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Seed orchards in Ukraine: past, present and prospects for the future

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Abstract

The seed orchards (SO) serve possibilities to collect seeds from the selected genotypes or to create artificial population throughout the controlled crossing of the target genotypes. Therefore, the seed material obtained from the clonal and seedling seed orchards offers unique opportunity to improve the genetic value of seeds. Thus, the seed orchards are considered as an important part of the forest seed base being the key object for both modern forestry and forestry research. This paper outlines the forest breeding activities associated with the seed production in the seed orchards in Ukraine over the last 70 years. During this period, the different aspects related to the establishment and management of the seed orchard were studied. In these processes, many failures had occurred, their causes and consequences were described. These main breeding activities were reported considering plain and mountain regions of Ukraine as well as specific aspects of the reproduction of the main forest tree species. As of 2019, the total area of the clonal seed orchards (CSO) reached 1040.3 ha, while seedling seed orchards (SSO) only 273.7 ha. The results of research on the growth, reproductive development, the morphology of the plus trees clones in the SO were generalized. The article on the current problems and challenges for Ukrainian forestry mainly related to forest tree breeding and there was also focus on forest seed industry. For the main forest trees species (Scots pine, English oak and other), targeted breeding programs should be developed. It is relevant to create the genetic bank of the forest seeds.

Key words

seed orchard, forest seed material, Ukrainian forestry, forest breeding, seed production

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Introduction

The seed orchards (SO) provide with improved and elite seed material for modern forestry being the most important seed source in many countries worldwide (Rosvall 2011; LSFRI Silava 2013; IUFRO 2017; FTBC and FBRC 2018). According to recent reports, in Sweden, 62% seeds of Norway spruce (*Picea abies* L.) and 94% of Scots pine (*Pinus sylvestris* L.) come from the clonal seed orchards (CSO) (IUFRO 2017). In turn, in North Carolina (USA), 98% of loblolly pine (*Pinus taeda* L.) seeds demand is covered by the seeds harvesting in the CSO. Moreover, the annual production of half-sib seedlings has increased from 26.5 to 116.3 million over the last 10 years (McKeand 2017). However, the seed production in the seed orchards of East-European countries covered only a small portion of their demand. In Ukraine, approximately 25% seeds of the forest trees are harvested at the permanent forest seed base units (Los et al. 2014).

The first concept of seed orchard was proposed by Friedrich von Burgsdorf, the director of the Forestry Academy in Berlin at the end of the XVIII century (Romeder and Shenbakh 1962). The practical implementation of the idea of establishing seed orchards through the grafting material collected from plus trees began after 1934 when the method was proposed by Carl Syrach Larsen (Larsen (1934) cited by Lindgren (2008)), and subsequently, developed in Sweden by Holger Jensen and Bertil Lindquist (Lindquist 1954). The concept of selecting plus trees and seed stands for the purpose of seed production was also independently proposed in Ukraine and Russia (Kobranov 1925; Falkovskyi 1927; Samofal 1929).

In Ukraine, the active work on the selection of plus trees and the creation of the CSO began after the Forest Breeding meeting in Moscow in 1957 (Recommendations 1965). The leader of this activity was S.S. Piatnytskyi (1964, 1967). Thus, the selection of plus trees was performed in 1957 (Davydova 1967), while establishing the first progeny tests of English oak (*Quercus robur* L.) was carried out in 1958. Subsequently, the same activity has been initiated for Scots pine in 1962 (Prylutskaia 1965). Later, the first clone banks of both species were established in 1964, while the first CSO of Scots pine and English oak in 1962 and 1964 respectively (Patlai 1965; Bilous 1970; Molotkov 1977).

As a result, a number of recommendations and normative documents were developed by the Ukrainian scientists (Recommendations 1971; Molotkov et al. 1977, 1993; Patlai et al. 1994). These documents regulate a wide range of organizational, methodological and technological processes aiming at creating, forming and effectively using the SO. Several such regulations were developed and implemented in the last years. Majority of them were applied in the establishment of forest seed base (Los et al. 2008); updating the knowledge related to forest seed production (Los et al. 2017b); effective usage of seeds from clonal seed orchards in the Carpathian region and creation seed orchards with improved genetic material (Yatsyk et al. 2017).

From the 1960s to 2013, all together 1,195.4 ha of SO were established (Tab. 1) from which 1,014.4 ha were registered by the State Forest Seed Breeding Inspection (now Ukrainian Forest Breeding Centre).

Table 1. Seed orchards in Ukraine created until 2013 (Los et al. 2014)

Species	Total area of seed orchards [ha]	
	clonal	seedling
Pinus sylvestris	572.5	96.6
Pinus pallasiana (*Pinus nigra* ssp. pallasiana)	35.1	9.0
Picea abies	20.4	3.8
Larix decidua	49.4	–
Abies alba	25.3	–
Pseudotsuga Menziesii	10.0	–
Quercus robur	293.0	60.4
Quercus rubra	–	2.0
Fagus sylvatica	–	16.0
Fraxinus excelsior	1.9	–
Total	1007.6	187.8

During the period of 2010–2015, with a focus on improving the effectiveness of forest seed production in Ukraine, the ‘Program for forest seed production development for 2010–2015’ (Program 2010) was applied to improve forest trees’ breeding in Ukraine. This program involved additional selection of plus trees and creation of new SO. As the main assumptions of the Program were not fully achieved, its duration has been extended till 2020.

Currently, the preliminary results of the Program's implementation have been gained. Thus, 722 plus trees were selected on the plain regions of Ukraine during the 2010–2014, in particular, on the Left Bank Steppe (338 trees), 173 of which are Scots pine trees, 45 – Crimean pine (*Pinus pallasiana* Lamb.) and 119 – English oak (Los et al. 2015). Moreover, 56 SO for 6 tree species in 8 regions were created, among them 13 CSO with an area of 58.5 ha, and 36 seedling seed orchards (SSO) with an area of 132.8 ha (Los et al. 2014). The summary of the previous experience has been reflected in the recommendations for the establishing and managing seed orchards (Tab. 2). As of 2019, according to the database of the Ukrainian Forest Breeding Centre, the total area of the CSO consists of 1052.4 ha, while the SSO occupy 129.9 ha.

Hayda et al. (2015) assumed that in Ternopil administrative region (Western Ukraine) 80 plus trees of English oak, Scots pine, European larch, Douglas fir and Black pine (*Pinus nigra* Arn.) were selected under the Program. Furthermore, the CSO of Japanese larch (*Larix leptolepis* Murr.) and Douglas fir (*Pseudotsuga menziesii* (Mirb) Franko), as well as the CSO composed of two larch species (Japanese larch and European larch) were established.

The CSO serve elite and certified seeds only if for presented on the CSO genotypes the results of their progeny testing are known (Mazhula 2008; Los et al. 2009; Tereshchenko et al. 2011; Hayda 2012). The progeny of more than 3,000 plus trees selected before the Program was implemented, were used to create 147 ha

Table 2. General recommendations for establishing clonal seed orchard (CSO) of chosen species (Yatsyk et al. 2017)

Species	Optimal number of clones	Min. area of CSO	Optimal methods of grafting	Forest types*	Spacing, m × m	Freq. of the mast years	Age of seed production			Seed production, mean (min–max) [kg/ha]
							first	profitable	maximum	
Pinus sylvestris L.	30–50	5	side veneer graft, splice graft, cleft graft	B_2, B_3, C_2, C_3	6×6–10×10	2–3	4	9	15	14 (9–18)
Picea abies	25–30	5	side veneer graft, splice graft	B_2, B_3, C_2, C_3, D_2, D_3	5×5–8×8	3–5	6	13	22–23	30 (20–75)
Abies alba	30–40	5	side veneer graft	C_2, C_3, D_2, D_3	5×5–8×8	2–3	9	14	18	70 (40–140)
Quercus robur L.	30–40	5	'in a bag', bark graft	D_2, D_3	8×8–10×10	3–5	5	14	20–22	450 (100–600)
Quercus petraea	30–40	5	'in a bag', bark graft	C_4, D_2, D_3, D_4	6×6–8×10	3–4	6	13	18–20	520 (300–700)
Fraxinus excelsior	20–25	3	bark graft	C_2, C_3, D_2, D_3	6×8–10×10	2–3	10	14	20	220 (120–350)
Fraxinus angustifolia Vahl.	20–25	3	bark graft	C_2, C_3, D_2, D_3	6×8–10×10	2–3	10	14	22	200 (100–320)
Larix decidua, *Larix leptolepis* (Sieb. & Zucc.) Gordon	30–40	5	side veneer graft, splice graft	C_2, C_3, D_2, D_3	8×8–12×12	1–2	6	13	18	20 (14–26)
Pseudotsuga menziesii (Mirb.) Franco	25–30	3	side veneer graft	C_2, C_3, D_2, D_3	6×8–10×10	3–4	8	10	15–20	10 (8–14)
Pinus nigra, *Pinus rigida* Mill.	20–25	3	side veneer graft, splice graft, cleft graft	B_2, B_3, C_2, C_3	6×6–10×10	2–3	7	12	12	12 (8–15)

* B_2 – fresh mixed coniferous forest, B_3 – moist mixed coniferous forest, C_2 – fresh mixed broadleaved forest, C_3 – moist mixed broadleaved forest, C_4 – boggy mixed broadleaved forest, D_2 – fresh broadleaved forest, D_3 – moist broadleaved forest, D_4 – boggy broadleaved forest.

of progeny tests (Tkach et al. 2013; Los et al. 2014). It was emphasized that the Program did not include the establishment of the clone banks and the progeny tests of the new and the selected plus trees (Hayda et al. 2015; Los et al. 2015).

Considering the high diversity of natural and geographical conditions of Ukraine, the establishment and management of the SO have a specific regional aspect. Indeed, this resulted from the regionalization of forest zones, which in turn cause different forest cover of administrative regions (Tab. 3), forest typology and seed regions (Krynytskyi et al. 2017).

Table 3. Area and forest cover of the administrative regions of Ukraine at 2011 (State Forest 2016)

Administrative region (Oblast)	Area of forests (thous ha)	Forest cower (%)
Autonomous Republic of Crimea	311.5	11.6
Cherkasy	315.1	15.1
Chernihiv	665.7	20.9
Chernivtsi	236.7	29.2
Dnipropetrovsk	179.2	5.6
Donetsk	184.1	6.9
Ivano-Frankivsk	571.0	41.0
Kharkiv	378.3	12.0
Kherson	116.3	4.1
Khmelnytskyi	265.1	12.8
Kirovohrad	164.5	6.7
Kyiv	655.4	22.6
Luhansk	292.4	11.0
Lviv	621.2	28.5
Mykolaiv	98.2	4.0
Odesa	203.9	6.1
Poltava	247.4	8.6
Rivne	729.3	36.4
Sumy	425.0	17.8
Ternopil	183.2	13.3
Vinnytsia	346.5	13.1
Volyn	624.6	31.0
Zakarpattia	656.7	51.4
Zaporizhia	101.0	3.7
Zhytomyr	1001.6	33.6
Total	9573.9	15.9

SO in Ukrainian plain regions

Scots pine

The SO of this species have been established in 13 Ukrainian administrative regions, mainly in the zones of Polissia (mixed forest) and Forest-steppe (Fig. 1). Their area accounts for 64% of the total SO area in the country. The most numerous SOs present in Kyiv, Volyn, Rivne and Kharkiv administrative regions. Among the SO of pine, SSO accounts for only 5.4%, while the majority of CSO are 1st generation seed orchards. The CSOs of 2nd generation accounts for only 13.7% of the total SO area. As a principal rule, the CSOs consist of the clones of plus trees, which originate from the same region where the CSO is establishing. Only four CSO have been created from the clones of the best genotypes selected on the basis of provenance tests.

In Ukraine, the first CSO of pine were established in Dubno Forest District of Rivne administrative region in 1962 upon an initiative of V.L. Vyshnevskyi (Molotkov 1977). In the subsequent years, the following CSO were created in Sumy and Kharkiv regions (Patlai 1965, 1968; Molotkov et al. 1982). Since 1976, in the Kyiv region, the SCO for Scots pine have been created by planting of the grafted plants with a covered root system (Shlonchak 1986). Important contribution into development and improvement of methodology and technology of establishment of Scots pine seed orchards were the studies in the Kharkiv region (Prylutskaia 1964; Gritsaychuk 1979; Shlonchak 1986; Molotkov and Patlai 1990; Mazhula 1993; Tereshchenko 2006).

The study on variation in growth parameters revealed low between clones' variation in height, and a moderate variation in diameter (respectively: 7.4% and 17.1%; Tereshchenko 2018). No difference was observed in the average height of the grafted and ungrafted trees, while the average diameter of the grafted trees was 34.5% lower than the ungrafted ones. Moreover, the modest differences in the crown length were detected.

The study of the CSO and the SSO, which were established at the same ecological conditions, showed that the CSO were more promising than the SSO. Due to the earlier onset of reproduction on CSO at the age of 13 years, twice higher quantity of cones were observed on CSO than on SSO. Moreover, 350% more of macrostrobili and 13% more microstrobili were formed on

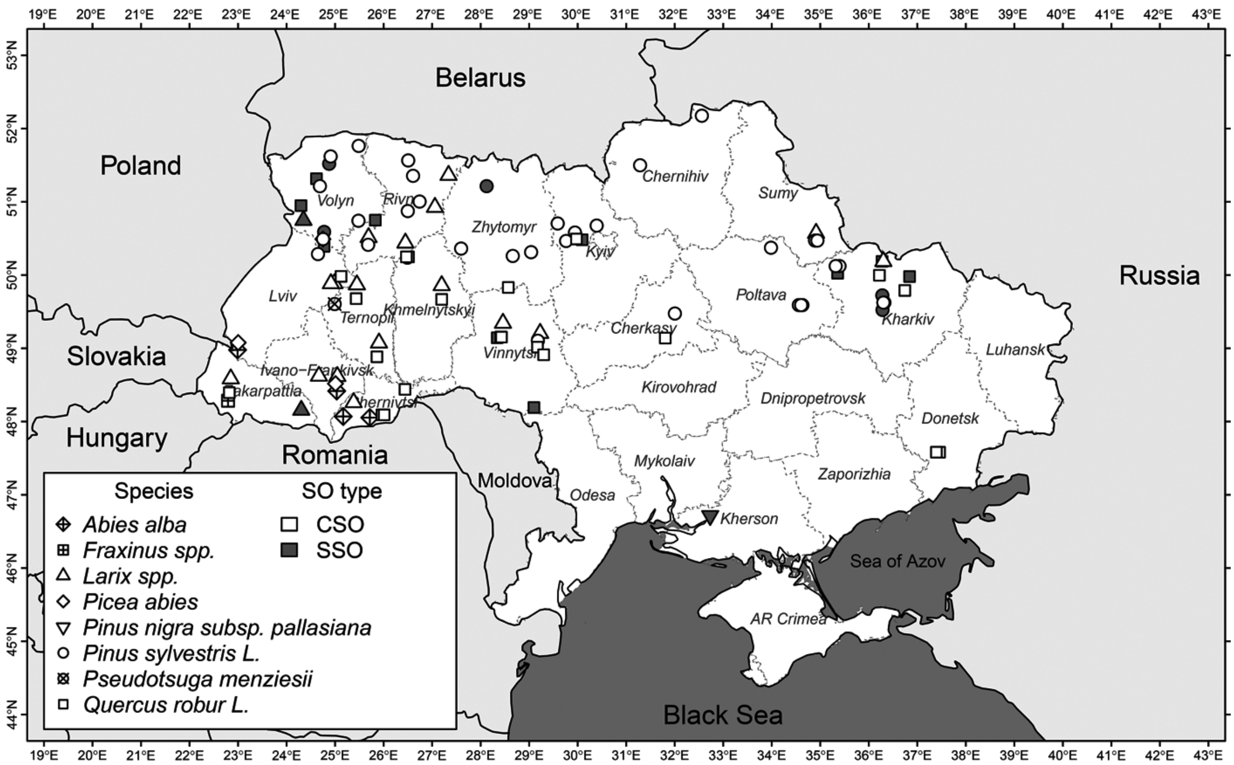

Figure 1. Location of seed orchards (SO) in Ukraine. CSO – clonal seed orchard, SSO – seedling seed orchard

the CSO (Mazhula 2006). The onset of seed reproduction on the CSO was observed at the age of 3–4 years and first industry-important harvests were possible at the age of 10–11 years old, while the highest seed crop was observed from 13 to 15 years old (Mazhula and Voitiuk 2000; Shlonchak and Shlonchak 2009). Up to the age of 6 years old, the microstrobili are formed only on the some few grafted trees, and at the age of 10 years old, they present in all trees (Shlonchak and Shlonchak 2009). Phenological observation of 348 clones flowering in Polissia and Forest-steppe zones revealed that the flowering time coincides in 80% of clones. The difference between the individual clones flowering time may be up to 10 days, thus, the variation in phenology should be considered when creating the SCO (Mytrochenko et al. 2002, 2007). The duration of the drought season, especially in May, after male flowering, had a negative effect on the development of first-year pine cones (Tereshchenko 2006).

Yielding ability, seed quality, and heritability are the main criteria for the effectiveness of the SO. In Kyiv region, the CSO of pine trees with 400 trees per ha at the age of 11–15 years-old may produce from 8.8 to 12.0 kg of seeds per ha. At the age of 20–25 years, with the quantity of 200 trees per ha, the seed yield reaches 17.8–18.2 kg of seeds per ha. The production potential of the best clones at the age of 20 years can reach even 36 kg per ha. The main results on various methods of crown forming of different age pine trees on the CSO revealed that multi-top trees produce more seeds than the single-top ones (Shlonchak and Shlonchak 2009).

Various methods of stimulation seed production are applied in the SO. Among them, soil fertilization may significantly improve seed crop. According to the investigations performed in Kyiv and Kharkiv regions, the best results were achieved by adding the mineral fertilizers, namely P_{200}; K_{90}; $N_{180}P_{180}K_{180}$ or $N_{100}P_{200}K_{100}$ together with perfusion by 0.06% boric acid solution. Fertilizer treatment did not affect the growth of the grafts, however, noticeably increasing the number of female and male flowers. The intensity of low-yield-clones flowering has increased by 56–87%, while high-yield-clones by only 17–20%. Two years after the fertilization, the cones yield of individual clones markedly increased from 2–214% (Mazhula 1993; Shlonchak and Shlonchak 2009).

The largest Scots pine clone bank, located in Kyiv administrative region was established in 1984–1990. 511 plus trees from Polissia and Forest-steppe zones were used to create unique clones' collection. Thanks to that a unique opportunity to study the genetic effect on the course of microsporogenesis was created. Based on the genetic material (330 clones from 8 regions) obtained from the clone bank, the study of meiosis in the process of microsporogenesis was performed. Deviations in meiosis process arise due to the occurrence of mei-gene mutation in the genome ('ps'; 'ms43'; 'sticky'; 'ds') and the rearrangement of chromosome (inversion, translocation). These processes were observed in 23% of the trees (from 16% of trees in the Rivne administrative region to 28% in Kharkiv administrative region). Specific regional variability, due to the factors that lead to the errors in meiosis during microsporogenesis, exists between the artificial populations (Mytrochenko 2017). Trees with mutant mei-gene of desynapsis ('ds') and heterozygotic chromosomal rearrangement in genomes are characterized by genetically determined low-seed cones and vitality of pollen grains. In the Kyiv region, trees with low-seed cones are found to be 2.5 times more frequent among the plus trees than in the natural stands. Moreover, between-regional variability among the plus trees fluctuates from 5% to 26% (Mytrochenko 2007, 2009).

The studies of the heritability of reproduction traits in the progeny of plus trees revealed that both genotype and growth conditions have the importance for seed productions for both clones and sib-progenies (Mazhula and Voitiuk 2000; Tereshchenko 2006). Therefore, the percentage of the full seeds varies from year to year. In the weak seed year, inter-clonal and inter-family variation may reach 59.5–69%, while in the good seed year, it reached only 13.3–27.7%. At the age of 15-years old, all the clones were characterized by the highest seed productivity, with 25–35 seeds per cone. However, these results were achieved in the good crop year (Tereshchenko 2006).

Based on the results from Scots pine provenance trials located in Trostianets Forest District (Sumy region), the CSO from the clones of the best provenance was established (Patlai and Molotkov 1981; Patlai 1983). At the age of 10, controlled crossing between clones was performed and their full-sib progeny were used to establish the progeny tests. The research of 36 years-old progenies revealed a high variability between intraspecific hybrids by growth indices (Tereshchenko et al. 2012).

In the early 90s, the CSO of both Scots pine and Norway spruce of Finnish origin were established in the area of 5.0 ha in the Vinnytsia administrative region. The main goal of the experiment was the study of seed productivity of the Finnish clones under the conditions of higher solar radiation and temperature. The main findings of these studies highlighted the earlier flowering of Finnish Scots pine clones (7–10 days earlier), when compared with the local origins (Neiko and Yurkiv 2017; Neyko et al. 2018). The Scots pine clones of Finnish origin under the conditions of Vinnytsia administrative region are characterized by a stable moderate cone production (2–3 points out of 5), significantly higher than the local origins (Neyko et al. 2018). In terms of Norway spruce clones of Finnish origin, a clear periodicity of seed production was observed. The highest cone productions period (2 points in 1–5 ranking scale) was noted in 2012 and 2016. In general, Norway spruce clones of Finnish origin may be distinguished from the local population on the basis of higher cone productivity (Neyko et al. 2016).

English oak

SO of this species have been established in 13 Ukrainian administrative regions. Currently, more than 350 ha CSO are registered, and half of them are located in Vinnytsia and Khmelnytskyi administrative regions. From 1977 until 1991, the Vinnytsia Regional Forest Seed Production Complex (VSPC) with CSO, SSO, and progeny test trials was created. Currently, VSPC is one of the most important seed objects in Ukraine with the area of 100 ha. Since 1964, grafting technologies were tested in Kolo-Mykhailivske forestry. Among the three used methods: under the bark, cleft graft and 'in a bag' (Bilous 1970), the last one was selected as the most appropriate for English oak. Currently, grafting 'in a bag' seems to be the most common one for creating CSO, not only in Ukraine but also in Belarus and Russia. Moreover, Bilous (1974) also developed a winter grafting method of English oak.

Additionally, Bilous (1973) worked on the other aspects of the CSO management, namely related to the reproductive processes. Seed production depression may be the result of either inter-annual variability or pests outbreaks and diseases events (Ilin and Olkhovskyi

1990; Bilous 2010). Currently, 116 ha registered SO in Vinnytsia administrative region is used for acorn harvesting but also for scientific studies. During the last ten years of observations, the clones were characterized by low acorns yield, while the highest level of reproductive organs formation was recorded in 2013 (Neiko et al. 2014). Moreover, a higher intensity of flowering during the last five years was specific for middle and late phenological forms of oak.

In the Kharkiv region, establishing of English oak CSO has been initiated in 1968 under the supervision of Piatnytskyi. Currently, the total area of the CSO accounts for 25.7 ha, while the SSO accounts for 15 ha (respectively 16.7 and 3.5 ha of which are certified). In the process of the CSO creation, the different methods of grafting were proposed (Davydova, unpublished data). Grafting was the 'in a bag' was selected as the best grafting method of the oak, moreover using non-ligneous scions of oak was applied. From the first years of CSO establishment, reproductive traits of oak clones were intensively investigated (Piatnytskyi 1970; Davydova and Sverdlova 1983). Based on 18 years of observation, the genetic effect on the reproductive abilities of the clones was confirmed (Los 2018). It has been revealed that the highest between clones' variability of seed production occur in intensively fruiting clones, while the smallest in clones with stable weak fruiting. Among three clone's groups (with low, middle and high seed productivity), the lowest difference between groups were observed during the weak seed years, while the highest during a good crop year. Thus, it is recommended to create the CSO only from the clones that are characterized by middle and high seed productions, with the preference to the last ones.

The study of Sverdlova (2002) on microsporogenesis process in different groups of seed productivity clones, shows negative correlations between the proportion of disturbances in the meiosis process and intensity of seed production.

The studies on stimulation of flowering and seed production on English oak CSO in Kharkiv region (Los and Uharov 2000), shows that the single complex mineral fertilization on the basis of liquid complex fertilizers (LCF), ammophos and carbamide (urea), did not affect the seed productivity of high seed production clones during. However, a relatively stable and statistically significant increase in seed productivity was found in groups of clones with middle and low seed productivity. Generally, the most effective complex fertilizers were those on the basis of LCF ($N_{34}P_{200}K_{100}$). In the Cherkasy administrative region, central Ukraine, the main emphasis was put on studying the effect of clone's flowering stimulation (Krasnoshtan 2000). The results of this study revealed that the treatment of tree crowns with chlorcholine chloride stimulates flowers formation both, female and male. However, a significant increase of female flowers was observed in the variants of 0.3% and 1.5% active component concentration (from 49 to 453 and from 44 to 378 flowers per tree respectively).

Study of Los and Borysova (2002) revealed clone-related morphological patterns in the form of leaf plates and acorns. Furthermore, work of Los (2009) highlighted high variability in the morphology of stalks of female flowers, forms of flower pistils and the number of ovaries on the stalk. Hence, between the clone variation in leaf shape, acorn, and flower morphology were implemented in the new methods of clone identification.

The comparison of crown morphology characteristic between 20-year-old SSO and 19-year-old CSO showed that the clones have wider crowns with larger volume, while the progeny have higher crowns than the clones (Los et al. 2017a).

European larch

Since 1964 in the Vinnytsia region, the works related to establishing of larch CSO began and the first seed orchard was established here in 1967. At the same time, methods of the grafting and grafts care were developed (Bilous 1972). Currently, the CSO are mainly located in the Forest-steppe zone in the regions of Lviv, Ternopil, Khmelnytsk, Vinnytsia, Kharkiv, and Sumy (Fig. 1). According to the observations, it was concluded that it is crucial for larch CSO to apply the proper and timely crown formation; moreover, it is important to select the optimal spacing namely 6 × 8, 6 × 10, 8 × 8 or 8 × 10 m (Tab. 2). The main rule is that the distance between rows should be equal to the topping height of trees, which prevents the shading effect (Grygoryeva 2010).

SO in the Ukrainian mountain regions

Since the second half of the 1960s, the first regular works on the CSO's setting up have been started by Carpathian Department of Ukrainian Research

Institute of Forestry and Forest Melioration. These activities faced with different problems as selection and grafting of plus trees, designing and managing of the CSO. Consequently, until the mid-'70s, the major tasks in these fields were solved. Additionally, promising indigenous tree species were included in these studies. Generally, the most important species for the studies were Scots pine of relict origin, European and Japanese larches, Douglas fir, English and sessile oak, (*Quercus petrea* Liebl.), Norway spruce, silver fir (*Abies alba* Mill.), European (*Fraxinus excelsior* L.) and narrow-leafed ashes (*F. angustifolia* Vahl.) (Moiseev et al. 1974; Kaplunovskyi and Pavlov 1976; Yatsyk and Chuiko 1978; Yatsyk and Hayda 2008; Yatsyk et al. 2008b; Mohytych et al. 2019).

At the same time, in the Carpathian region, breeding stations, farms for forest seeds production, breeding nurseries, and later also breeding state forestry enterprises were established. The works on grafting and breeding became more intensively. But at the same time, as in the whole of Ukraine, the appropriate scientific control over these institutions and practical activity was lost. Proper scientific support has become impossible by the transition to large amounts of practical work and this negatively affected their quality. The majority of plus trees' progenies were untested. This resulted in 80% of plantations uncertified by the commissions. The genetic potential of the plus trees and the potential of positive trees was also not taken into account. During their certification, the main focus was made on the productivity, quality and stability of trees, but the evaluation of the intensity of flowering and fruiting was given less importance.

Nowadays, in the Carpathian region, the area of all CSOs are 360 ha, of which more than 50% (159.3 ha) are accepted. Most of them are located in Lviv administrative region (37.8%), while less in Chernivtsi (21.0%), Ternopil (20.7%) and Ivano-Frankivsk (17.9%) administrative regions. The lowest area of the CSO is in the Zakarpattia region (2.6%) (Yatsyk et al. 2017).

Various aspects of the CSO management as the clone composition on the CSO, crown formation, soil maintenance, and stimulation of seed productivity were developed. On the basis of these activities, the general recommendations for seed orchards established in the Carpathian region were proposed (Kaplunovskyi 1974a, 1974b, 1984; Yatsyk 1981; Yatsyk et al. 1981; Molchenko 1982). It was found, that under the Carpathian region conditions, planting completely formed grafts is the best method for creating the CSO. For grafting, rootstocks cultivated on the nursery from one, two, three and four-years-old are recommended (respectively: ash, pine, and larch, oak and Douglas-fir, spruce and fir).

Another important issue of the CSO management in Carpathian region was the optimal spacing for both clonal and seedling seed orchards. As it was not known about optimal spacing, various spacing has been applied. Hence, on many SO, an initial spacing of 3 × 4, 4 × 4, 4 × 5 m were thickened. For this reason, at the age of 15–20, the crowns of the clones were highly overlapped, and the branches have died to a height of 4–5 m. As a result, such seed orchards changed into usual forest stands where the reproductive processes were declined. In the mid-80s, another spacing were proposed: for Norway spruce or Silver fir – 5 × 5 m; for Scots pine – 5 × 6 or 6 × 6 m; for larches, oaks and ashes – 6 × 8 m. Furthermore, the manual formation of crowns was accepted. The crowns' pruning was recommended when the clones reached a height of 3.5–4.0 m, while the top cutting was applied 30 cm above the last branch whorl. The last treatments led to the slowing of new tops' appearance.

The studies of optimal soil tending on the CSO were completed in the 1990s (Ravliuk and Nykoliuk 2005). According to the authors of this study, keeping black fallow during the first 4–5 years, and after that seeding and systematic mowing of perennial grasses with high azote accumulation capacity (i.e., Rapeseed (*Brassica napus*), Vetch (*Vicia sativa*), Lucerne (*Medicago sativa*)) is the most effective technology.

It is commonly known that the genetic value of seeds from the CSO is determined by the mating design, which depends on the number of clones and ramets, individual clones' contribution to the formation of a common gametes pool, reproductive phenology and the scale pollination with foreign pollen. For the quantitative determination of these factors and consequences of their influence on the genetic variability at the Norway spruce, European larch and Douglas fir CSO in Kolomyia Forest District the Kang's and Lindgren's (1998, 1999) methodological approaches were used. According to this methodology, the average number of macro- and microstrobili on the clone, sibling coefficient (ψ), group coancestry (Θ), the effective number of parents (Np), relative effective number of parents (Nr) and expected inbreeding (F) were studied.

In 2010 and 2012, at the Norway spruce CSO (established in 1987, 19 clones) flowering intensity and seed productions were monitored (Hayda et al. 2012; Hudyma et al. 2013). The results showed a weak and unbalanced distribution of female strobili among clones and the more frequent and balanced distribution of male strobili. Moreover, in 2010 the average number and coefficient of variation for macrostrobili were 9 and 147.5% respectively, while for microstrobili, it was 2078 and 47.1% respectively. In turn, in 2012, the intensity of strobili formation was higher, while the between clones variation in quantity was lower (163 and 56.2% respectively for macrostrobili, and 7281 and 42.5% respectively for microstrobili). Variability of clones' fertility was lower and through this effective number of clones – both maternal and parental (respectively: 14.4 relative to 6, and 16.1 relative to 15.5) – was higher in 2012 than in 2010. Thus, in 2012, the observed reduction of relative genetic diversity (GD) of the predicted orchard crop in the year of intensive flowering was lower than in 2010, the year of weak flowering.

Another study on silver fir clones revealed that in 2010, the variability of strobili quantity was lower than on Norway spruce CSO (Yatsyk et al. 2010). The variability of female strobili and male strobili quantity was 58.3 and 34.5% respectively. As a consequence, silver fir CSO was characterized by low sibling coefficient and group coancestry, and the effective number of clones was close to the actual number of clones. Thus, 74.7% of clones participated in the formation of seeds as maternal individuals and 89.4% – as male ones.

Sishchuk et al. (2013) reported the highest intensity of strobili formation observed on European larch CSO (established in 1985, 20 clones). In this study, the average number of macro- and microstrobili in 2010 were 500 and 2742 respectively, while in 2012, 821 and 4486 respectively. Moreover, the majority (78–92%) of clones were involved in the seeds' formation. Considering the above, a low level of inbreeding coefficient (2.9 and 2.2%) was predicted for both years. The dynamic of relative genetic diversity in seeds crop was modelled (Sischuk et al. 2013), with two different approaches: (a) harvesting the same seed quantity from each clone and (b) the genetic thinning on the CSO. In the first case, a low increase in the expected level of genetic variability was observed, while in the second case, removing of low-yielding clones led to reducing the number of effective parental trees (especially on the CSO with a small total number of clones), and to a certain level, a decrease of the genetic diversity on the CSO.

The studies of Shtogryn et al. (2013) on Douglas fir CSO (established in 1987, 19 clones) showed that the sibling coefficient in the measurement years ranged from 1.262 to 1.330. The expected loss of genetic diversity in the Douglas fir seeds in 2010 was the highest among all investigated tree species ($\Delta GD = -0.039$). In the case of formation of seed lots with the same proportion of each clone, a certain reduction of genetic variability in the seed material was possible (in 2012 from 0.033 to 0.028). Such an approach can only be applied in the years with a high cone crop.

Another important issue in the SO management is preventing plants from herbivore pressure. Currently, in Ukraine, the fenced SOs better fulfil their functions. Seed orchards protection takes on meaning in the context of the negative effect of spreading diseases and pests. According to Kaplunovskyi (1974a, 1981), the volume of the seed crop depends on the level of diseases and pests. In some years, the proportion of damaged cones and seeds may reach even 80%.

The study of the temporal variation in the seed production on the CSOs revealed the importance of determining their optimal life cycle (Hayda and Yatsyk, personal communication). The authors assumed that the most effective period for clones of Norway spruce, silver fir, European larch and Douglas-fir is the period from 15 to 45 years. In the later period, the exploitation of the CSO is less effective, the seed productivity decline, and after that, the clones degrade and gradually die. However, for more accurate determination of optimal life cycle of different species, additional and wider scale studies are needed.

Previous studies in Carpathian region and adjacent territories justify the profitability and validity of seeds' production on the CSO for such species, as larch, fir, spruce, Douglas fir and ash (Yatsyk and Ravliuk 2004, 2005; Ravliuk and Yatsyk 2006; Saviak et al. 2006; Yatsyk et al. 2006, 2008a; Hayda et al. 2008). Nowadays, in this region, the CSO partly provide the forestry demand for high-quality seeds.

Conclusions

Based on the last 70 years of breeding activity in Ukraine, mainly related to the forest seed production and improvement, four major periods can be defined: (a) from the mid of the 1950s to the mid of 1970s – the first plus trees' selection, establishing of the first SOs and progeny tests, developing of the effective grafting methods and strategies of the SO management; (b) from the mid of the 1970s to the early 1990s – wide-scale creation of the SOs and progeny tests, improving technologies of the SO's creation and their management; (c) from the beginning of the 1990s to 2010 – weak activity in the forest tree breeding seed production decline on the SOs; (d) from 2010 to present days – the recovery of the activity in forest tree breeding and seed production, developing new strategies for the future breeding activity in Ukraine.

Last period of breeding activity focuses on (a) studying growth, phenology and reproductive processes in clones, half-sib, and full-sib families; (b) breeding of promising clones for their use on the second generation CSO; (c) studying inter-annual variation in the SOs' seed productivity.

The current state of improved seed base allows defining the future goals for breeding activity in Ukraine. Seed production on the SO should be one of the priority directions in the Ukrainian forestry. The SOs and progeny tests require continuous monitoring of their suitability for the production of improved seeds and the selection of the best genotypes. The forest seed zoning should be updated, in order to meet the current needs for the seed material in Ukrainian forestry. For the main forest trees' species, the targeted breeding programs should be developed. While creating the new breeding programs, a wide network of provenance and progeny tests, as well as seed orchards with improved genetic material, should be considered. Moreover, forest seed base should be supplemented with new forest gene banks. It requires, however, financial support for the leading forest breeding institutions, mainly forest research institutes. In addition, for stimulating interest in forest genetics and breeding in forestry universities, the current trends in forest tree breeding should be shared among the young generation of Ukrainian researchers.

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