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Review

Heterobasidion root rot in forests on former agricultural lands in Poland: Scale of threat and prevention

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This paper describes the specifics of forests on former farmlands in Poland and their protection as well as preventive measures taken. The review refers to polish literature on the threat by root rot caused by *Heterobasidion annosum* (Fr.) Bref. to pine and spruce plantations established on post-agricultural lands on an area of more than 1400 000 ha. In Europe, the latter presents an outstanding example of only one of its kind operation towards increasing the forest cover both at a country and continent level. Currently, economic problems due to the fungus concern an area of about 200 000 ha yearly. During the past 30 years, PgIBL® preparation with *Phlebiopsis gigantea* (Fr.) Jülich was regularly applied in Poland's Scots pine stands (*Pinus sylvestris* L.) to effectively prevent and control the spread of root rot disease, yet it has not been registered by the European Commission. In literature on root rot in Europe, there is scarce information with regard to this topic.

Key words: Post agricultural land, afforestation, *Heterobasidion*, *Phlebiopsis*, biological control

INTRODUCTION

Root rot caused by *Heterobasidion annosum* (Fr.) Bref. has been one of the most significant economic problems in polish forests for many years. Serious damage has been specifically observed in Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karst. stands cultivated on soils formerly under agricultural use. Historically, the mortality of trees introduced onto such "unsuitable sites" has been recorded in Poland for over 110 years (Płoński, 1930). In Poland, approximately 172.6 000 ha of wastelands and post-agricultural lands were afforested after World War I, and already by the year 1938 serious damage due to *H. annosum* was observed on an area of 1676 ha. After World War II, former agricultural lands, pastures, grasslands, and wastelands have been continually afforested (Sierota, 2012b).

According to then regulations on forests (1953, 1961), tree stands established on former agricultural lands were treated as forecrop, for the reason that at the beginning, the stands were agrocenoses-like and constituted the first rotation of forest. The idea was that roots of planted trees, developing mycorrhizas and fallen down leaves from introduced trees and shrubs should modify former arable soil into forest soil in advance of natural ecological succession (Ilmurzyński, 1969; Bergmann, 1993). Key tree species introduced onto post-agricultural areas were: Scots pine, Norway spruce, birch (*Betula* spp.), larch (*Larix decidua* Mill.) and alder (*Alnus* spp.), and for the most part these were dense and pure cultures or mixed to 50%.

Approximately 1 156 000 ha of former agricultural lands and abandoned farm sites were afforested during the years 1947 to 1997, and 704 000 ha of such forests were state owned as well as managed by the government (State Forests). Afforestation increased forest cover in

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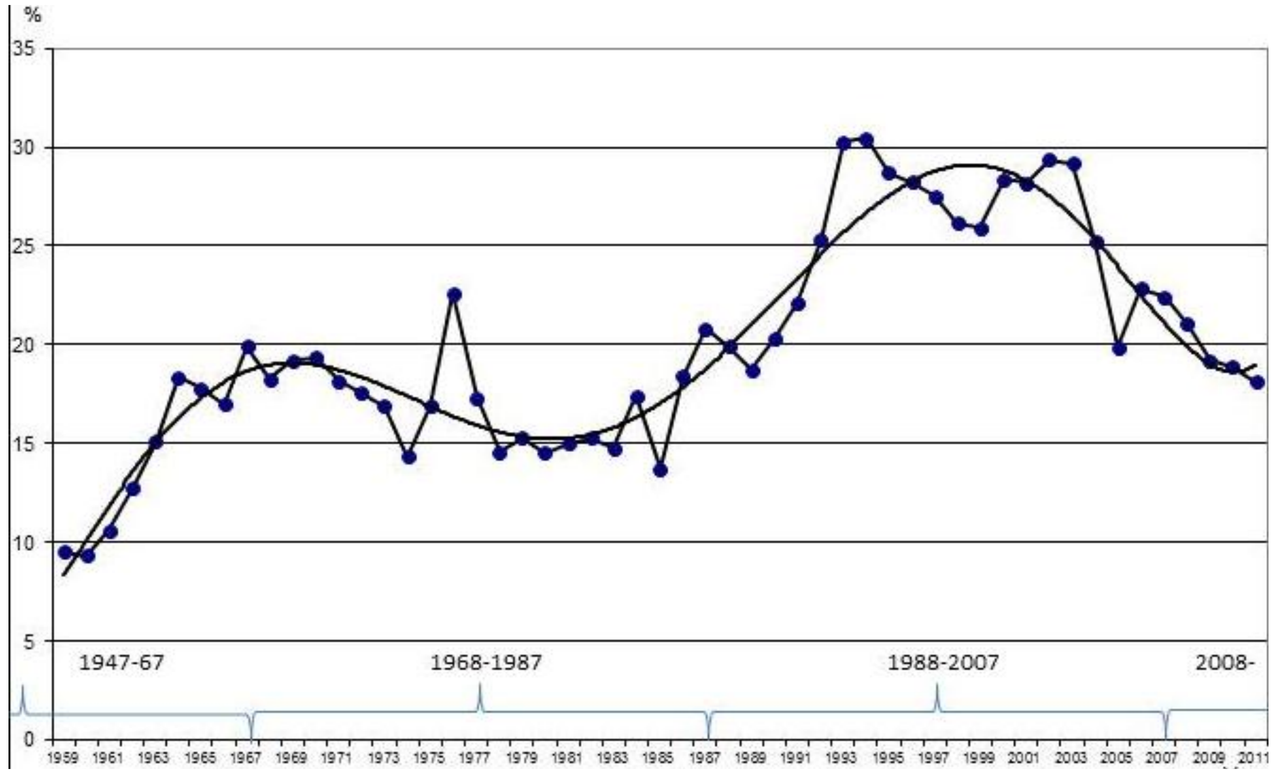

Figure 1. Participation of root rot damaged stands in the area of afforested former agricultural lands (%) in 1947 to 2011 along with polynomial trend line. Brackets (clips) on the bottom shows 20 years' age classes of afforestation since 1947 (Sierota 2011, modified).

Poland from 20.8% in 1946 to 29.2% in 2010. At present, forest cover of land area in Poland amounts to 30.5%. (Rozwałka and Fonder, 1996; GUS, 2006, 2010, 2012).

First significant fungal damages were recorded in afforested areas already at the end of the 1950s and 1960s (Orłoś, 1963). In north-eastern Poland, pine and spruce plantations were severely damaged due to *H. annosum* on an area of 13 700 ha. As the amount of afforested area increased, the incidence of the pathogen kept spreading (Figure 1).

By 1976 (within 30 years of afforestations), the progress of the disease was recorded in 13 700 ha of plantations and 122 000 ha of stands older than 20 years. Within 50 years (till 1996) the damage due to *H. annosum* in state forests was found in stands of all age classes covering an area of 201 900 ha. In 1997, Gdansk, Wroclaw, and Pila Forest Directorates reported high incidence of the disease in affected stands that is, 6.4, 4.9, and 4.8% of the forested area, respectively. In some forest districts, *H. annosum* damage was found in more than 10% of stands, and in the Ciechanow Forest District (central Poland) up to 44.6% of pine stands showed infections at root level caused by the pathogen (Sierota, 1996b). Root rot disease occurs with different severity throughout the country, and this is inter alia due to the differentiated age of stands on post-agricultural lands as well as soil types and kinds of stump infections (Małecka and Sierota, 2003). An increasing trend in the acreage of root rot infected tree stands has been observed for about 30 years (Figure 1). This can be attributed to increment peaks in the stands established during subsequent afforestation operations since 1947 (Sierota, 2011).

Although some stands cultivated on arable soils are not affected by *H. annosum*, the occurrence of the pathogen in the majority of first-rotation stands results in increased conifer tree mortality as well as in greater susceptibility to abiotic damage and pests. Succeeding gaps in affected stands sustain weed growth and are rarely naturally regenerated by deciduous trees (owing to poor sites). In several forest districts, the condition of impacted forests leads to salvage-harvest at only 30 to 40 years of age. Reforestation of the harvested areas with traditional pine plantations according to the forest rules for such sites generates a risk of damage in second-rotations that may result in salvage harvest of even younger stands (Sierota, 1995).

Poland was the second country in Europe (after United Kingdom), where as early as in 1970 Rishbeth's ideas to control root pathogens were introduced and initial experiments with *Phlebiopsis gigantea* (Fr.) Jülich (*H.*

annosum competitor) were carried out on semi-economical scale (Sierota, 1975, 1981, 1984). In Poland, the original method of production and practical application of PgIBL® preparation with the competitor was developed in the 1970s and 1980s and until 2010 it was constantly improved (Pratt et al. 2000).

However, despite the fundamental book devoted to this important fungus edited by Woodward et al. (1998) and the recent publication of Garbelotto and Gonthier (2013), there lacks either important information on past and current aspects of root rot disease in Poland or quotations from Polish subject literature. The present paper is to fill the existing information gap and present an unbiased picture of substantive spread and control of root rot in Poland.

FACTORS AFFECTING DISEASE DEVELOPMENT

Soil

Agriculturally, cultivated soils differ from typical forest soils in many ways. First, the impervious soil layer ("plough footing") of farmed soils that consists of broken soil particles often inhibits water saturation from lower soil levels to the surface. Arable soils are relatively rich in nitrogen, while phosphorous and calcium are often deficient, as well as in organic matter, especially at a depth of 20 to 25 cm. The carbon/nitrogen ratio in the arable cover varies from 8 to 12, whereas in forest soils, it varies from 12 to 30 depending upon the soil layer. The pH of cultivated soils (pH: 6 to 8), particularly in the surface layers, is usually higher than that of forest soils (pH: 4 to 5), thus various bacteria and Actinobacteria (Actinomycetes) prevail there (Richards, 1974). Additionally, the numbers of beneficial soil fauna in former agricultural soils are 10 to 15 times lower than in forest soils providing less favourable conditions for the creation of organic matter needed for sufficient tree nutrition (Szujecki, 1990).

Roots of agricultural plants and some fungi that inhabit farm soils produce allelochemicals that can negatively affect other plants and often stimulate the development of various parasitic fungi. On the other hand, the development of fungi antagonistic to and competing with *H. annosum* is often constrained (Kwasna and Sierota, 1999; Kwaśna et al., 2000; Szwajkowska-Michałek et al., 2012). A substantial difference between forest and cultivated soils is that, the latter lack litter as well stumps and a variety of roots, which as a rule provide a source of energy for fungi that utilize cellulose and lignin and for insects that feed on decay by-products of wood (Rykowski, 1990).

Furthermore, chafer grubs (*Melolontha* spp.), which frequently forage in agricultural soils (Sierpiński, 1969; Malinowski, 2007) increase the risk of *H. annosum* infection. Nuorteva and Laine (1968) showed that, the grubs injuring the bark of tree roots can provide points of entry for spores or mycelium of *H. annosum* that endure in the soil. Likewise, Skrzecz (1996) described the role of the large pine weevil *Hylobius abietis* (Linnaeus) as a vector of root rot fungi in root systems.

Host plant

In Poland, by reason of poor soils (resultant of the Baltic Ice Age) afforested post-agricultural lands were planted mainly with Scots pine (about 700 000 ha). Pine transplants were often of undefined provenance, and every now and then, not vigorous enough to adapt to new growth conditions. The procedures of ploughing do not break up the lower layers of soil saturated with iron ions, and therefore the development of root systems in young pine trees was highly limited. Consequently, the roots of growing trees expanded horizontally resulting in an inadequate supply of water to the roots, especially during drought periods. Such root deformations in pine (also in spruce) made trees frost prone during cold winters. The roots of numerous first-rotation pine trees (30 years old) are now expanded within soil upper layers, to the depth of merely 20 cm (Sierota and Sternak, 1993; Sierota, 1995; Szewczyk, 2013).

Dense planting at that time (oftentimes more than 20 000 transplants/ha) required prompt thinning that generally was not conducted in the past and ultimately the roots of growing trees contacted each other. The roots of young trees were time and again flattened, folded or damaged during insertion into a soil notch. These defects were recognized in approximately 70% of young trees that died in the first season after planting, especially during the periods of climatic anomalies (Sierpiński, 1969; Puchniarski, 2000; Mykhayliv and Sierota, 2010).

It is well known that, tree roots can be infected by *H. annosum* through natural cracks in outer bark layers as well as via lenticels or mechanically damaged tissues (e.g. due to insect feeding or root movement during windy periods). The anatomical wood features of pine or spruce cultivated in post-agricultural soils make it easy for *H. annosum* hyphae to readily penetrate. Trees growing on ex-agricultural sites produce more spring wood and wide cells with thinner walls. This effect is observed mostly when trees are young being results of intensive utilization of soil nutrient stock (especially nitrogen) (Jelonek et al., 2005; Mańka, 2005).

SPREAD OF DISEASE IN FIRST AND SECOND ROTATION STANDS

The rate of disease development depends primarily on the characteristics of pathogen presence, genotypic constitution of the host tree and environmental conditions

(Sierota, 1998a; Sierota et al., 1998). The rapid development of *H.annosum* is notably supported by high planting density and rapid expansion of tree roots (Sierota 1995). Furthermore, mycelium of the pathogen can grow throughout arable, fertilized soils or inhabit roots of annual plants and shrubs (e.g. *Juniperus* spp*.*) and utilize these as a "channels" to grow along (Sierota, not published).

Tree mortality occurs in infected pine plantations within 1 year of pathogen invasion (Żółciak et al., 2006). In the following year, individual trees or their small groups simultaneously die throughout the plantation. Adjacent trees are infected in time, depending on the position of their root systems and on the number of root contacts with infected trees. Gradually, groups of diseased trees become disease centres that are formed in widely-spread foci throughout the plantation. Over a 4 years period, numerous trees are killed and consecutively conjoined disease centres turn into gaps (Sierota, 1997b; 1998d; Sierota et al., 1998; Zółciak et al., 2006).

According to Rishbeth (1963, 1975), it is clear that, stumps left behind in thinned plantations provide the main point of pathogen entry into healthy crops and remain the predominant source of infection. The surfaces of freshly cut stumps are remarkably susceptible to *H. annosum* colonization by means of airborne spores (basidiospores and conidia). The spores develop into mycelium that grows down into stump roots which often contact healthy roots of adjacent trees (Sierota, 1995; Zółciak et al., 2006). Subsequently, the state of health of living trees is constantly threatened by the presence of infection sources in close proximity. The risk of *H. annosum* invasion through root contacts is increased in pine plantations cultivated on sandy soils. Under these conditions, pine trees grow extended roots (in a range of many meters from tree trunks), that on one hand may hinder the development of visible disease symptoms, and on the other hand increase a possibility of simultaneous infection of several trees (Sierota, 1997b).

The spread of *H. annosum* in stumps is affected by resistance processes in attacked trees (Sierota, 1998c). Furthermore, competing and antagonistic fungi can prevent the invasion of stump surfaces by the pathogen. However, natural colonization of stumps and roots by competitors does not sufficiently restrict *H. annosum* attacks, which are often followed by rapid spread of the disease. The saprotrophic fungus *P. gigantea* is the main competitor of *H. annosum* in pine stands. The indigenous occurrence of *P. gigantea* is influenced by the quantity of airborne spores as well as timing of tree felling, even though its incidence amongst other fungi isolated from pine roots is generally low.

In mature pine, stands disease development is usually less intense. Single trees may be killed due to *H. annosum* infection but dying of tree groups is not commonly observed. The symptoms of pathogen occurrence can be seen on the edges of gaps resulting from windblows (Rykowski and Sierota, 1983a; Sierota and Małecka, 2004a; Sierota et al., 2007; Sierota, 2011a). However, windblown trees are usually removed quickly during sanitation, and therefore the appearance of a mature stand oftentimes does not reflect the real state of root health (Rykowski and Sierota 1983a). In case of rapid disease development, the number of killed trees increases followed by the aforementioned losses in forest cover (Sierota, 1997c; Sierota and Małecka, 2003; Zółciak et al., 2006).

Similarly to the processes observed in pine stands, *H. parviporum* Niemela and Korhonen spreads throughout spruce and other species stands (*H. abietinum* Niemela and Korhonen in *Abies alba* Mill. stands) mainly by way of secondary infection (Łakomy and Werner, 2003; Kraj and Kowalski, 2010; Łakomy et al., 2012). Fungus mycelium progresses from infected stems and/or roots towards tissues which surround the root core in bigger roots. This is followed by well recognized expansion of the pathogen in the heartwood at the butt end and fungus advancement in the heartwood up the tree stem. The results of research to date have revealed a hypothesis about the progression of *Heterobasidion* spp. mycelium via roots of birches and other tree species that grow in coniferous stands (Sierota, 1995, 1997b, 2011).

Post-agricultural areas previously afforested with pine and spruce stands being salvage-harvested due to the disease caused by *H. annosum*, were usually reforested with second-rotation pine and spruce plantations. The occurrence of the pathogen in transplant root systems as well as traditional tilling practices created conditions where 4 to 5 years old trees were frequently killed throughout these plantations. Tree mortality was enhanced by the presence of infected stumps of salvage-harvested trees, as pathogen mycelium can survive in stump heartwood for several years. The passage of the disease from infected stump roots to healthy roots of replanted trees is often promoted by root contact. During the phase of intensive tree growth, the number of root contacts keeps increasing. Root excavation in 5 years old plantations showed roots of 8 trees on 2 m^2 plots. In a 15 years old stand, the roots of 47 different trees were observed within a 1 m long section of 20 cm deep soil layer (Sierota, 1995, 1998d).

PREVENTIVE AND THERAPEUTIC PRACTICES

Frequent occurrence of the pathogen in pure pine or spruce stands on farm soils indicates necessity for structural changes in these stands (reconstruction) along with several counteractive actions that can prevent disease spreading (e.g. introduction of saprotrophic Basidiomcetes). Such control measures are important in already existing plantations and should be taken into account when new plantations are designated or established (Twarowska, 1972; Sierota, 1987, 1996a).

The selection of high quality seeds of native origin as well as suitable growth conditions for seedlings in nurseries are very important when designing a new plantation. During soil preparation practices, the timing of tilling should be determined taking into consideration indigenous climatic conditions and grub control measures. Depending on regional soil conditions, deep full tilling or subsoil plough tilling can loosen plough footing in arable soils allowing for the growth of tree roots vertically instead of horizontally (Sierota, 2001b).

The use of biological substrata (e.g. sawdust, compost consisting of bark, tree branches, peat) stimulates biochemical changes in arable soils that are advantageous for forest tree growth. Application of such substrates in arable soils induces changes in soil pH and influences populations of microorganisms that can activate ecological processes characteristic of forest soils (Sierota and Kwaśna, 1998; Kwaśna et al., 2001).

During the periods of intermediate cutting, clear-felling or preparation of skidding trials, inoculation of all the remaining stumps with proper competing fungi such as *P. gigantea* or other stump decomposing fungi (e.g. *Tricholomopsis rutilans* (Schaeff.) Singer, *Hypholoma fasciculare* (Huds.) P.Kumm.) is necessary (Sierota, 1995; Napierala-Filipiak and Werner, 2000; Oszako and Sierota, 2003). This seems to be important, especially in Scots pine plantations that are endangered by existing sources of infection, e.g. occurrence of the pathogen in adjacent stands. Although the treatment is labour consuming, it can significantly reduce losses due to *H. annosum* in the following phases of stand growth. Introducing saprotrophic Basidiomycetes into forest stands cultivated on post-agricultural soils can significantly advance biological control of root pathogens (Rykowski and Sierota, 1983b; Sierota, 1975, 1981, 1984, 1986).

Until the year 2010, *P. gigantea* in PgIBL® was commonly applied in plantations. Year by year, this fungus becomes a natural component of newly established forest ecosystems on post-agricultural lands, decomposes wood of pine roots rapidly, and in addition it reproduces from sporocarps intensively (Sierota, 1997a, 1998b; Pratt et al., 2000; Małecka et al., 2012). The capability to exclude *H. annosum* from its food resource makes *P. gigantea* practically useful in terms of the concept of biotechnological prophylaxis and pest control in forestry. The reduction in *H. annosum* spread throughout coniferous stands and a significant decrease in tree mortality resulting in an increase of crop production are the main economic benefits of using *P. gigantea* (Rykowski and Sierota, 1984; Sierota, 1995, 2001a; Sierota and Małecka, 2003; Zółciak et al., 2006).

In 40 years old pine stands not subject to biological treatment, losses caused by *H. annosum* (compared with the polish yield tables) were as follows (Sierota, 1997c):

i) Stand density (m^3 per ha) decreased from 0.9 to 0.6 (standard = 1);
ii) Current increment of growing stock (m^3) decreased by 50 to 60%;
iii) Thick wood standing volume decreased by 27.8 to 69.5 m^3/ha depending on intensity of fellings.

The preparation PgIBL®, consisting of viable mycelium of *P. gigantea* grown on sterilized beech (*Fagus* spp.) sawdust, was successfully used to prevent the colonization of stump surfaces by *H. annosum* in Poland's pine stands cultivated on post-agricultural lands (Rykowski and Sierota, 1977, 1983b; Pratt et al., 2000; Małecka et al., 2012). The efficiency of spring and fall treatments is 100% as long as stumps are sufficiently handled (tapping, covering with litter, etc.). The latter increases labour costs by approximately 10%; however, the additional costs are counterbalanced both by ecological and economic advantages (Sierota, 2002).

The efficiency of *P. gigantea* inoculation in pine stands cultivated on post-agricultural soils is determined by plantation age as well as disease severity. Preventive measures carried out in young stands during the first clear felling can significantly decrease the risk of disease spread all through plantations. Preventive measures carried out in a stand already infected with *H. annosum* can reduce pathogen spreading and result in health improvement of the treated stand. Moreover, the risk of disease propagation in subsequent forest plantations on these areas can be significantly decreased (Rykowski and Sierota, 1984; Sierota, 1997b, 1997c, 1998a).

The success of the biological method of prevention and control of root rot in Scots pine stands results in:

i) Decrease of primary infection risk either from stump surface or roots.
ii) Decrease of secondary infection risk (root-by-root).
iii) Deactivation of *H. annosum* mycelium in root tissues.
iv) Great reduction of *H. annosum* fruit body production.
v) Rapid and effective decay of the root system, and consequently soil nutrients' increase as well as soil status favouring fungal secondary succession.
vi) Enrichment of arising "forest site on post-agricultural land" with saprotrophic Basidiomycetes which play an important role in the energy cycle of forest ecosystem.

In Poland, artificial inoculation of stumps with *P. gigantea* is obligatory in first-rotation Scots pine stands established on post-agricultural lands. Until 1992, the preparation PgIBL® was used to control about 18.2 million of freshly cut stumps. In 1992 to 1997 the preparation was successfully used on an area of 280, 460 ha of thickets and stands, and in the last decade the biological method was performed on 226, 5 000 ha (Sierota, 2001a; GUS, 2012). Taking into account a great number of stumps to preserve and labour consumption during the treatment, a simplified technique was tested (Sierota, 1998b; Sierota and Małecka, 2004b). The dispersed treatment is based essentially on protecting with *P. gigantea* only the stumps of selected trees (25%) in a stand destined for removal just one year before regular felling operations. The stumps treated with fruiting bodies of the competitor are “parent stumps” which reinforce natural and desirable colonization of the stumps left behind after harvesting the remaining 75% of trees. This approach decreases treatment costs by 5 to 30% (Sierota and Małecka, 2004b).

Recently, partial stand conversion has been undertaken in threatened Scots pine monocultures. When first symptoms of the disease occur, small excision nests are done along with simultaneous application of *P. gigantea* biological treatment onto conifer stumps. Subsequently (at some stage in the autumn or next year), deciduous tree species are planted in the gaps, consistent with soil fertility at a given site. This procedure is called "artificial gap method" and it appears to be an effective prophylactic and therapeutic measure (Sierota and Małecka, 2004a; Sierota et al., 2007). The method embraces both: biotechnological aspects, that is, biological preparation with the competitor which effectively controls the pathogen in 3D soil space, and elements of environmental engineering, that is, introduction of more resistant deciduous tree species into the area of treated coniferous trees. Changes occurring in soils, sites, and stands subject to the artificial gap method of stand reconstruction are comparable with those naturally developing in existing gaps which are not associated with the pathogen’s activity (Sierota, 2011b).

CONCLUSIONS

Forest plantations on post-agricultural soils in Poland are artificial communities. Diseases and other harmful effects that occur in these plantations reflect natural adaptation resulting from multi-directional impacts of the forces of nature. These adaptive changes, however, do not follow the goals of forest management and do not introduce advantageous effects from the anthropogenic point of view. The occurrence of *H. annosum* in plantations naturally enhances reconstruction of monoculture stands, but on the other hand, the pathogen increases mortality of numerous trees in subsequent rotations and also adds to CO_2 emission by leading to root decomposition (Sierota, 2012a). Therefore, creation of stable and pest-resistant forests on post-agricultural lands is not possible without properly-directed management efforts at each and every stage of stand development. The biological method of root rot prevention in threatened stands, with special reference to use *P. gigantea* and similarly acting preparations, plays a fundamental role in this concept (Rykowski, 1990; Sierota, 1995, 1998a; Małecka et al., 2012). In view of the above, polish forestry has high expectations for the use of European Union registered isolates in registered preparations.

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