which have never been investigated in the no-tillage system. However, there are no reports on the reduction of tillage in the cultivation of fibre crops except the recent article by authors of the present study [7], in which the effects of the no-tillage system on weed infestation, flax yield and physical and biological soil properties are presented.

There are no data available in literature on the effect of tillage systems on the yield of flax fibre and its quality. Therefore research in the area is fully justified and the results may indicate that the re-

Table 1. Additional cost of conventional tillage compared to no-tillage system in PLN·ha-1.

Cultivation treatment	Treatment unit cost, PLN·h-1	Runtime, min·ha-1	Treatment total cost, PLN·ha-1
Skimming	125	50	104.17
Harrowing	114	20	38.00
Pre-winter plowing	127	70	148.17
Spring harrowing	114	20	38.00
Seedbed preparation	144	40	96.00
		Total	**424.34**

Table 2. Monthly precipitation in mm and average air temperatures in °C during vegetation period in years 2011 - 2012.

	Year	Months					
		IV	V	VI	VII	VIII	IX
Average temperatures, °C	2011	11.7	14.1	18.6	17.9	18.8	15.3
	2012	8.8	14.8	16.0	19.2	18.7	14.3
	1950-2010	7.6	13.1	16.3	17.8	17.4	13.1
Monthly precipitation, mm	2011	14	34	58	175	35	46
	2012	22	77	163	198	60	30
	1950-2010	38	54	64	76	62	50

duction of inputs in tillage is worthwhile to increase the production margin of this crop. The flax fibre production margin can also be increased by replacing the traditional manufacturing method with a homomorphic fibre production system that uses fewer machines, energy and time, resulting in much lower production costs.

The production of homomorphic fibre simplifies the harvest of flax and employs only one set of machinery for fibre extraction and one system of yarn spinning, replacing the hackling system for long fibre and carding system for short fibre spinning. Processing retted straw for the homomorphic fibre production system yields noil or very good class tow, resembling fibre that is more uniform, both in its structure and bulk. This type of fibre is used in new applications as compared to traditional retted fibre. Mechanical, enzymatic or chemical processing leads to the improvement of homomorphic fibre in terms of its length and linear density and makes it useful for spinning blended yarns with cotton, wool or synthetic fibres by conventional - like cotton and woollen spinning systems [25, 26].

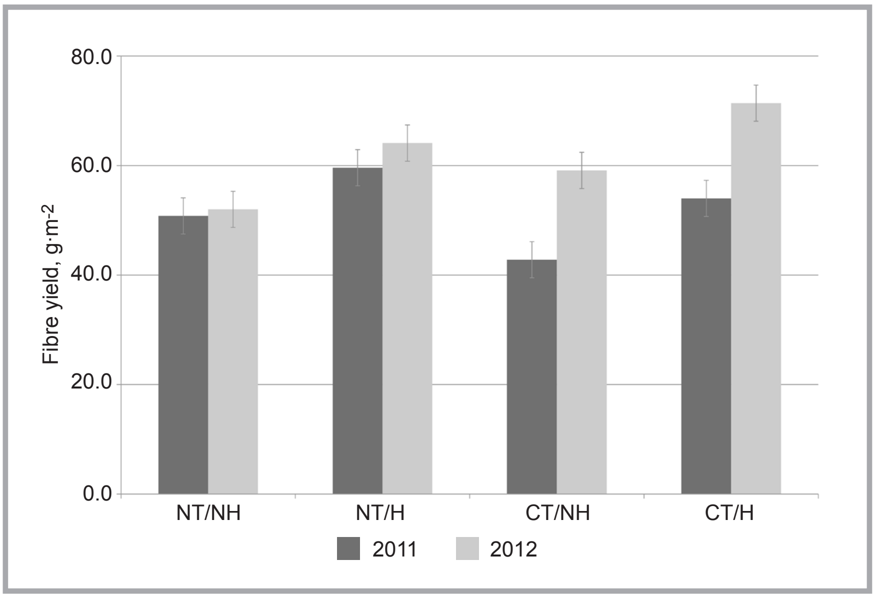

Figure 1. Yield of fibre flax depending on the tillage system and weed control. $LSD_{0.05}$ – 6.67. CT – conventional tillage, NT – no tillage, H – herbicide treatment, NH – no herbicide.

The aim of the preliminary studies presented was to determine the effect of tillage systems and weed control on the yield and quality of homomorphic flax fibre and to demonstrate the possibility of its production cost reduction by changing the flax cultivation system and weed control. The influence of the interaction of experimental factors with the weather on the yield and quality of homomorphic flax fibre was also investigated.

Materials and methods

Field experiments were conducted in 2011 - 2012 in Pakosław, Wielkopolska on albic luvisols typic hapludatfs. The experiments covered two factors: The first order factor was two ways of tillage: conventional tillage versus direct sowing without pre-sowing cultivation (differences shown in ***Table 1***). The second order factor was weed control using Chisel 75WG (DuPont, Switzerland) herbicide (a.i.: methyl tifensulfuron + chlorosulfuron) at 30 g·ha-1 applied with an auxiliary Torpedo, versus no weed control. Conventional tillage treatments were used, such as skimming, harrowing, pre-winter ploughing, spring harrowing and seedbed preparation. The cost of these treatments was estimated according to data from the Wielkopolska Agricultural Advisory Centre [27]. These costs were not incurred in the cultivation without ploughing.

The weather pattern presented is from the Weather Station in Brody, belonging to the University of Life Sciences, located circa. 5 km from the experimental fields. Fibre flax (variety Tabor) was sown at 2500 seeds per m^2 in a row spacing of 10 cm. Fertilisation applied was (kg/ha): 40 N, 80 P_2O_5 and 120 K_2O. Phosphorus and potassium fertilisers were applied in autumn and nitrogen in spring before the sowing of flax. Winter wheat was of the previous crop to flax. Standard practices were used for growing flax with conventional tillage. The effect of the factors investigated on weed infestation, flax yield as well as physical, chemical and biological properties of the soil has been reported previously [7]. The present study is a supplementation and continuation of the thesis mentioned above and addresses the effect of the tillage systems and weed control on the yield of homomorphic flax fibre and its quality. Laboratory tests were performed at the Institute of Natural Fibres and Medicinal Plants in Poznań. Flax was harvested in the 3rd decade of August. Straw was water retted in an experimental retting tank, after which it was mechanically processed on a laboratory scale tow producing unit. Measurements of fibre parameters were conducted according to Polish Standards in force.

The moisture content in the homomorphic fibre was determined by weighing and drying samples in a laboratory drier at 105 °C until the stable weight of the sample (PN-91/P-04601). Fibre impurities were determined by the removal of all contaminants using tweezers and calculating their weight ratio in the whole sample (PN-79/P-0468). The average length of fibre was measured by evening the base of the handful and manual segregation of fibre belonging to a particular length class. The results of measurements were used to calculate the average length of the fibre (BN-186/7511-16). The force at break, elongation at break and tenacity were determined by static drawing (PN-P04676). The linear density of the fibre was tested by the gravimetric method (PN-73/P-04677).

The results were evaluated statistically with R statistical software version 3.0.2 [28]. ANOVA tests were followed by *post hoc* analysis with Fisher's LSD test from the agricolae package [29] at significance level α = 0.05.

Results and discussion

Fibre yield

A significant factor influencing the yield of flax fibre was the weather (***Table 2***).

In the years of experiment, the average sum of rainfall during the vegetation period differed substantially. In 2011 the rainfall from April till September totalled 362 mm while in 2012 it was 550 mm. The average temperatures were 14.2 and 13.9 °C, respectively. Lower precipitation in 2011 as compared to 2012 reduced the yield of flax fibre regardless of the effect of experimental factors (***Figure 1***). The amount of rainfall also differentiated the effect of the factors tested on the yield of fibre. In the drier year 2011, a lower yield of fibre was obtained with conventional tillage than in the no-till system. However, in 2012, characterized by optimum water conditions in the soil, a higher yield of fibre was obtained in conventional tillage compared to the no-till system.

Table 3, *Content of fibre in the straw and fibre impuritiy content in %. Average for 2011-2012. Different small case letters (a, b) indicate significant differences between treatment means according to Fisher's LSD test (p < 0.05).*

Tillage system	Weed control	Fibre content in the straw, %	Fibre impurity content, %
Conventional tillage (CT)	no herbicide (NH)	14.20[b]	8.50[a]
	herbicide (H)	17.00[a]	9.07[a]
No tillage (NT)	no herbicide (NH)	15.20[b]	6.20[b]
	herbicide (H)	17.13[a]	7.00[b]
LSD (p = 0.05)		1.09	0.89

The cost of flax production in the to-tillage system may be reduced by 424 PLN per hectare compared to conventional tillage (***Table 1***) by the reduction of cultivation treatments. When choosing among cropping systems, producers are often faced with a trade-off between increases in annual yield and increases in yield variability or financial risk. As producers become increasingly risk averse, they tend to choose cropping systems that display lower income variability [30]. Much higher variability in fibre yield influenced by weather was observed with conventional tillage (32% with herbicide and up to 38% without). Weather dependent variability in the yield with the no-tillage system was much lower (7.5 and 2%, respectively). A different effect of the tillage system on the yield of fibre in studied years resulted from the effect of the tillage system on the soil moisture content. The no-till system increased the soil moisture content regardless of the year and increased the yield in a dry year, but has no effect in a wet year. This has been reported for many plant species and is well-documented in relatively rich literature [21, 22, 31, 32], confirming the credibility of our observations for fibre flax.

The effect of soil moisture on the yield of flax fibre has not been investigated so far. It can be assumed, however, that the yield of flax fibre, besides its percentage share in flax plants, depends mainly on the yield of plants. Heller [33] reported that higher moisture in the environment extends the vegetation of fibre flax, supporting higher crop yield. This explains the results obtained in this study, which showed that in a dry year, higher soil moisture content in the no-till system had a positive effect on flax fibre.

The application of herbicide increased the yield of fibre regardless of the tillage system used (***Figure 1***). Yield increase as an effect of herbicide use has also been reported by other authors [8, 9, 34].

No information on the effect of herbicides on flax fibre yields is available in the literature, while there are works showing an increase in straw yield. Therefore it is widely accepted that the percentage increase in fibre under the influence of herbicides would be similar to that in straw yield. In the present study we show that the yield of fibre increased as an effect of herbicides to the higher extent than the that of flax plants itself (as discussed earlier [7]). We observed not only an increase in fibre yield but also a rise in its content in the straw (***Table 3***). It indicates that the yield of fibre depends on both the yield of straw and fibre content therein.

Quality parameters of fibre

The increase in fibre content as an effect of herbicide use can be correlated with the reduction of protein content in flax as reported by Soliman [8]. In the chemical composition of most plant species there is a negative correlation between the carbohydrate and protein content.

In this study the content of fibre depending, to a higher degree, on herbicide use than on the tillage system. Chemical weed control in both the conventional and no-till systems increased the content of fibre, while no differences in fibre content were found between the tillage systems (***Table 3***). Praczyk and Heller [9] also reported that high weed infestation reduces the content and quality of fibre in flax.

Weed control had a significant influence on the fibre length (***Figure 2***, see page 36), which was higher when herbicide was used both with and without a plough. When no herbicide was used, the fibre length did not depend on the tillage system. However, it was determined by the tillage system when herbicide was used, which was longer in the conventional system than in no-tillage. The differences are the result of lower plant population in the no-till system than in conventional tillage. A lower stand contributes to the tendency of flax to produce branches reducing

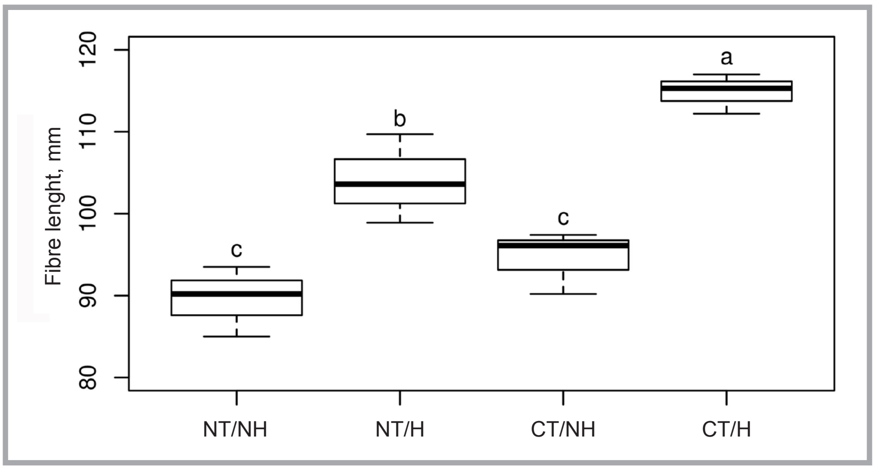

Figure 2. *Influence of tillage system and weed control on flax fibre length. Different small case letters (a, b, c) indicate significant differences between treatment means according to Fisher's LSD test (p < 0.05).*

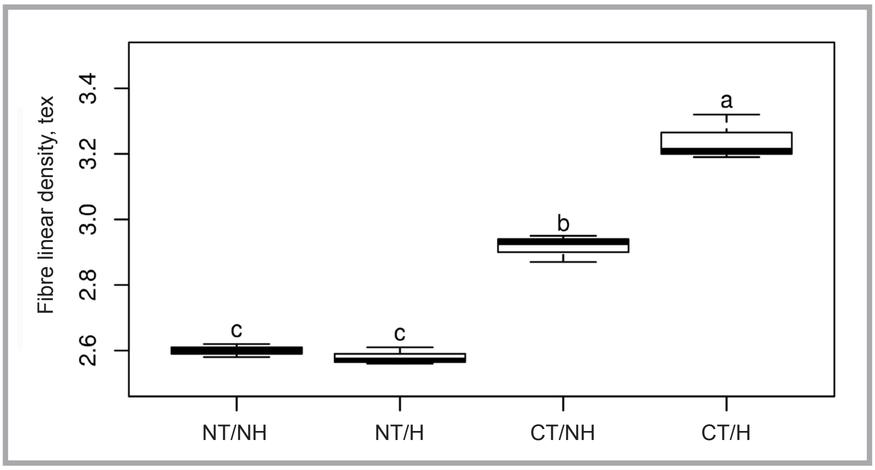

Figure 3. *Influence of tillage system and weed control on flax fibre linear density. Different small case letters (a, b, c) indicate significant differences between treatment means according to Fisher's LSD test (p < 0.05).*

Table 4. *Breaking elongation and specific flax fibre strength under static tension; Different small case letters (a, b) indicate significant differences between treatment means according to Fisher's LSD test (p < 0.05).*

Tillage system	Weed control	Elongation at break, %	Tenacity, cN/tex
Conventional tillage (CT)	no herbicide (NH)	25.7^b	18.6^b
	herbicide (H)	32.5^a	26.1^a
No tillage (NT)	no herbicide (NH)	24.3^b	15.8^b
	herbicide (H)	31.6^a	26.5^a
LSD (p = 0.05)		3.16	4.81

the technical length of the stem and the length of fibre.

A negative effect of not using herbicides on fibre length can also be explained by the number of plants per area unit. Weeds, as a result of competition with flax in the initial stage of growth, cause the thinning of flax and reduction in the stand, which, as discussed above, increases the branching of the stem and, in consequence, a reduction in fibre length.

The tillage system and weed control had a significant effect on fibre linear density (***Figure 3***). Lower linear density characterised fibre obtained from no-till objects, regardless of the weed control, while in conventional tillage fibre obtained from objects with weed control was thinner than those without weed control. Lower linear density characterised fibre from the no-till system regardless of the use of herbicides, while in the traditional system, which resulted in higher linear density, it did depend on herbicide use. It was lower when herbicide was not used compared to when it was not.

Analysing the properties of the fibre in relation to its static elongation, it has been shown that the application of the herbicide allowed the increase of both the elongation at break and tenacity (***Table 4***). The method of cultivation did not differentiate either the elongation at break or the tenacity of fibre, which is due to the competition of weeds with flax for water and nutrients, thus impairing the quality of the fibre.

The fibre impurity content was significantly differentiated by both the tillage system and weed control (***Table 3***). In the no-till system the impurity content in the fibre was lower than in fibre obtained from the traditional tillage system. In both tillage systems the impurity content in the fibre was lower in objects without weed control, which can also be explained by the extended vegetation period and delaying the process of fibre cell lignification. Limitation of this process reduces both the amount of impurities composed mainly of wood and lignin and their easier removal.

Conclusions

It was shown that the cost of flax cultivation in the to-tillage system may be reduced by 424 PLN per hectare compared to conventional tillage. The yield of flax homomorphic fibre was dependent on both the weed control and tillage method. Weed control with herbicide, regardless of the tillage system, increased the yield of fibre, resulting from both the increase in straw yield and the share of fibre in the straw. The effect of tillage on the yield of fibre varied depending on the amount of rainfall. In a dry year it was higher and in a year of optimum moisture it was lower for no-tillage compared to conventional cultivation.

The tillage systems and weed control differentiated the length and linear density of homomorphic fibre as well as the impurity content in it. Interaction between the factors investigated and qualitative parameters of the fibre was proven. The tillage system had no effect on the length of fibre when no weed control was used. However, if weed control was used, longer fibre was obtained in the conventional tillage system. In the no-till system, the fibre was thinner, regardless of the weed control, while in the traditional tillage, lower linear density of fibre was obtained when weed control was not applied. The fibre elongation at break and its tenacity did not depend on the cultivation system. In contrast, the use of herbicides increased both the degree of elongation and fibre strength. Short-term studies presented herein do not allow unambiguous assessment of tillage for the flax fibre obtained and research should be continued.

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