NARDI FUNDULEA, ROMANIA
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ROMANIAN AGRICULTURAL RESEARCH, NO. 31, 2014
Print ISSN 1222-4227; Online ISSN 2067-5720

THE INFLUENCE OF NITROGEN ON THE AGRONOMIC TRAITS OF FIBRE FLAX CULTIVARS

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ABSTRACT

Cultivar trials with fibre flax were set up in three years (2008-2010) and in two locations: at the experimental fields of the Faculty of Agriculture in Zagreb on eutric cambisol and of the College of Agriculture at Križevci on pseudogley on level terrain. The aim was to determine the influence of nitrogen fertilization on the agronomic traits (dry stem yield, dry stem yield after retting, total fibre yield, share of total fibre, long fibre yield and share of long fibre) of five fibre flax cultivars. The selected cultivars were fertilized with different nitrogen rates (0, 30, 60 and 90 kg/ha) at different times. The trials were carried out according to the RCBD with four replications. According to the results of the three-years research into the agronomic traits of fibre flax, significant differences were established among the cultivars and among the added nitrogen rates under study. The cultivars Agatha, Viola and Electra recorded higher values of investigated traits (dry stem yield, dry stem yield after retting, total fibre yield, long fibre yield) in three years and share of total fibre and share of long fibre in one of two years. The optimal nitrogen rate for fibre flax according to the obtained results was 30 kg nitrogen ha^{-1}.

Key words: cultivars, dry stem yield, *Linum usitatissimum* L. nitrogen fertilization, share of total and long fibre, total and long fibre yield.

INTRODUCTION

Flax is one of the oldest textile fibres used by mankind and possibly the oldest. The principal areas in the world where textile flax has traditionally been cultivated, and to a large extent still is, are northwest and eastern Europe, and China and Egypt (Mackiewicz-Talarczyk et al., 2008). However, flax was used to produce textile products, which in the West had been progressively replaced by articles made from cheaper fibres such as cotton, jute, polyester, and polypropylene. In the last years, the ecological and health issues are assuming greater importance in the minds of the consumers for natural fibres in developed countries (Salmon-Minotte and Franck, 2005). Compared to other textile fibres, flax cultivation requires less fertilizer and weed control chemicals than cotton. It is a good rotation crop. It selectively absorbs heavy metal pollutants from contaminated soils. It grows in temperate climates, where there is an abundance of good quality, available land (unlike cotton). It is biodegradable (unlike synthetic fibres). It requires no greater energy input during manufacture than do other fibres, and less than is required for synthetic fibres. Flax fibre is non-allergenic. It is comfortable to wear due to its rapid absorption and desorption of moisture. It is easily washed.

Flax as a renewable textile raw material is increasingly gaining in importance and the range of its use is spreading in different industry branches, resulting from the fact that above ground parts of the flax plant can be completely used. Besides for the conventional use, e.g. for casual and luxury clothing, interest for the use of flax fibres for technical textiles, such as biocomposites, is increasing, whereby coarse flax fibres are gaining in

Received 20 June 2013; accepted 20 September 2014. First online: 15 April 2014. DII 2067-5720 RAR 2014-373

importance. Although tow was less important in the past, nowadays it is considered to be a valuable ingredient of insulation materials (thermal/sound insulation), and it has found its use in the paper industry (banknotes). There is also interest in the use of wooden remains of the plant after the fibre extraction, in the manufacture of interior car parts, storage containers, biodegradable containers, insulation of trusses and walls (Shekhar and Van Sumere, 1992; Šurina et al., 2009).

The fibre flax has traditionally been cultivated in most parts of Croatia. Fibre flax culture has been practically abandoned in this country despite the increasing number of family farms, and textile and other industries interested in the resumption of its production. Croatia has not own fibre flax cultivars. Therefore, it is necessary to introduce foreign flax cultivars, which have the greatest potential of the adaptation to Croatian climate conditions. Since flax grows in damp and moderately warm areas, and is sensitive to high temperatures, hot and dry winds at the stage of intensive growth and flowering, it may be assumed that the newly formed climate conditions would cause the reduction of its valuable agronomic traits, and as a consequence the reduction of textile technological fibre traits.

Nitrogen fertilization is one of the most important crop management interventions for growing fibre flax. Nitrogen is the most important plant nutrient that influences the development of plants and thus the developmental stages of the plant as well as the yield and fibre quality of flax fibre. A large amount of nitrogen increases vegetative flax mass, which causes lodging, increases the stem thickness and a the amount of wooden core, the fibre becomes coarser and less strong (Yagodin et al., 1991; Augustinussen, 1992; Easson and Long, 1992; Cremaschi et al., 1996; Badiyala et al., 1998; Zedan et al., 1999; Dimmock et al., 2005; Butorac et al., 2009). Adequate selection of cultivars and production technology, as well as suitable processing, would provide natural fibres for the textile industry, and raw materials for other branches of economy, with minimal environmental pollution.

So, the objective of the investigations was to identify the possibility of the introduction of foreign fibre flax cultivars to the continental lowland region of the Northwestern Croatia, and to determine the influence of nitrogen fertilization on the agronomic traits of fibre flax cultivars.

MATERIAL AND METHODS

Cultivar trials with foreign fibre flax were carried out at the experimental field of the Faculty of Agriculture of Zagreb (45°49'26" N, 16°02'07" E), on eutric cambisol and at the experimental field of the College of Agriculture of Križevci (46°02'23" N, 16°54'62" E), on pseudogley on level terrain. The trials involved five fibre flax cultivars: Viking (Cooperative Liniere de Fontaine Cany, France), Viola (Van de Bilt Zaden, The Netherlands), Venica (Agritec, Czeck Rep.), Agatha and Electra (Cebecco Seed, Netherlands).

The content of the nutrients in the soil and pH values are given in Table 1. Fertilization with 100 kg ha^{-1} P (as superphosphate) and 150 kg ha^{-1} K (potassium salt) was done within basic tillage. Flax was fertilized with different N rates (0, 30, 60 and 90 kg ha^{-1}) at different times (urea (46%) and calcium ammonium nitrate (27% N)). No N was added in the first trial treatment. In the second fertilization treatment, all N was added before sowing (30 kg N ha^{-1}). In the third fertilization treatment, 30 kg N ha^{-1} were added before sowing, and 30 kg ha^{-1} in a single fertilizer application at the average plant height of 10 cm; in the fourth fertilization treatment, 30 kg ha^{-1} were added before sowing, and 30 kg at the average plant height of 10 and 20 cm each.

The trials were laid out according to the randomized complete block design (RCBD) with four replications. The main trial plot size was 10 m^2 (10 rows x 0.1 m row spacing x 10 m length). Sowing was carried out using a plot seeder (Wintersteiger, Austria). Fibre flax seeding was performed on 31st March 2008, on 1st April 2009 and on 29th March 2010. Sowing density was 2 500 germinable seeds m^{-2}.

Table 1. The content of nutrients in the soils and pH

Year	P_2O_5 (mg/100 g)	K_2O (mg/100 g)	Total nitrogen (%)	pH
Zagreb				
2008	22.6	18.0	0.18	7.21
2009	21.1	25.0	0.15	6.94
2010	19.9	19.9	0.12	6.91
Križevci				
2008	24.2	18.3	0.11	4.59
2009	28.6	17.6	0.10	4.21
2010	30.9	19.4	0.09	5.04

P_2O_5, K_2O – Al-method; Total nitrogen - HRN ISO 13878:2004; pH - HRN ISO 10390:2004

The agronomic traits investigated were dry stem yield, dry stem yield after retting, total fibre yield, share of total fibre, long fibre yield and share of long fibre. Pulling by hand was carried out at yellow-green ripening. Plants were pulled from an area of 1 m^2. Dry stem yield was determined after de-seeding. Flax stems were then placed in tank of water at 30 °C for 4 days under controlled conditions.

After retting stems were removed from the tank. They were dried at 60 °C for 30 hours and weighed. A scutching machine was used to separate straw (woody matter) from fibre, whereupon the yields of total and long fibres (using a set of hackling pins), and their respective share, were estimated. Data of all the traits studied in each location and year were statistically processed by the analysis of variance. Differences between mean values were analysed using Duncan's multiple range test (Duncan, 1955).

RESULTS AND DISCUSSION

Statistically significant differences were recorded among the cultivars for investigated traits of fibre flax, except for dry stem yield in 2010 at Križevci, share of total fibre in 2008 at Zagreb and share of total fibre and share of long fibre in 2010 at both locations (Tables 2 and 3).

Table 2. Means of agronomic traits of fibre flax in dependence on the cultivar in Zagreb during the three growing seasons (2008, 2009 and 2010)

Cultivar	Dry stem yield ($t\ ha^{-1}$)	Dry stem yield after retting ($t\ ha^{-1}$)	Total fibre yield ($t\ ha^{-1}$)	Share of total fibre (%)	Long fibre yield ($t\ ha^{-1}$)	Share of long fibre (%)
2008						
Viking	4.53^{c}	3.72^{c}	1.10^{d}	29.58^{a}	0.70^{c}	18.60^{b}
Viola	5.14^{abc}	4.41^{b}	1.34^{bc}	30.37^{a}	0.95^{b}	21.61^{a}
Venica	4.77^{bc}	4.13^{bc}	1.23^{cd}	29.98^{a}	0.86^{b}	21.23^{a}
Agatha	5.73^{a}	5.06^{a}	1.54^{a}	30.60^{a}	1.14^{a}	22.42^{a}
Electra	5.18^{ab}	4.48^{b}	1.38^{b}	30.94^{a}	0.98^{b}	21.97^{a}
2009						
Viking	4.54^{b}	3.62^{b}	0.83^{b}	22.82^{b}	0.63^{b}	17.18^{b}
Viola	5.28^{a}	4.39^{a}	1.09^{a}	24.85^{a}	0.89^{a}	20.26^{a}
Venica	4.73^{ab}	3.86^{ab}	0.96^{ab}	25.01^{a}	0.76^{ab}	19.72^{ab}
Agatha	4.96^{ab}	4.12^{ab}	1.05^{a}	25.44^{a}	0.85^{a}	20.43^{a}
Electra	5.32^{a}	4.50^{a}	1.15^{a}	25.60^{a}	0.95^{a}	20.93^{a}
2010						
Viking	5.58^{b}	4.24^{c}	0.79^{b}	18.44^{a}	0.66^{b}	15.69^{a}
Viola	7.33^{a}	6.46^{a}	1.44^{a}	22.35^{a}	1.04^{a}	16.26^{a}
Venica	5.74^{a}	5.01^{bc}	1.00^{ab}	19.97^{a}	0.81^{ab}	16.55^{a}
Agatha	6.83^{a}	6.03^{ab}	1.21^{ab}	19.89^{a}	0.94^{ab}	15.66^{a}
Electra	6.90^{a}	5.84^{ab}	1.26^{a}	21.40^{a}	0.91^{ab}	15.76^{a}

Values within a column marked with the same letter are not significantly different ($P<0.05$)

Table 3. Means of agronomic traits of fibre flax in dependence on the cultivar in Križevci during the three growing seasons (2008, 2009 and 2010)

Cultivar	Dry stem yield (t ha^{-1})	Dry stem yield after retting (t ha^{-1})	Total fibre yield (t ha^{-1})	Share of total fibre (%)	Long fibre yield (t ha^{-1})	Share of long fibre (%)
2008						
Viking	6.58^{c}	5.70^{c}	1.60^{d}	28.21^{a}	1.30^{c}	22.55^{b}
Viola	8.36^{a}	7.76^{a}	2.13^{a}	27.38^{a}	1.80^{a}	23.28^{a}
Venica	7.30^{b}	6.06^{c}	1.81^{c}	30.33^{a}	1.56^{b}	25.34^{a}
Agatha	7.96^{ab}	7.35^{a}	2.00^{b}	27.27^{b}	1.67^{b}	22.78^{a}
Electra	7.65^{b}	6.75^{b}	1.90^{bc}	28.12^{a}	1.60^{b}	23.70^{a}
2009						
Viking	7.29^{b}	6.02^{b}	1.53^{e}	25.42^{c}	1.28^{d}	21.31^{d}
Viola	8.49^{a}	7.06^{a}	2.22^{a}	31.41^{a}	1.93^{a}	27.27^{a}
Venica	7.23^{b}	6.05^{b}	1.66^{d}	27.50^{bc}	1.43^{c}	23.45^{cd}
Agatha	8.46^{a}	7.01^{a}	2.13^{b}	30.48^{ab}	1.86^{a}	26.66^{ab}
Electra	7.96^{ab}	6.62^{a}	1.83^{c}	27.73^{bc}	1.61^{b}	24.46^{bc}
2010						
Viking	8.63^{a}	5.79^{b}	1.26^{b}	21.93^{a}	0.74^{c}	12.92^{a}
Viola	9.73^{a}	7.09^{a}	1.48^{a}	21.21^{a}	1.08^{a}	15.47^{a}
Venica	8.85^{a}	6.57^{a}	1.34^{a}	20.77^{a}	0.84^{bc}	13.20^{a}
Agatha	9.34^{a}	6.59^{a}	1.43^{a}	21.96^{a}	0.94^{ab}	14.48^{a}
Electra	9.07^{a}	6.65^{a}	1.42^{a}	21.80^{a}	0.95^{ab}	14.60^{a}

Values within a column marked with the same letter are not significantly different ($P<0.05$)

In addition, statistically significant differences were recorded among different nitrogen rates for all investigated traits of fibre flax in 2008 and 2009 and for dry stem yield, dry stem yield after retting, total fibre yield and long fibre yield in 2010 at Križevci (Tables 4 and 5). No significant interaction was recorded for any traits or any location, so interactions were not included in the factors shown here and were not discussed any further. Accordingly, the factors affected the studied traits independently.

The highest dry stem yield was achieved by the cultivars Viola, Agatha and Electra for three years and both locations (Tables 2 and 3). No significant differences were recorded among these cultivars for dry stem yield, except for Electra in 2008 at Križevci. Viola gave the highest dry stem yield after retting, total fibre yield and long fibre yield in three years at Križevci and one year at Zagreb. The highest share of total fibre and share of long fibre were achieved with the cultivars Electra and Agatha in two years at Zagreb and cultivars Venica and Viola in one year at Križevci.

Comparing locations, all cultivars achieved higher values of dry stem yield, dry stem yield after retting, total fibre yield and long fibre yield in three years and of share of total fibre and share of long fibre in two years at Križevci. The obtained values of studied traits in these cultivars resulted from flax production on heavier soil (pseudogley on level terrain), in which some of winter moisture remained available in spring months. This is consistent with previous investigations reported in the literature (Daenekindt, 2003; Pavelek, 2001). According to previous investigations dry stem yields after retting ranged between 6.0 and 7.0 t/ha, total fibre yield between 1.8 and 2.0 t/ha, share of total fibre between 25 and 30%, long fibre yield between 1.3 and 1.6 t/ha and share of long fibre between 20 and 25%.

The below-means values of the investigated traits, particularly those recorded at Zagreb in 2008 and in 2009, were a consequence of adverse weather conditions during flax growth and development (moisture deficiency throughout the growing period in April (Zagreb 39.7 mm, 52.0 mm; Križevci 30.8 mm, 27.4 mm) and in May (Zagreb 44.1 mm, 48.8 mm; Križevci 27.9 mm, 62.4 mm), as well as excessively high temperatures in May and June in the intensive flax growth stage – absolute maximum temperature in May was at Zagreb 33.7°C, 31.3°C; at Križevci 32.9°C, 33.1°C and June at Zagreb 32.7°C, 30.1°C; at Križevci 32.0°C, 31.3°C). The quantity of precipitation in May is crucial for fibre yield and quality in Croatian ecological conditions. Plants reached the yellow-green ripening two to three weeks earlier (20.-25. June). The plants were shorter. The mean values for total fibre yield, long fibre yield, share of total fibre and long fibre at Zagreb and at Križevci in 2010 were influenced by plant lodging due to rough weather and strong wind at the end of May and at the beginning of June.

Results of previous investigations of nitrogen fertilization of flax fibre are different, depending on the added amount of nitrogen, time of application, soil nitrogen supply and weather conditions (Yagodin et al., 1991; Augustinussen, 1992; Easson and Long, 1992; Badiyala, 1998; Sudakov et al., 1993; Savikurki, 1994; Lokot and Sadchenko, 1995; Cremaschi et al., 1996; Vostal, 1997; Zedan et al., 1999; Butorac et al., 2010).

There was no significant increase of investigated agronomic traits when amounts higher than 30 kg ha^{-1} were added, except for dry stem yield, dry stem yield after retting, total fibre yield and long fibre yield in 2009 at Križevci (Tables 4 and 5). Increasing fertilization from 30 to 60 kg N ha^{-1}, caused slightly increased values, but after application of 90 kg ha^{-1} N, values were reduced.

Table 4. Means of agronomic traits of fibre flax in dependence of nitrogen rates in Zagreb during the three growing seasons (2008, 2009 and 2010)

Nitrogen fertilization (kg N ha^{-1})	Dry stem yield (t ha^{-1})	Dry stem yield after retting (t ha^{-1})	Total fibre yield (t ha^{-1})	Share of total fibre (%)	Long fibre yield (t ha^{-1})	Share of long fibre (%)
2008						
0	4.48^{c}	3.80^{c}	1.10^{b}	29.00^{b}	0.70^{c}	18.36^{c}
30	5.25^{ab}	4.50^{ab}	1.42^{a}	31.74^{a}	1.02^{a}	22.85^{a}
60	5.70^{a}	4.99^{a}	1.54^{a}	30.85^{a}	1.15^{a}	23.10^{a}
90	4.86^{bc}	4.16^{bc}	1.23^{b}	29.59^{a}	0.85^{b}	20.37^{b}
2009						
0	4.44^{b}	3.57^{b}	0.84^{b}	22.67^{b}	0.64^{b}	17.91^{b}
30	5.02^{ab}	4.11^{ab}	1.04^{a}	25.07^{a}	0.83^{a}	20.15^{ab}
60	5.43^{a}	4.61^{a}	1.18^{a}	25.53^{a}	0.98^{a}	21.12^{a}
90	4.95^{ab}	4.09^{ab}	1.01^{ab}	24.65^{a}	0.81^{ab}	19.63^{ab}
2010						
0	5.77^{a}	4.92^{a}	0.95^{a}	19.25^{a}	0.74^{a}	14.92^{a}
30	6.62^{a}	5.60^{a}	1.17^{a}	20.69^{a}	0.91^{a}	16.58^{a}
60	6.19^{a}	5.90^{a}	1.28^{a}	21.72^{a}	0.97^{a}	16.72^{a}
90	6.59^{a}	5.63^{a}	1.14^{a}	19.97^{a}	0.86^{a}	15.71^{a}

Values within a column marked with the same letter are not significantly different ($P<0.05$)

Table 5. Means of agronomic traits of fibre flax in dependence of nitrogen rates in Križevci during the three growing seasons (2008, 2009 and 2010)

Nitrogen fertilization (kg N ha^{-1})	Dry stem yield (t ha^{-1})	Dry stem yield after retting (t ha^{-1})	Total fibre yield (t ha^{-1})	Share of total fibre (%)	Long fibre yield (t ha^{-1})	Share of long fibre (%)
2008						
0	6.95^{b}	6.09^{b}	1.61^{c}	26.42^{b}	1.38^{c}	21.54^{b}
30	7.84^{a}	6.94^{a}	2.03^{a}	29.51^{a}	1.67^{ab}	24.30^{a}
60	7.95^{a}	7.15^{a}	2.08^{a}	29.05^{a}	1.74^{a}	24.43^{a}
90	7.54^{ab}	6.72^{a}	1.85^{b}	27.73^{a}	1.56^{b}	22.91^{a}
2009						
0	6.58^{c}	5.60^{c}	1.51^{c}	26.92^{b}	1.29^{c}	22.94^{b}
30	7.55^{b}	6.42^{b}	1.91^{b}	29.54^{ab}	1.66^{b}	25.57^{ab}
60	9.10^{a}	7.32^{a}	2.21^{a}	30.20^{a}	1.93^{a}	26.38^{a}
90	8.72^{a}	6.88^{ab}	1.88^{b}	27.38^{ab}	1.62^{b}	23.63^{ab}
2010						
0	7.75^{b}	5.11^{b}	1.13^{b}	21.42^{a}	0.75^{c}	14.84^{a}
30	9.31^{a}	6.74^{a}	1.42^{a}	21.44^{a}	0.97^{ab}	14.56^{a}
60	10.12^{a}	7.32^{a}	1.45^{a}	21.47^{a}	1.06^{a}	14.55^{a}
90	9.31^{a}	6.96^{a}	1.42^{a}	20.80^{a}	0.86^{bc}	12.58^{a}

Values within a column marked with the same letter are not significantly different ($P<0.05$)

The amount of 20 to 40 kg N ha^{-1} was recommended in previous investigations to obtain optimum stem yields, fibre yields, share of fibres and fibres quality (Yagodin et al., 1991; Augustinussen, 1992; Savikurki, 1994; Wijnholds, 1994; Lokot and Sadchenko, 1995; Cremaschi, 1996; Vostal, 1997; Badiyala, 1998; Zedan et al., 1999). This is in agreement with the results of our research. In some other previous investigation, nitrogen fertilization did not have any significant effect for stem yields, fibre yields and share of fibres (Easson and Long, 1992; Sudakov et al., 1993; Lokot, 1994; Rossini and Casa, 2003).

CONCLUSIONS

On the basic of the results obtained, the following conclusions can be drawn:

- Statistically significant differences were recorded among the cultivars for investigated traits of fibre flax, except for dry stem yield in 2010 at Križevci, share of total fibre in 2008 at Zagreb and share of total fibre and share of long fibre in 2010 at both locations.
- Statistically significant differences were recorded among different nitrogen rates for all investigated traits of fibre flax in 2008 and 2009 and for dry stem yield, dry stem yield after retting, total fibre yield and long fibre yield in 2010 at Križevci.
- The below-means values of the investigated traits, particularly those recorded at Zagreb in 2008 and in 2009, were a consequence of adverse weather conditions during flax growth and development (moisture deficiency throughout the growing period in April and in May as well as excessively high temperatures in May and June in the intensive flax growth stage).
- The cultivars Agatha, Viola and Electra recorded highest values of investigated traits (dry stem yield, dry stem yield after retting, total fibre yield, long fibre yield) in three years and share of total fibre and share of long fibre in one or two years.
- The optimal nitrogen rate for fibre flax according to the obtained results was 30 kg nitrogen ha^{-1}.

Acknowledgement

This research was carried out as part of the project "The effect of nitrogen on agronomic traits and quality of fiber flax cultivars", financed by the Ministry of Science, Education and Sports of the Republic of Croatia.

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