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WEATHER FACTORS AND BASIC NUTRIENT REQUIREMENTS FOR THE CULTIVATION OF INDUSTRIAL HEMP (*CANNABIS SATIVA* L.)

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Summary. Hemp (*Cannabis sativa* L.) is one of the plants that have accompanied mankind for thousands of years. Fiber hemp belongs to the group of useful plants whose large yields of biomass can be used in a variety of ways. The enormous potential of this plant is used in almost every industry sector: from pulp and paper industry to light industry (clothing, textiles) as well as in other manufacturing branches which include toys, flower pots, disinfecting mats and even funeral urns. Hemp is characterized by high plasticity and resistance to changing agro-climatic factors, thanks to which extreme weather conditions are not an obstacle to its cultivation. However, similarly to other species, the final yield is contingent on the interaction of several important factors. Hemp variety, sowing density, harvest time and fertilization are relevant factors which have a bearing on shaping hemp's biomass. The influence of weather conditions on the yield of biomass and the content of cannabinoids is not to be underestimated either. Poland has a long-standing tradition of growing and processing hemp. The nineteenth century and the beginning of the twentieth century turned out to be extremely successful for hemp, because its cultivation was widespread almost all over Poland. In the 1920s and 1930s, the hemp acreage was about 29,000 ha. The cultivation of industrial hemp in our country is subject to strict legal restrictions formulated in the Act of July 29, 2005 on Counteracting Drug Addiction (with further amendments). Nevertheless, interest in this fascinating plant is growing.

Key words: industrial hemp, (*Cannabis sativa* L.), fertilization, agrotechnics, weather factors

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INTRODUCTION

Fiber hemp belongs to the group of useful plants whose large yields of biomass can be used in a variety of ways [Jankauskienë 2015, Rupasinghe et al. 2020]. The enormous potential of this plant is used in almost every industry sector: from pulp and paper industry to light industry (clothing, textiles) as well as in other manufacturing branches which include toys, flower pots, disinfecting mats and even funeral urns [Rana 2010, Angelini et al. 2016, Andre et al. 2016, Fike 2016, Manaia et al. 2019, Rupasinghe et al. 2020].

Currently, more than half of the obtained fiber is used in the pulp and paper industry. Less demand is observed in the production of insulation materials and composites, and as little as a few percent is used as technical fibers [Lekavicius et al. 2015]. It is estimated that the textile use in the clothing industry accounts for a negligible percentage. Hemp chaff is primarily a raw material that serves as a bedding for horses and smaller animals. This material is also used in horticulture as a component of composites and as a substrate for mycelium. Hemp seeds, in turn, are a raw material for the food and cosmetics industries [Karus 1998, Callaway 2004, Truta et al. 2009, Mańkowska et al. 2015, Angelini et al. 2016, Fike 2016, Rupasinghe et al. 2020].

Hemp is a reservoir of specific chemical substances, including terpenes, phenolic compounds and cannabinoids, the most important of which are: tetrahydrocannabinol – Δ9THC, cannabidiol – CBD and cannabinol – CBN, which are used in the production of drugs due to their high therapeutic potential [Rana 2010, Ben Amar 2006, Chandra 2010, Hill et al. 2012, Kotuła et al. 2014, Mańkowska et al. 2015, Rajput et al. 2018, Zielonka et al. 2020, Makowiecka and Wielgus 2020]. Given that some of them are psychoactive substances, the cultivation of hemp is subject to certain legal restrictions [Fike 2016, Manaia et al. 2019].

The condition for obtaining the highest and the best quality crops is the preliminary determination of the purpose of cultivation, because each of the purposes of crop use requires appropriate agrotechnics, allowing the use of the yield potential of hemp [Grabowska and Koziara 2005, Burczyk et al. 2009a, b, Manaia et al. 2019].

Appropriate adaptation of agrotechnical requirements to the purpose of cultivation (textile, biomass, seeds) and taking into account a number of interacting factors, such as: sowing density [Burczyk et al. 2009a, Grabowska and Koziara 2005], type of soil and its abundance in nutrients, forecrop, weather factors – precipitation and temperature [Grabowska 2000, Struik and others 2000, Baraniecki 2014, Jankauskienë 2015, Manaia et al. 2019] is relevant in the cultivation of hemp.

Therefore, in order to be able to use all the active substances found in hemp that are beneficial for human health and life, one must follow the developed agrotechnical recommendations that shape the metabolism of this fascinating species.

SOIL SELECTION, FORECROP AND FIELD PREPARATION

Choosing the right soil results in a measurable and satisfactory yield. The most suitable soils for hemp cultivation are ones with proper air-water relations, rich in humus, black earth and wheat-beet type loess [Grabowska 2005, 2007]. Sandy, light and heavy loamy soils are not suitable for the cultivation of hemp. Constantly wet soils with unregulated humidity ratios are not suitable for cultivation of this species either [Dempsey 1975, Körber-Grohne 1988, Fike 2016, Struik et al. 2000]. Baraniecki [2014] obtained the highest seed yield on the black soils and rendzinas with a neutral reaction, on which he cultivated Białobrzeskie cultivar after the root crops, using low nitrogen doses. On the other hand, the highest straw yields were obtained on brown, acidic soils, where he applied a high dose of nitrogen after papilionaceous soil. However, light soils should not be ruled out, provided that the appropriate pH of the soil is maintained (minimum pH 6) and that optimal soil moisture is ensured during the emergence of plants. What is more, constantly wet soils with unregulated humidity ratios are not suitable for cultivation of this species, and neither are grasslands or plowed fallow.

When sowing certified seed, particular attention should be paid to the selection of the position. Good forecrops for hemp are: root crops, perennial legumes and cereals. Hemp, on the other hand, is an excellent forecrop for all plants, especially cereals (e.g. winter wheat). According to Boìcsa et al. [2000] cultivating winter wheat after fiber hemp resulted in a yield increase of about 10–20%. Hemp does not have special requirements for the forecrop, but it is demanding with regard to soil culture, its nutrient content and water availability in the soil.

According to Boìcsa et al. [2000], Fike 2016, Cierpucha [2013] and Mańkowski et al. [2020] hemp tolerates succession relatively well. For several years, it can be grown in monoculture without loss of crops (industrial plantations). In such a situation, higher doses of fertilizers should be used. However, growing hemp in monoculture is not recommended as its high potential is not being exploited. With the share of cereals in the country exceeding 60%, it is easy to choose the right forecrop.

In the case of certified seed plantations, monoculture is excluded (the Seed Act of November 9, 2012, with further amendments). Preparation of the field should be in accordance with good agricultural practice. The basic agrotechnical treatment in the cultivation of hemp is autumn deep plowing, reaching about 28 cm, which is left in a sharp furrow. Any treatments performed in the spring period should be limited, preferably when only the top layer of soil remains loosened and leveled [Rębarz 2009]. In addition, the cultivation of hemp is possible in farms using simplified cultivation methods - no-till system [Grabowska 2005].

DATE OF SOWING AND SOWING SEEDS

The analysis of the climate and soil conditions in Poland has shown that the cultivation of hemp is possible almost everywhere in the country. However, attention should be paid to the selection of the cultivation purpose [Grabowska 2005, Cierpucha 2013, Fike 2016, Mańkowski et al. 2020]. The optimum date for sowing industrial hemp depends on the region of the country. In southern Poland, the optimum period is in the first decade of April, whereas in central and northern Poland it is in the third decade of April and in the first decade of May. The optimum date for hemp sowing in Germany is from the end of April to the beginning of May [Boìcsa et al. 2000]. A similar situation is observed in Italy [Cosentino et al. 2012]. Delaying the sowing date shortens the growing season, which, in turn, reduces the quantity and quality of the crop [Grabowska 2005, Rębarz 2009, Cosentino et al. 2012, Fike 2016].

The optimum depth for sowing hemp is 3–4 cm [Grabowska and Koziara 2005, Amaducci et al. 2008a, b, Rębarz 2009, Cierpucha 2013, Mańkowski et al. 2020]. Oleszak [2020] states that the seeds can be sown at the depth of 2 cm. However, it depends on the type of sowing machine. For single-seed sowing, the optimum depth is 2 cm, and for row sowing it increases to 4 cm.

In mineral soils, deeper sowing can significantly reduce plants' emergence. An important factor determining seed vigor is the thousand-seed weight (TSW). Increasing the sowing depth to 7 cm lowered germination of large seeds (TSW 20 g) to 47%. In case of small seeds (TSW 12 g) sowing to the same depth, germination reached only 20% [Boìcsa et al. 2000]. The sowing density, as well as the row spacing, is primarily determined by the purpose for which the hemp is grown. The recommended sowing standard for certified seed cultivation is 7–15 kg ha^{-1} of seeds, depending on the type of seed machine (point or row) and the germination power of the seeds, which gives about 45 to 90 germinating plants per 1 m^2. Using the given seeding rate, it can be assumed that the decay during the growing season can range between 5 and 15%. The applied sowing rate depends primarily on the energy, germination capacity and TSW. Plant decay depends on many interacting factors, i.e. weather conditions, fertilization, seed germination energy and sowing density. The higher the sowing density, the greater the decay. The percentage of disappearances also depends on the sowing rate, which, in turn, depends on the germination rate and TSW.

The row spacing of the hemp seed plantation is 35–60 cm (the Seed Act of November 9, 2012, with further amendments). The optimum inter-row spacing for this purpose is 45 cm, known as the so-called 'beetroot' spacing. Applying such a distance, it is possible to remove flatlands from the plantation. It also makes it easier to carry out field inspections in hemp seed plantations. On the other hand, the spacing of rows on industrial plantations is not regulated by any act and varies from 7 to 20 cm. According to Burczyk [2009a, b], proper determination of hemp sowing density is a very important condition for shaping the yields of biomass, straw, seeds, cellulose panicles and fiber. The author showed that the correct standard of hemp sowing depends on the purpose of use. Therefore, in straw and cellulose cultivation it is 30 kg ha^{-1}, and for seeds it is 10–15 kg ha^{-1}. In turn, Hall et al. [2014] investigated the effect of hemp sowing density on weed development and yield. They showed that increasing the plant density from 100 to 200 pieces per m^2 significantly reduced the weight of weeds (from 23.2 to 6.5 g m^2), and after increasing the plant density to 300 and 400 m^2, their weight further decreased to 2.6 and 1.5 g.m^2 The above-mentioned results are also confirmed by Struik et al. [2000] and Bennett et al. [2006].

In the cultivation of hemp for industrial and food seeds and for plant material (panicles) with the use of cannabinoids and essential oils, the recommended sowing standard is 20–30 kg ha^{-1} seeds, which gives about 120–180 germinating plants per 1 m^2. Using the given sowing rate, it can be assumed that the decay during the growing season can amount to about 20%. The row spacing in this case is not regulated by the Seed Act and it can be any, i.e. cereal (10–12 cm) or vegetable.

In hemp plantations intended for cellulose and biocomposites, the recommended sowing standard is 30–40 kg ha^{-1} seeds, which gives about 180–240 germinating plants per 1 m^2. Applying the given seeding rate, it can be assumed that the decay during the vegetation period may amount to about 20–25%. Just like in the case mentioned above, the row spacing is not regulated by the Seed Production Act either and it can be any, i.e. cereal (10–12 cm), vegetable or other.

In turn, in the cultivation of hemp for the textile industry, the recommended sowing standard is 50–60 kg ha^{-1} of seeds, i.e. about 300–360 germinating plants per 1 m^2. Applying the given sowing rate, it can be assumed that the decay during vegetation can amount to as much as 30–40% in case of good seed vigor, and even 70% in case of low seed vigor. Again, the row spacing is not regulated by the Seed Act and can be any.

Proper determination of the sowing density of hemp is a very important condition for shaping the yield of biomass, straw, seeds, cellulose panicles and fiber [Jankauskienë 2015, Rupasinghe et al. 2020].

The fruit of hemp is egg-shaped fruit – nut, colloquially known as hemp seed. They are single-seeded, with a visible slight lateral flattening. The seeds have a pattern on the shell – a mosaic that is characteristic of the type of hemp and resemble the shell of a turtle [Karus et al. 1998]. The diameter of the nut varies between 3–4 mm. For wild and northern hemp, the TSW is 8–12 g [Beuth and Dowgielewicz 1958], reaching 12–18 g for the intermediate type, and amounting to 18–26 g for the southern type. Some seeds of other plant species, e.g. hops (*Humulus lupulus*) and Japanese hops (*Humulus japonicus*), may initially be confused with hemp nuts, but the characteristic mosaic allows for easy identification [Remberg 2009]. Each fertilized flower produces one nut which flakes off as it matures, becoming an excellent food for birds [Pate 1994, Pate 1999, Rupasinghe et al. 2020].

WATER REQUIREMENTS OF HEMP

Hemp's water uptake is greatest in the early stages of development, and its deficiency in this period results in inhibition of growth and development of young plants [Struik et al. 2000]. According to Beutha and Bytnerowicz [1958], hemp's demand for water is very high, because to produce 1 kg of mass, it needs about 1.5–2 times more water than rye and barley, and even 3 times more water than corn. According to Grabowska [2005], during growing process the demand for water for the production of 1 kg of dry matter ranges from about 600–700 mm, and the optimum amount of rainfall should be 250–300 mm. Boìcsa et al. [2000] report that during the period of the most intense growth, hemp's demand for water increases to 300–500 liters kg^{-1} dry weight.

Despite the high transpiration rate, these plants do not tolerate long-term water retention in the soil [Struik et al. 2000, Jankauskienë 2015]. Although hemp has a higher transpiration coefficient than cereals, due to its growing season, it shades the soil longer, so hemp reduces unproductive water evaporation from the soil. A common phenomenon currently occurring in Poland are soil droughts combined with an average air temperatures increase. These factors may additionally affect the process of soil drying, which, in turn, results in a negative phenomenon called soil erosion [Krasowicz 2015]. Thus, the cultivation of hemp helps to maintain a good condition of soil, and due to good shade, the desirable water conditions in the soil are observed.

Fully developed hemp can withstand a short period of drought as well as deficiencies of permanent irrigation [Boìcsa and Karus 1997, Struik et al. 2000, Jankauskienë 2015]. However, as noted by Grabowska and Koziara [2001], short periods of dryness, lasting about 4 months, resulted in a significant drop in yields, amounting to 7–8 t ha^{-1}. However, this factor, acting in the periods of initial and final development of the plant, did not reduce the yield and did not disturb the proper development (mainly growth) of hemp. The studies of Hai and Rippchen [1994] and Schumann et al. [1999] confirm the conclusions that the unfavourable factors in the initial stage of hemp plant development do not affect the final yield and do not disturb the further development of these plants.

Hemp is more drought-resistant compared to cotton [Andre et al. 2016] or maize [Burczyk et al. 2008], which was reflected in higher yields from 1 ha in a year with unfavourable weather conditions. According to Baraniecki [2014], high rainfall during the sowing and germination period showed significantly negative correlation with the weight of a thousand seeds. Moreover, the high sum of precipitation in June caused a decrease in the content of long fiber, and thus an increase in the content of short fiber.

HEAT AND LIGHT REQUIREMENTS OF HEMP

As with water requirements, hemp has high thermal demands. This factor determines the proper growth and development of the plant. Seeds begin to germinate when the soil temperature rises to 8–10°C, and, subsequently, emergence takes 8–12 days. The emerging young leaves are greenish-golden-gray in colour. At the stage of 4–5 pairs of leaves, plants tolerate frosts to –5°C, but their development is stopped until favorable weather conditions appear [Boìcsa et al. 2000]. Similarly, Grabowska [2005] notes that about 10°C is the proper temperature for the germination of nuts. Sowing seeds in cold and unheated soil results in delayed germination and infestation of the plantation. Moreover, a delayed sowing date shortens the vegetation period of hemp and has a negative effect on the amount and quality of crops [Grabowska 2005]. Baraniecki [2014] showed that high temperatures in April, i.e. during the sowing and emergence period, were positively correlated with the yield of straw and seeds. Young hemp plants tolerate short-term frosts well [Oleszak 2009], according to Boìcsa and Karus [1998] it is even as low as –10°C. As plants grow, they become more sensitive to negative temperatures.

Cultivars grown in Central European conditions in order need about 110–115 days and a total temperature of 1900–2000°C to fully develop, while for mature seeds it reaches 2700–3000°C. Early hemp varieties have slightly lower demands, as their temperature requirement is between 1600 and 1700°C [Boìcsa et al. 2000]. According to Dutch research based on cultivation in climatic chambers, the optimum daily average temperature for the proper growth of hemp is within 19–25°C [van der Werf 1994]. On the other hand, when the daily averages drop to 10–15°C, the development of hemp stops and the emerging weeds die as a result of complete shading. When the temperature rises to 16°C, vegetation resumes, and then the daily increments of hemp may reach 4–6 cm. These studies indicated that plants grown at 19°C would attain the same height in less than 40 days as those grown at 10°C in 90 days.

High air temperatures are very favourable during the period of intensive growth, which is in June and July. Under favourable conditions, plant growth can reach 10–12 cm a day [Grabowska 2005], and even up to 20 cm a day.

Baraniecki [2014] showed a negative correlation of the seed yield with the average temperature in July. This is explained by the reduction in the viability of hemp pollen grains under the influence of high temperatures. The author also showed that the higher the temperatures during the whole growing season, the higher the yields of seeds and straw.

Hemp is a short-day plant [Struik et al. 2000, Amaducci et al. 2008a, b, Faux 2014]. Depending on the amount of light delivered throughout the day, these plants regulate their development. Due to the length of the day and favourable thermal conditions, the best regions for growing hemp for seeds in Poland are Dolnośląskie and Lubelskie regions [Grabowska 2005].

NUTRIENT REQUIREMENTS OF HEMP

Balance of individual nutrients supplied to the plant during the growing season determines the yields. The basic activity in determining rational fertilization is the assessment of soil abundance in individual macroelements. The assessment of soil reaction as well as the content of absorbable phosphorus, potassium and magnesium should be performed once every 3–5 years [Jadczyszyn et al. 2010]. Apart from the abundance of nutrients in the soil, fertilization should be balanced taking into account the position and purpose of plant use. Hemp is one of the plants that perfectly valuate the soil [Rębarz 2009]. This plant tolerates natural fertilization such as manure well, while mineral fertilization is tolerated relatively well. Due to the extensive root system, hemp makes good use of nutrients present in the soil [Boìcsa et al. 2000]. Hemp is not a very demanding plant [Struik et al. 2000, Jankauskienë 2015]. It is generally accepted that the doses of the basic ingredients in kg ha^{-1} should be: 80–120 N; 70–100 P_2O_5 and 150–180 K_2O. When grown for fiber, the N : P : K ratio should be 1 : 0.7 : 1.5 and for seeds it should amount to 1 : 0.8 : 1. However, currently, the doses of the basic ingredients in kg ha^{-1} should be as follows: 60–120 N; 70–100 P_2O_5 and 120–180 K_2O.

Fertilization should be done in early spring, about 2–4 weeks before the planned sowing.

Nitrogen (N), as in the case of other plants, influences the growth of green mass. The demand of hemp for this ingredient occurs almost throughout the growing season. However, it is most strongly absorbed during the period of the most intense growth, falling in the second month of the growing season. Nevertheless, excess nitrogen negatively affects the quality of the fiber and additionally extends the maturation period [Grabowska and Koziara 2005, Jankauskienë 2015]. As a result of this, the content of this nutrient in the soil should be precisely determined, and the amount of introduced N should be adjusted accordingly after determining the purpose of cultivation [Beutha and Dowgielewicz 1958, Grabowska and Burczyk 2005, Jankauskienë 2015]. As nitrogen doses were increased, with the simultaneous increase in sowing density, a significant reduction in plant density during harvesting and an increase in straw yields as a result of an intensive increase in green mass were noted [Grabowska and Koziara 2005]. Baraniecki [2014] confirmed the above dependencies and showed that the dose of 100 kg N ha^{-1} allowed to obtain the highest yields of straw on deer soils, but at the cost of seed yield. Equally high straw yields can be obtained by cultivating hemp in brown soils, rendzinas and black soils, but after using a lower nitrogen dose [Baraniecki 2014]. Therefore, when growing hemp for seeds, lower doses of nitrogen should be used, taking into account also the interaction of other factors such as the physico-chemical properties of the soil and the forecrop.

Potassium (K) is the most valuable macronutrient necessary for the proper development of fibrous plants because it affects the production of fiber with very good quality parameters [Jankauskienë 2015]. The plant absorbs this element throughout the growing season, most intensively from the beginning of flowering when the process of fiber formation in the stem begins [Grabowska 2005]. As shown by Finnan and Burke [2013], almost 75% of this element is cumulated in the straw.

Phosphorus (P) regulates the basic processes in the plant and is also responsible for the proper filling of nuts. The most intensive uptake of this nutrient begins from the beginning of flowering. Appropriate balance of phosphorus doses is extremely important, especially when running a seed plantation.

Calcium (Ca) also plays a big role when growing hemp. This macronutrient has a beneficial effect on the soil, improving its structure. Moreover, it improves other physicochemical properties of the soil and stimulates the development of soil's fauna and flora. Most of the soils in Poland have a low pH [Grabowska 2005, Krasowicz 2012]. As soil acidity is reduced, the bioavailability of soil components improves. On acidified soils, it is recommended to perform liming with the addition of Mg during disking or possibly before winter tillage in the amount of 15 q/ha CaO on lighter soils or 20 q/ha CaO on heavier soils. When the pH is below 6, the soil must be limed. The best solution is to lime the stubble and mix the lime with the soil using a disc harrow. The best soil de-acidifying agent is lime in the form of fertilizer chalk (carbonate chalk) (with high reactivity), which improves the pH in the first year after application.

CONCLUSION

Hemp is characterized by high plasticity and resistance to changing agro-climatic factors, thanks to which extreme climatic conditions are not an obstacle to cultivation. Many studies indicate that the following factors play an important role in shaping their biomass: variety, sowing density, harvest time, and fertilization mentioned in this article. The influence of weather conditions (the amount of water and air temperature during the growing season) on the yield of biomass and the content of cannabinoids is determined to be significant as well. In addition, nitrogen fertilization and the phase of plant development – the content of cannabinoids decreases with the development and aging of plants.

Polish varieties of industrial hemp can be grown all over the country and allow growers to obtain satisfactory crops, despite the diverse soil and microclimatic conditions.

REFERENCES

Amaducci S., Zatta A., Pelatti F., Venturi G., 2008a. Influence of agronomic factors on yield and quality of hemp (*Cannabis sativa* L.) fiber and implication for an innovative production system. Field Crops Res (107), 161–169.

Amaducci S., Zatta A., Raffanini M., Venturi G., 2008b. Characterization of hemp (*Cannabis sativa* L.) roots under different growing conditions. Plant and Soil (313), 227–235.

Andre Ch. M., Hausman J.F., Guerriero G., 2016. Cannabis sativa: The Plant of the Thousand and One Molecules. Front. Plant Sci. 7(19), 1–17.

Angelini L.G., Tavarini S., di Candolo M., 2016. Performance of new and traditional fiber hemp (*Cannabis sativa* L.) cultivars for novel applications: stem, bark and core yield and chemical composition. J. Nat. Fibers 13(2), 238–252. DOI: 10.1080/15440478.2015.1029193

Baraniecki P., 2014. Plonowanie konopi siewnych (*Cannabis sativa* L.) w zależności od czynników siedliskowych i agrotechnicznych [PhD thesis]. Biblioteka IWNiRZ, Poznań [in Polish].

Ben Amar M., 2006. Cannabinoids in medicine: A review of their therapeutic potential. J. Ethnopharmacol. (105), 1–25.

Bennett S.J., Snell R., Wright D., 2006. Effect of variety, seed rate and time of cutting on fiber yield of dew-retted hemp. Industrial Crops and Products (24), 79–86.

Beuth B., Dowgielewicz S., 1958. Technologia konopi. Wydaw. Przemysłu Lekkiego i Spożywczego, Warszawa [in Polish].

Boìcsa I., Karus M., 1997. Der Hanfanbau. C. F. Muller, Heidelberg [in Deutsch].

Boìcsa I., Karus M., 1998. The cultivation of hemp. Botany, varieties, cultivation and harvesting. Hemptech, Sebastopol [in Deutsch].

Boìcsa I., Karus M., Lohmeyer D., 2000. Der Hanfanbau. Botanik, Sorten, Anbau Und Ernte, Markte Und Productlinien. Vollstandig uberarbeitete Und erganzte 2. Landwirtschaftsverlag GmbH, Münster [in Deutsch].

Burczyk H., Grabowska L., Kołodziej J., Strybe M., 2008. Industrial Hemp as a Raw Material for Energy Production. J. Ind. Hemp. 13(1), 37–48.

Burczyk H., Grabowska L. Strybe M., Konczewicz W., 2009a. Effect of Sowing Density and date of harvest on biomass, straw, panicle, seed, cellulose and fiber yield of industrial hemp. J. Nat. Fibers (6), 115–126.

Burczyk H., Kaniewski R., Konczewicz W., Kryszak N., Turowski J., 2009b. Konopie włókniste źródłem olejków eterycznych. Pamiętnik Puławski (151), 37–49 [in Polish].

Callaway J.C., 2004. Hempseed as a nutritional recourses: an overview. Euphytica (140), 65–72.

Chandra S., Lata H., Mehmedic Z.,. Khan I.A., ElSohly M.A., 2010. Assessment of cannabinoids content in micropropagated plants of *Cannabis sativa* L. and their comparison with conventionally propagated plants and mother plant during developmental stages of growth. Planta Medica (76), 743–750.

Cierpucha W., 2013. Technologia Uprawy i Przetwórstwa Konopi Włóknistych. Nowa metoda rekultywacji terenów zdegradowanych w rejonie Kopalni Węgla Brunatnego (KWB) Konin z zastosowaniem uprawy konopi włóknistych. Project of collateral from the financial instrument LIFE + of the European Union and co-financed by the National Environmental Protection and Water Management measures 11ENV/PL/445, 12–31 [in Polish].

Cosentino S.L., Testa G., Scordia D., Copani V., 2012. Sowing time and prediction of flowering of different hemp (*Cannabis sativa* L.) genotypes in southern Europe. Ind Crops Prod. (37), 20– 33.

Dempsey J.M., 1975. Fiber crops. Hemp. University of Florida Press, Gainesvile.

Faux A.M., 2014. Quantitative approach of the genetic determinism of sex expression in monoecious hemp (*Cannabis sativa* L.), and its relationship with flowering phenology and stem and seed yields [PhD thesis]. Universite Catholique de Louvain. Retrived from: http://hdL.handle. net/2078.1/142449 [access: 19.12.2020].

Fike J., 2016. Industrial Hemp: Renewed Opportunities for an Ancient Crop. Crit Rev Plant Sci. (35), 5–6, 406–424. DOI: 10.1080/07352689.2016.1257842

Finnan J., Burke B., 2013. Potassium fertilization of hemp (*Cannabis sativa*). Ind Crops Prod. (41), 419– 422.

Grabowska L., 2000. Wpływ warunków siedliskowych i agrotechnicznych na wzrost, rozwój i plonowanie konopi [PhD thesis] Biblioteka IWNiRZ, Poznań.

Grabowska L., 2005. Rola infrastruktury i techniki w zrównoważonym rozwoju rolnictwa. IMBER, Warszawa [in Polish].

Grabowska L., 2007. Konopie włókniste wracają na polskie pola. Pomorskie wieści rolnicze (10), 15–16 [in Polish].

Grabowska L., Burczyk H., 2005. Wybrane zagadnienia z uprawy konopi włóknistych w Polsce. Zagadnienia Doradztwa Rolniczego (4), 121–127 [in Polish].

Grabowska L., Koziara W., 2001. Wpływ temperatury i opadów na plonowanie konopi włóknistych odmiany Białobrzeskie. Natural Fibres 45, 7–17 [in Polish].

Grabowska L., Koziara W., 2005. The Effect of Nitrogen Dose, Sowing Density and Time of Harvest on Development and Yields of Hemp Cultivar Bialobrzeskie. J. Nat. Fibers 2(4), 1–17.

Hai H., Rippchen R., 1994. Das Hanf-Handbuch. Der Grüne Zweig 173, Löhrbach [in Deutsch].

Hall J., Bhattarai S.P., Midmore D.J., 2014. Effect of industrial hemp (*Cannabis sativa* L.) planting density on weed suppression, crop growth, physiological responses, and fiber yield in the subtropics. Renewable Bioresources 2(1), 1. Retrieved from: http://www.hoajonline.com/journals/pdf/2052-6237-2-1.pdf

Hill A.J., Williams C.M ., Whalley B.J., Stephens G.J., 2012. Phytocannabinoids as novel therapeutic agents in CNS disorders. Pharmacology & Therapeutics (133), 9–97.

Jadczyszyn T., Kowalczyk J., Lipiński W., 2010. Zalecenia nawozowe dla roślin uprawy polowej i trwałych użytków zielonych. Materiały szkoleniowe nr 95. IUNG-PIB, Puławy.

Jankauskienë Z., 2015. Screening of industrial hemp (*Cannabis sativa* L.) cultivars for biomass yielding capacities in Lithuania. J. Nat. Fibers 12(4), 368–377. DOI: 10.1080/15440478.2014.929556.

Karus M., Gahle Ch., Pendarovski C., Vogt D., Ortmann S., Grotenhermen F., 1998 Hanfsamen und Hanföl als Lebens- und Heilmittel: ein Ratgeber. nova- Institute, Köln [in Deutsch].

Körber-Grohne U., 1988. Naturpflanzen in Deutchland: Kulturgeschichte und Biologie. Konrad Thesis Verlag, Stuttgart [in Deutsch].

Kotuła L., Sobstyl P., Sobstyl J., Chwil P., Terlecki K., Karwat J., Gil-Kulik P., Niedojadło A., Kocki J., 2014. Application of medical Cannabis in patients with the neurodegeneration disorders. Modern Phytomorphology (6), 121.

Krasowicz S., 2012. Przesłanki racjonalnego wykorzystania gleb polski. Roczniki Naukowe Stowarzyszenia Ekonomistów Rolnictwa i Agrobiznesu. Instytut Uprawy Nawożenia i Gleboznawstwa - PIB w Puławach 14(5): 113-117. [in Polish].

Lekavicius V., Shipkovs P., Ivanovs S., Rucins A., 2015. Thermo-insulation properties of hemp-based products. Latv. J. Phys. Tech. Sci. (1), 38–51.

Makowiecka J., Wielgus K., 2014. Therapeutic Potential of Cannabinoids – Retrospective and Historical Developments. J. Nat. Fibers (11)3, 185–198. DOI: 10.1080/15440478.2013.861782

Manaia J.P., Manaia A.T., Rodriges L., 2019. Industrial Hemp Fibers: An Overview. J Fibers 7, 106. DOI: 10.3390/fib7120106.

Mańkowska G., Luwańska A., Wielgus K., Bocianowski J., 2015. Evaluation of cannabinoid content in selected varieties of *Cannabis sativa* L. Biul. IHAR (227), 79–86.
Mańkowski J., Kołodziej J., Pudełko K., Kozłowski R.M., 2020. Bast fibres: the role of hemp (*Cannabis sativa* L.) in remediation of degraded lands. In: R.M. Kozłowski, M. Mackiewicz-Talarczyk (eds), Handbook of Natural Fibres. Elsevier, Caqmbridge, 2, 393–417.
Oleszak G., 2009. A może konopie. Tygodnik rolniczy (35), 28–29 [in Polish].
Pate D.W., 1994. Chemical ecology of *Cannabis*. JIHA 2(1), 32–37.
Pate D.W., 1999. Hemp seed: a valuable food source. Advances in hemp research. The Haworth Press, Binghamton, New York.
Rajput R., Kumar K., 2018. A Review on *Cannabis sativa*: Its Compounds and Their Effects. Int. J. Pharm. Sci. Rev. Res. 53(2), 12, 59–63.
Rana A., 2010. Floral Biology and Pollination Biology of *Cannabis sativa* L. Int. J. Plant Reprod. Biol. 2(2). 191–195.
Rębarz M., 2009. Konopie. Rośliny przemysłowe. Produkcja roślinna 3, 280–288 [in Polish].
Remberg B., 2009. Recommended methods for the identification and analysis of cannabis and cannabis products. United Nations Publication, New York. Retrieved from: https://www.unodc.org/documents/scientific/ST-NAR-40-Ebook_1.pdf. [access 08. 05. 2017].
Rupasinghe V.H.P., Davis A., Kumar K., Murray B., Zheljazkov V.D., 2020. Industrial Hemp (*Cannabis sativa* subsp. *sativa*) as an Emerging Source for Value-Added Functional Food Ingredients and Nutraceuticals. Molecules 25, 4078. DOI: 10.3390/molecules25184078
Schumann E., Peil A., Weber W.E. 1999. Preliminary results of a German field trial with different hemp (*Cannabis sativa* L.) accessions. Genet. Resour. Crop Evol. 46, 399–407.
Struik P.C., Amaducci S., Bullard M.J., Stutterheim N.C., Venturi G., Cromack H.T.H., 2000. Agronomy of fiber hemp (*Cannabis sativa* L.) in Europe. Ind Crops Prod 11, 107–118.
Werf H.M.G. van der, 1994. Crop physiology of fiber hemp (*Cannabis sativa* L.) [PhD thesis], Agricultural University,Wageningen.
Zielonka D.M., Kiraga Ł., Kozłowski R.M., 2020. Medical potential of cannabis: an overview. In: R.M. Kozłowski, M. Mackiewicz-Talarczyk (eds), Handbook of Natural Fibres. Elsevier, Cambridge, 2, 419–448.

CZYNNIKI POGODOWE I PODSTAWOWE WYMAGANIA SKŁADOWE DLA UPRAWY KONOPI PRZEMYSŁOWYCH (*CANNABIS SATIVA* L.)

Streszczenie. Konopie (*Cannabis sativa* L.) są jedną z roślin, które towarzyszą ludzkości od tysięcy lat. Konopie włókniste należą do grupy roślin użytkowych, których duże plony biomasy mogą być wykorzystane w różnorodny sposób. Ogromny potencjał tej rośliny wykorzystywany jest w niemal każdym sektorze przemysłu: od celulozowo-papierniczego, poprzez przemysł lekki (odzież, tekstylia), a także w innych gałęziach przemysłu, takich jak zabawki, doniczki, maty dezynfekcyjne, a nawet urny pogrzebowe. Konopie charakteryzują się dużą plastycznością i odpornością na zmienne czynniki agroklimatyczne, dzięki czemu ekstremalne warunki pogodowe nie są przeszkodą w ich uprawie. Jednak, podobnie jak w przypadku innych gatunków, ostateczny plon jest uzależniony od od współdziałania kilku ważnych czynników, takich jak: odmiana konopi, gęstość siewu, termin zbioru oraz nawożenie. Nie należy również lekceważyć wpływu warunków pogodowych na plon biomasy i zawartość kannabinoidów. Polska ma wieloletnią tradycję uprawy i przetwarzania konopi. Wiek XIX i początek XX wieku okazały się dla konopi niezwykle pomyślne, gdyż ich uprawa była rozpowszechniona niemal w całej Polsce. W latach 20. i 30. ubiegłego wieku areał konopi wynosił około 29 tys. ha. Uprawa konopi przemysłowych w naszym kraju podlega ścisłym ograniczeniom prawnym sformułowanym w Ustawie z dnia 29 lipca 2005 r. o przeciwdziałaniu narkomanii (z późniejszymi zmianami). Mimo to, zainteresowanie tą fascynującą rośliną jest coraz większe.

Słowa kluczowe: konopie przemysłowe, (*Cannabis sativa* L.), nawożenie, agrotechnika, czynniki pogodowe