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Effect of herbicides on yield and quality of straw and homomorphic fibre in flax (*Linum usitatissimum* L.)

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ABSTRACT

Fibre flax (*Linum usitatissimum* L.) is a very poor competitor with weeds, and to obtain acceptable yields, weeds should be effectively controlled. Very little information is available on the tolerance of flax to herbicide applications. Types of applied herbicides determine not only the yield of flax but can also affect yield of fibre, its quality and may affect processes (physical, chemical and enzymatic) used in the refining of homomorphic fibres to increase their thinness and divisibility. Presented basic field research was carried out in the years 2011–2012. In the studies the impact of three herbicides (with a.i. linuron, bentazon and chlorsulfuron) was examined on the control of weeds, course of vegetation and yield and quality of flax homomorphic fibre. The applied herbicides had a significant impact on the weed control, the length of the vegetation, straw yield, the percentage of fibre in the straw, weight and length of the fibre and its thinness and divisibility. The lowest number and mass of weeds and the highest flax straw yield and fibre quality was obtained after chlorsulfuron application. Bentazon, despite its high herbicidal effectiveness, reduced both the amount and quality of fibre yield when compared to chlorsulfuron, due to its phytotoxic effect on flax. Pre-emergence linuron application resulted in the longest fibres and highest fibre content in flax straw.

1. Introduction

Flax does not compete well with other plants, and yield and quality are improved with weed control (Foulk et al., 2004; Harker et al., 2011). According to Nalewaja (1996) the reduction of flax yield without weed control in the northern US states ranged from 36 to 70%. Significant reductions of flax yield resulting from its weed infestation were also observed by other authors (Friesen, 1986; Stevenson and Wright, 1996). Weeds contribute not only to the reduction of yield but also substantially reduce its value and suitability for processing and potential to obtain good quality fibres (Bilalis et al., 2012; Heller et al., 2012).

Selection of herbicides for weed control in flax has only slightly changed in recent years due to the relatively small size of its growing area – especially for fibre – and lack of interest of chemical manufacturers to seek for and register of new formulations for use in this plant (Heller et al., 2006). Profound changes in the composition of segetal weed communities lead to the need for new herbicides for weed control in flax and to study again active substances used for many years in flax production. This is caused by constant introduction of new preparations for weed control especially in widely grown plant species. Also simplifications in the crop rotation and tillage alter the composition of the weeds infesting the cultivated fields. (Tørresen et al., 2003; Ramsdale et al., 2006; Bilalis et al., 2012; Dąbkowska et al., 2007).

These changes can be evidenced by comparing presently occurring weed species in flax with those observed in prior decades. Heller (1992) and Nalewaja (1996) in their works from 70s and 80s of the last century recognised dominant species in flax to be: *Chenopodium album* L., *Sinapis arvensis* L., *Cirsium arvense* (L.) Scop., *Polygonum nodosum* Pers. and *Polygonum convolvulus* L. In contrast, currently the most prevailing are: *Echinochloa crus-galli* L., *Viola arvensis* Murr., *Geranium pusillum* L. and *C. album* L. (Heller and Praczyk, 2007; Mańkowski et al., 2013; Pudełko et al., 2015). The aforementioned change leads to a reassessment of herbicides that have been on the market for many years. So far, no studies have been performed on their impact on the quality of the fibres in flax. Different chemical compounds in herbicides may influence the fibre quality indirectly through the weed control effectiveness

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and directly on flax, not only on the yield of straw but also on the content, length, thinness and divisibility of fibre.

The herbicides recommended for weed control in flax generally contribute to the yield increase, and therefore possible negative effect on the crop have not been extensively analysed before. Herbicides, depending on their type, may have phytotoxic effects on flax causing all sorts of morphological and physiological changes of varied intensity, like drying out of leaves, chloroses, deformations, stunting and delayed flowering and maturity (El-Saht et al., 1994; Rother and McKercher, 1989). Most of these changes are small, transitional and not always attributed to the reduction in the plant yield (Wall and Kenaschuk, 1996). However, they may affect both the yield size and fibre quality.

Flax is a source of industrial fibres and, as currently processed, provides long and short fibres. Long line fibre is used in manufacturing high value linen products, while short staple fibre has historically been the waste from long line fibre and used for lower value products (Jhala and Hall, 2010). Presently, flax fibres have become an important part of new composite materials utilized in automobile and constructive industries. Bio-composites made up from the flax fibre could be an eco-friendly and biodegradable alternative to conventional plastics (Bodros et al., 2007). Recently, in order to reduce the cost of flax fibre production, a new cheaper method for the isolation and production has been introduced, leading to obtain homomorphic fibre of relatively good quality. After processing of the straw by the homomorphic method, a more homogeneous fibre is obtained with a structure similar to a high-quality motted tow. Further mechanical, chemical and enzymatic processing allows for using fibre for the production of yarns blended with cotton, wool, chemical fibres, and high-quality pulps and composite materials (Mańkowski, 2003).

Homomorphic fibre production needs still to be tested with respect to both the cultivation of flax and its post-harvest processing. So far no studies have been conducted on the effect of herbicides on the quantity of straw and homomorphic fibre yield and quality. The yield of fibre flax depends to a large extent on the maintenance of the plantation free of weeds and herbicide effectiveness depends on the composition of weed communities, which changes gradually.

The aim of the study was to evaluate the efficacy of herbicides to control weed species currently dominant in the fibre flax cultivation, their effect on the yield of flax and fibre, and to determine the effect of herbicides on the quality of the homomorphic fibre.

2. Materials and methods

Field experiments were conducted in years 2011–2012 in the Experimental Station of Institute of Natural Fibres and Medicinal Plants in Sielec Stary, province Wielkopolska, Poland. The experiment was prepared each year in a randomized complete block design. Univariate tests were quadruplicated on the area of 20 m^2 each on the soil classified as albic luvisols typic hapludatfs (according to the U.S. Soil Taxonomy). Fibre flax variety Luna was sown after sugar beet, which fore crop was corn. Fibre flax was sown at 2500 seeds per m^2 in a row spacing of 8 cm. Fertilization applied was (kg ha^{-1}): 40 N, 80 P_2O_5 and 120 K_2O. Phosphorus and potassium fertilizers were applied in autumn and nitrogen in spring before sowing of flax. Agricultural practises used were in accordance with the recommendations for the cultivation of fibre flax.

The research factors were three herbicides: pre-emergence applied Afalon (a.i. linuron) at a dose of 0.65 kg a.i./ha and post-emergence Basagran 480 (bentazon) at 0.75 kg a.i./ha and Glean 75 DE (chlorsulfuron) 9 g a.i./ha. The selection of herbicides was based on current use practises among Polish flax growers. Three active ingredients tested herein (available in a variety of herbicides) are used in Poland for 80–90% of the area of weeded flax as the most effective agent against currently dominant weeds in a flax. Afalon and Glean were used in recommended low doses in the presented study. In contrast, the dose was reduced for Basagran because our previous studies showed possible damage to flax after recommended doses of bentazon.

Table 1
Monthly precipitation [mm] and average air temperatures [°C] during vegetation period in years 2011–2012.

	Months						
Year	April	May	June	July	August	September	Mean/Sum
Average temperatures [°C]							
2011	11.7	14.1	18.6	17.9	18.8	15.3	16.5
2012	8.8	14.8	16.0	19.2	18.7	14.3	15.2
1950–2010	7.6	13.1	16.3	17.8	17.4	13.1	14.2
Monthly precipitation [mm]							
2011	14	34	58	175	35	46	362
2012	22	77	163	198	60	30	570
1950–2010	38	54	64	76	62	50	344

Sowing dates were April 8 and April 20 in 2011 and 2012 respectively. Afalon was applied 1 day after sowing. Herbicides used post-emergence were applied at the herringbone stage (BBCH 12-14) (Smith and Froment, 1998; Heller et al., 2012) of flax. Basagran was applied on May 9 (2011) and May 21 (2012) while Glean on May 14 and May 26 respectively. Two weeks after application of post-emergence herbicides the number and the total mass of weeds was identified. Measurements were carried out in quadruplicate on each plot at the area of 0.25 m^2. Flax was harvested on August 2 in 2011 and August 16 in 2012 when most of the plantation was rated visually to be at the green–yellow maturity stage (BCCH 83).

The presented weather pattern data is from the Weather Station in Sielec Stary (Table 1). In the years of experiment the average temperatures during flax growth season differed only a little and precipitation was higher in 2012 than in 2011, particularly large differences occurred in June. The plots were not irrigated in the course of experiment.

Qualitative laboratory tests were performed at the Institute of Natural Fibres and Medicinal Plants in Poznań using accepted Polish standards (PN). The moisture content in the homomorphic fibre was determined by weighing and drying samples in a laboratory drier at 105 °C until stable weight of the sample (PN-91/P-04601). Fibre impurity content was determined by 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 particular length class. The results of measurements were used to calculate the average length of the fibre (PN-186/7511-16). Force at break, elongation at break and specific strength were determined by static drawing (PN-P04676). The linear density and divisibility of the fibre were tested by a gravimetric method (PN-73/P-04677).

The results were evaluated statistically with the R statistical software version 3.0.2 (Core Team, 2013). ANOVA tests were used to test main effects of treatment and possible interactions. When ANOVA showed no year effect or interaction, then the data from both years were combined and analysed post hoc with Fisher's LSD test from agricolae package (De Mendiburu, 2013) at a significance level $\alpha = 0.05$. When significant year effect was indicated, mixed model analysis was performed using lme4 package (Bates et al., 2014) with herbicide as a fixed effect and year and year-herbicide interaction as random effects. In such cases post hoc pair-wise Tukey's contrasts comparisons were performed with multcomp package (Hothorn et al., 2008). Considering environments as random permits inferences about the treatments to be made over