DOI: 10.2478/frp-2021-0004
Wersja PDF: www.lesne-prace-badawcze.pl

Leśne Prace Badawcze / *Forest Research Papers*
Marzec / March 2021, Vol. 82 (1): 31–36

REVIEW ARTICLE

e-ISSN 2082-8926

Potential problems in cultivating *Tilia cordata* Mill. in seed orchards

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Abstract. The first seed orchards of lime trees *Tilia cordata* Mill. were established in Poland in the Susz Forest District in 1985. Currently, there are 21 seed orchards of this species in the country in order to satisfy the seed demand and preserve the species as well as its genetic diversity. Due to disease symptoms occurring in *Tilia* trees and irregular fruiting, an attempt was made to collect information on the problems of seed orchards and their characteristics in Poland. In order to achieve this goal, the average annual seed yield and the total amount of seeds collected in orchards located in Poland were analysed and compared. Each of the selected orchards currently has several dozen different *Tilia* clones, which mainly serve to preserve genetic diversity. These orchards are producing seeds from which new tree seedlings are grown and therefore increases in yield are desired. In this study, we analysed orchard location and their seed yield based on the information provided by Forest Districts and the National Seed Register, in which foresters record data on the collection of seeds as well as breeding difficulties resulting from unsuitable soil types. We were able to determine that seed yield is primarily influenced by the age of the trees. In addition, trees are exposed to changing weather conditions each year, which may not always be conducive to seed formation. Furthermore, it is during seed collection that the disease symptoms or nutritional deficiencies of trees are observed and recorded, which may not occur every year due to the variability of seed formation and demand. In addition, trees are exposed to changing weather conditions each year, which may not be conducive to seed formation.

Keywords: seed production, forest crops, tree yielding, plant cultivation

1. Introduction

The first seed orchards of forest tree species in Europe were established in Great Britain (1931), Sweden (1946), Hungary (1950) and Poland (1964). Initially, silvicultural practices were applied only on coniferous species, namely Scots pine *Pinus sylvestris* L. and larch *Larix decidua* Mill. (Kowalczyk et al. 2011). In the past, forest management significantly influenced the composition of forest communities, resulting in the dominance of several tree species with high commercial value. However, for several decades, there has been a move away from monocultures, systematically increasing the proportion of other tree species, mainly deciduous. As a consequence, successive crops have been introduced in order to establish a seed base for the acquisition of forest reproductive material. Currently, the total area of forest seed orchards in Poland, according to the National Register of Forest Basic Material (KRLMP) (BNL 2019), is 1643.08 ha.

Seed orchards (SO) are selected clones (groups of individuals with the same genetic composition, obtained from a single specimen through asexual reproduction) or pedigrees (offspring of a parent tree obtained through sexual reproduction), subject to special management and isolation rules in order to maximally limit the pollen supply from external sources (Kowalczyk et al. 2011). Seed orchards are established in order to obtain abundant harvests of seeds with increased genetic value, as well as to facilitate seed collection and intensify yields (Kocięcki 1988; Kowalczyk et al. 2011). They are subject to a selective breeding program to improve seed production (Kowalczyk et al. 2011). Seeds from selected stands (seed stands excluded from harvesting)

Received: 2.11.2020 r., accepted after revision: 2.02.2021 r.

and of known origin (commercial seed stands) as well as material from parent trees, clones and clonal mixtures are also used in forestry. Seed orchards are additionally a valuable base for preserving the genetic variability of forest trees – *in vitro* gene banks (Kowalczyk et al. 2011). Due to the increasing demand for seeds of various coniferous and deciduous tree species in Poland in the last decades, new seed orchards have been established, including orchards of small-leaved lime *Tilia cordata* Mill. This could be a valuable species in a changing climate due to its wide ecological amplitude, drought tolerance, and food source for pollinating insects (Pigott 2012).

The first orchard of this species in Poland was established in 1985 in the Susz Forest District and has an area of 7.79 ha. Subsequent orchards appeared quite regularly, currently forming a base of 21 seed orchards, according to KRLMP (BNL 2019). The established orchards are or can be a source of the most valuable reproductive generative and vegetative material, they also serve to preserve the genetic diversity of the species. The establishment of such a large seed base in the country is part of the "Programme for the conservation of forest genetic resources and selective breeding of trees in Poland for 2011–2035" (Fonder 1992, 2006; Matras 1992, 2000; Ludwikowska et al. 2011).

T. cordata is widely distributed in Europe, but due to its relatively sparse occurrence in western European forests and low economic value in the current timber market, the issue of harvesting its seeds has been insufficiently understood. As many commonly grown trees of greatest economic importance have been shown to be potentially vulnerable to the effects of climate change (Bradshaw et al. 2000; Leuschner et al. 2009; Zajączkowski et al. 2013), it is very likely that small-leaved lime will become an increasingly sought-after and valued species for forest managers, as it may play an important role in forest adaptation to climate change (Bernadzki et al. 1998; Brzeziecki et al. 2016).

The aim of the study was to collect information on small-leaved lime seed crops in Poland and to indicate their importance in forestry. Basic information on the location of all orchards registered in Poland, their area and year of establishment are presented. The volume of seed yields obtained from orchards in the period 1985-2013 is described, and an attempt is made to indicate the problems of cultivation faced by selected units.

The study used both literature data and unpublished materials from the following forest districts: Jastrowie (Piła RDSF), Łopuchówko (Poznań RDSF), Pniewy (Poznań RDSF), Susz (Olsztyn RDSF) and Świerczyna (Szczecinek RDSF), as well as data from KRLMP (BNL 2019). The data collected in the study concerning the costs of establishing the crop and the expenses of forest districts relating to this task are from archival materials that were made available to the authors. The selected crops are located in the Zachodniopomorskie, Warmińsko-Mazurskie and Wielkopolskie Provinces.

2. Characteristics of the species

Small-leaved lime is a European deciduous species with a wide but scattered distribution. Its occurrence is strongly correlated with temperature values (Pigott, Huntley 1981; Boratyńska, Dolatowski 1991), and its natural range is primarily in central Europe, from northeastern France to central Russia. The distribution of the species in the Mediterranean region is mainly limited by summer droughts and low humidity (Pigott, Pigott 1993; Radoglou et al. 2008). Small-leaved lime occurs naturally in a wide range of soil types, from podzols to brown soils to rendzinas, as well as in soils with a wide range of textures: from soils with high clay and silt content to soils containing mainly sand (Radoglou et al. 2008). Currently, the proportion of this species varies widely across Europe – scattered in western Europe and more common in eastern Europe (De Jaegere et al. 2016).

Small-leaved lime in Poland occurs most abundantly in the eastern and southern parts of the country (Boratyńska, Dolatowski 1991; Gil, Zajączkowski et al. 2014). Flowering begins at the end of June and usually ends at the end of July, but this is highly dependent on the region of Poland. Nectar production depends on temperature, and flowering intensity varies between years. The flowers are entomophilous and attract many species of pollinating insects, active both in daytime and at night (Pigott 2012). Small-leaved lime trees produce a seed crop almost every year (Tal 2006). Light, drought and frost are important factors for flower development (Pigott 1975). Frosts and low summer temperatures are the most often cause of crop failures (Pigott, Huntley 1981; Kowalczyk et al. 2011). Plants enter the flowering phase at different ages, which translates into irregular yields from individual specimens, depending on the intensity and phenology of flowering, as well as the number of male and female flowers in individual specimens. At the same time, lime has a remarkable capacity for vegetative reproduction as part of its life strategy, which gives it an advantage over other species (Brzeziecki, Kienast 1994).

Small-leaved lime is quite commonly used by humans and has a range of applications, among others as an ideal species for afforestation in rural and urban areas as well as former agricultural land (Zajączkowski 2001; Skolud 2006; De Jaegere et al. 2016). Although the small-leaved lime is not a major forest-forming species, its seed stands (sets of trees with similar morphological characteristics, growing in close proximity and interacting with each other) are hi-

ghly valued in forestry. Lime is an admixture species that improves nutrient circulation. Its leaves are rich in mineral elements and their rapid decomposition has a positive effect on soil quality, especially in nutrient-poor sites (Hagen -Thorn et al. 2004). Furthermore, its ability to grow well on steep slopes and in ravines makes it a very useful species for soil stabilisation on wooded slopes (De Jaegere et al. 2016). Lime flowers are also an important source of pollen and nectar for bees (Anderson 1976). The species therefore provides many benefits and significant ecosystem services.

3. Cultivation problems

Small-leaved lime seed orchards are located mainly in the northern part of Poland, with only a few in the south and east of the country. The orchards are very diversified in terms of area (Table 1). In order to establish them, genetic material that was the closest in terms of origin to the area of cultivation was used. The current health status of the trees varies, and breeding problems mostly concern the acclimatisation of tree seedlings. Tree diseases causing reduced or no regular seed yields are observed in the orchards (Jabłoński et al. 2017). The most common diseases of small-leaved lime are: anthracnose, leaf rust, cankers on the bark caused by a group of fungal pathogens and verticilliosis (Orlikowski, Wojdyła 2003). According to the expert opinions commissioned by the forest inspectorates to diagnose the reasons for lime tree die-out, the causes are often disturbances in the availability of water, which prevent the proper development of the plants (periodic droughts or too much precipitation as well as inappropriate soil aeration). According to many authors, bad soil conditions are responsible for the death of seedlings and reduced yield of trees (Ludwikowska et al. 2011). Sobczak (1999) shows that it is the abundance of organic matter reserves in the soil that affects the health of the trees and may determine their continued viability. According to Rolbiecki et al. (2013), field nurseries are especially prone to tree degradation during many years of intensive use. The need for regular fertilisation and monitoring soil quality in seed orchards for optimal plant growth and yield is also suggested by Ludwikowska et al. (2011). Fertilizing lime trees with compost in relation to mineral fertilisation can lead to faster seedling growth even by 55% (Rolbiecki et al. 2013). These authors also report that organic fertilisation significantly affects the height growth of three-year-old lime seedlings (by 18% on average), and mulching can increase their root collar diameter by up to 11%. Both of these factors also have a positive effect on the development of the entire plant, especially the size of the leaf area, which was larger in organically fertilised plants. Another important argument for the use of organic fertilisation and mulching in nurseries is the increase in the number of leaves per plant. An interesting observation of Rolbiecki et al. (2013) is that the proposed solutions give noticeable effects in seedlings only in the second and third year, while they are not seen in the first year. Hilszczańska and Sierota (2006) explain that some mycorrhizal fungi (*Hebeloma* (Fr.) P. Kumm., *Laccaria* Berk. and Broome and *Thelephora* Ehrh. ex Willd.) can inhibit plant development at an early stage of mycorrhizal establishment. According to Gawroński (2004) and Koreleski (2006a, b), successful afforestation on lower quality land depends mainly on the use of seedlings of an appropriate quality. However, Rolbiecki et al. (2013) and Ludwikowska et al. (2011) provide another hypothesis to explain the poor condition of trees. In their opinion, the cause of seedling death may be the staggered development of leaf buds. However, there is still a lack of scientific studies unequivocally explaining the causes of plant death and further research is needed on the growth and yield of *Tilia* species and clones.

4. Tree yields at selected small-leaved lime seed orchards

The small-leaved lime seed orchards discussed in this paper were established over the last few decades, i.e. 1985-2014, which is associated with varying tree maturity in terms of the extent of their yields. This factor may be most responsible one for the plants' volume of seed production under optimal weather and habitat conditions. An adequately selected site for the cultivation of small-leaved lime trees may contribute to an improved crop yield, as well as limit the occurrence of problems due to disease symptoms. Maintaining seed orchards also involves a number of activities to keep the trees in optimal health. Forest districts' costs here include, in particular, the need for regular maintenance, care and fertilisation of the crop during the period when the trees are not bearing fruit (on average, the first 6–10 years). This entails maintaining the seed orchard in optimal health and habitat condition, which can consist of many factors, described below from selected examples of orchards. Long-term cultivation of small-leaved lime, focused on the long-term acquisition of seeds for production purposes, allows the current level of seed yield from an orchard to be determined. On average, it is possible to obtain 25-100 kg of seeds per year from 1 ha of an orchard (Chałupka et al. 2011). Seed harvests from individual orchards have so far been very varied.

In the small-leaved lime tree seed orchard in the Susz Forest District (the oldest in Poland), maintenance costs have thus far included the following: plant care, pest protection, habitat expertise regarding soil condition, removal of overgrowth from trees, fence repairs, mowing the orchard, fertilisation (with potassium salt, nitro-chalk, ammonium nitrate,

Table 1. The basic characteristics of *Tilia cordata* Mill. seed orchards in Poland based on KRLMP (BNL 2019)

Regional Directorate of the State Forest	Forest District	Area [ha]	Year of establishment	Total seed harvest until 2013 [kg]	Avarage seed harvest [kg]
Białystok	Bielsk	6,05	1986	3 345,60	223,04
	Krynki	4,40	2000	144,50	28,90
Gdańsk	Gdańsk	1,89	1987	32,00	10,66
	Kwidzyn	3,59	1997	540,00	67,50
Katowice	Opole	5,45	2014	-	-
Krosno	Leżajsk	4,03	1992	1 012,00	77,84
Lublin	Świdnik	5,45	1991	797,00	61,31
Łódź	Grotniki	6,62	1997	632,80	39,55
Olsztyn	Olsztyn	16,05	1997	1 162,00	145,25
	Susz	7,79	1985	2 327,50	232,75
Piła	Jastrowie	4,00	1987	154,60	22,08
Poznań	Łopuchówko	2,20	1996	39,50	6,58
	Pniewy	4,32	1996	263,30	32,91
Szczecin	Głusko	2,71	1992	10,00	10,00
Szczecinek	Świerczyna	4,43	2000	91,10	8,28
Toruń	Brodnica	3,60	2013	-	-
	Jamy	5,15	2012	-	-
	Szubin	4,36	2012	-	-
Warszawa	Łuków	6,58	1996	-	-
Wrocław	Oborniki Śląskie	4,99	2004	62,55	6,95
Zielona Góra	Krzystkowice	5,30	2012	-	-

KRLMP – National of Forest Base Material, BNL – Forest Seed Office

superphosphate, copper sulphate, zinc sulphate, lime, urea). In the Świerczyna Forest District, costs were incurred with regard to: stem whitewashing, removal of suckers, sowing grass mixtures, tree pruning, pruning and inventorying graft vitality. In the Pniewy Forest District, unplanned costs in establishing the orchard were those relating to the repeated purchase of the trees that froze in the first years of the orchard's existence and their replanting.

The problems faced by the forest districts in cultivating trees may have affected the crop yield. From information gathered at selected forest districts in the country, it is known that only a few individuals regularly produce seeds. It also happens that the seeds are not harvested due to lack of demand for seed. The average price of one kg of small-leaved lime seeds has been 45 PLN in recent years (unpublished data from Susz Forest District). Therefore, it seems that from the economic point of view, maintaining seed orchards is not profitable. Despite the various problems in the cultivation of small-leaved lime, the most important reason for doing so is to preserve genetic diversity. Maintaining this specific base will allow the future reconstruction of tree stands by using clones from the seed crops.

5. Summary

Orchards, which currently serve as a source of seeds for further stages of forest restoration, especially mixed deciduous forests using small-leaved lime, play an important role in Poland in preserving genetic material. The aim defined in terms of cultivating this type of crop is first of all to counteract monoculture crops, which are a threat to the diversity of the plants and animals in the forest environment. An important factor allowing this phenomenon to be counteracted is the establishment of, among others, seed orchards, which are a natural gene bank for many plants. The many years of experience of Polish forest districts in operating lime tree orchards show that their biggest problem is in finding suitable sites for cultivation. The collected information also proves that this may be an element which lowers the seed yield of trees. In addition, symptoms of tree diseases are often observed, as well as nutritional deficits in the soils. The joint work of foresters and the exchange of experiences from previous breeding attempts to increase tree yields can contribute to improving the current situation regarding tree health. The breeding problems observed in the last few decades, significantly challenging the work of foresters, can be minimised by conducting broader research in the field of this species' preferences in relation to selecting the optimal habitat for small-leaved lime, and by developing one widely available database of information on the issues pertaining to its seed crops.

The data presented in this paper show a relationship between the age and maturity of trees and their seed yield. It is important to store surplus seed from harvests in years with higher yields in order to reduce the need to purchase lime seed from other sources in the future. However, keeping seeds too long can also contribute to a reduction in seed germination capacity.

Conflict of interest

The authors declare the absence of potential conflicts of interest.

Acknowledgements and funding sources

The research was financed from the authors' own resources. The authors thank the employees of the Forest Districts of Susz, Świerczyna, Jastrowie, Łopuchówko and Pniewy for sharing information on small-leaved lime tree cultivation in the seed orchards discussed in this paper.

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Contribution of the authors

M.F. – concept, literature review, corrections; M.K. – literature review, analysis of collected material from the forest districts and registers, writing the first version of the manuscript; W.B.C – literature review, corrections.