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The use of herbicides to regulate weeds in forest nurseries and crops in Poland

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Abstract

Weeds competing with seedlings of trees for nutrients, moisture, light and space, drown out their growth in nurseries and forest crops. Currently, in forestry, weed control is mainly carried out in forest nurseries, less often during the preparation of the area intended for afforestation, but sporadically in forest crops. The most important species of weeds threatening seedlings of forest trees include *Senecio vulgaris, S. silvaticus, Deschampsia caespitosa, Pteridium aquilinum, Agropyron repens, Calamagrostis epigeios and Equisetum arvense.*

In Poland, herbicides have the largest share (about 50%) in the sale of plant protection products, but the scale of their use in forests is small, compared to agriculture. In 2012, 915 herbicides were registered in the country, out of which only 14 products (0.5%) were for use in forestry. In the years 1999–2019, 31 herbicides were registered for the protection of forest nurseries and crops, which included 13 active substances belonging to 11 chemical groups, of which 9 active substances have been used up to now. Most herbicides (15–16) were used in the years 2004–2006, the lowest in 1999–2000 and in 2014 (4 products). The most popular active substance has been glyphosate contained in 18 products.

Key words

herbicides, active substances, forest nurseries, weed control, forest protection

Introduction

Along with domestication of some plants and their cultivation in the fields, attention was paid to problems related to the emergence of undesirable vegetation (Holm et al. 1997; Adamczewski 2011). Weeds belong to the plants with low life requirements, characterized by high resistance to adverse climatic and soil conditions, including meteorological conditions, rapid growth and development as well as high regenerative abilities as well as fast breeding rate (Kuester et al. 2014). The prevalence of weeds over cultivated plants is therefore related to their specific biological properties, which means that they compete for nutrients, humidity, habitat and light (Gorzelak 2000; Maxwell and Luschei 2004). In addition, the presence of weeds in crops and the shading they cause, affects the lower temperature of the soil and contributes to the reduction of the intensity of microbiological processes. Thus, yield reduction is a direct result of the competition of weeds with plants grown for nutrients, light and water. In addition, pests and diseases related to weeds and substances released

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by weeds may cause a threat to forest plants (Gorzelak 1998; Maxwell and Luschei 2004). Therefore, in order to obtain good results in plant production, it is necessary to apply appropriate care treatments, for example, to fight weeds.

Conducting a chemical fight against undesirable vegetation is in some cases a necessity that leads to greater productivity of farm fields and forest habitats (Oerke and Dehne 2004; Oerke 2006)). Economic losses caused by weeds are significant. It is assumed that in climatic and soil conditions close to Poland, they are greater than losses caused by pests and diseases together (Oerke and Dehne 2004). The amount of losses in the yield of crop plants depends on the climatic conditions and on the crop (Peters et al. 2014). They are the highest in tropical climate conditions (above 50%), and slightly lower in moderate climate conditions (on average around 20%) (Oerke and Dehne 2004; Peters et al. 2014).

Weed eliminating treatments were already used in antiquity, and for this purpose, salt and ash were used (Kraehmer et. al. 2014). However, the beginnings of selective control of unwanted vegetation with the help of chemical compounds dates to the second half of the 19th century, thanks to the work of the French botanist and phytopathologist Alexis Millardet (Ainsworth 1981). At the turn of the 19th and 20th century, many new chemical compounds such as sulfuric acid, iron sulphate, copper nitrate, ammonium and potassium salts, sodium nitrate and ammonium sulphate were introduced to the fight against weeds. Some of these compounds were used in significant quantities until the middle of the 20th century (Baker 1974). In addition, at the beginning of the 20th century, aqueous solutions of chlorates were used, whereas in forestry, sodium chlorate was used for the first time in 1928 to control blueberry (*Vaccinium myrtillus* L.) (Holm et al. 1997). The first widespread herbicide was the compound 2.4 D (short for the name 2,4-dichlorophenoxyacetic acid), introduced into agriculture after the Second World War, which stimulates plants to uncoordinated growth. This compound enabled the selective control of dicotyledonous weeds and although it was discovered more than 70 years ago, it is still very commonly used in plant protection.

The use of herbicides, as well as other plant protection products, has its advantages and disadvantages, hence it is necessary to analyse the potential benefits and the possibility of hazards that arise from the use of herbicides (Maxwell and Luschei 2004). The most important advantages of herbicides include their high efficiency, ease of use on large surfaces at relatively low cost and the possibility of destroying weeds already in the earliest stages of development of the crop. However, the main disadvantage of using herbicides is the possibility of damage to crop plants and the resistance of weeds. In addition, weed control may negatively affect ecosystem functions, interfere with soil processes and existing food dependencies between fauna, flora and microflora. Weeds have a big impact on the development of bacteria and other soil microorganisms, which determine the fertility of soil, and are the place of development and existence of insects, birds and small mammals. It should be emphasized that the mentioned disadvantages of the use of herbicides are usually associated with their improper use. Compliance with the recommendations of producers of preparations and principles of good plant protection practice minimizes the risk of negative effects. Due to the fact that the weeds appearing in low intensity may not adversely affect the cultivated species or have only a slight impact, their chemical control is not always justified. For this reason, the term ‘weed control’ is replaced by the term ‘weed regulation’, which means maintaining the number of weeds at an acceptable level, not threatening cultivated species (Dobrzański and Adamczewski 2009; Łukaszewicz 2013).

The aim of the work is to present qualitative changes related to active substances contained in herbicides’ used in the protection of nurseries and forest crops, including their activity in the plant. The focus was on the years 1999–2019 due to unusually dynamic changes in the European and Polish legislation regarding the number of pesticides authorized for use in agriculture and forestry.

The analyses used lists of plant protection products recommended for using in forestry, registers of plant protection products made available by the Ministry of Agriculture and Rural Development and other scientific publications related to activities undertaken in the protection of forest nurseries.

The most important species of weeds in nurseries and forest crops

Generally, weeds can be classified into two classes: monocotyledones – *Monocotyledones* (grasses, sedges, sieves and others) and dicotyledons – *Dicotyledones* (glaucous, hypericaceae, complex and others) (Łukaszewicz 2013). This division is important in the weed control, especially if chemical agents are used for individual classes of plants (Kraehmer et al. 2014). Forest crops are established in various areas, and depending on this, we can present typical forest weeds and those associated with field, meadow and pasture vegetation, as well as those related to anthropogenic areas (post-mining, glade, etc.). However, due to the length of development, we divide the weeds into short-lived (annual and biennial plants) and perennials, which have the ability to reproduce vegetatively.

Gorzelak (1998) considered the biggest threat to nurseries to be weeds such as common barnyard grass (*Echinochloa crus galli* (L.) P. Beauv.), hairy crabgrass (*Digitaria sanguinalis* (L.) Scop.), pearl millet (*Setaria glauca* (L.) P. Beauv.), yellowcress (*Rorippa islandica* (Oeder) Borb.) and birdeye pearlwort (*Sagina procubens* L.). In turn, Łukaszewicz (2013) for short-lived weeds most often found in forest crops in the first years after soil preparation included species of the genus: groundsel or old-man-in-the-Spring (*Senecio* spp.), *Erigeron* spp. and apetalous sandwort (*Moehringia trinervia* (L.) Clairv.) and lthistle (*Cirsium lanceolatum*) (Savi.) Ten.). Among the perennial weeds commonly found in forests, he listed swallowwort (*Chelidonium majus* L.), common buttercup (*Ranunculus acris* L.), tufted hairgrass (*Deschampsia caespitosa* (L.) P. Beauv.), common yarrow (*Achillea millefolium* L.), or long runners like couch grass (*Agropyron repens* (L.) P. Beauv.), bushgrass (*Calamagrostis epigejos* (L.) Roth) and horsetail (*Equisetum arvense* L.).

Dixon and Clay (2004) divided the most disruptive weeds occurring in nurseries depending on the method of seedling production. According to him, cultivations refurbished with cuttings with an open root system are most endangered by the following annual weeds: groundsel (*Senecio vulgaris* L.), annual Kentucky bluegrass (*Poa annua* L.), field violet (*Viola arvensis* Murr.) and perennial: couch grass (*Elymus repens* (L.) Gould), field horsetail (*Equisetum arvense* L.), creeping yellowcress (*Rorippa sylvestris* (L.) Besser). In the case of crops regenerated with cuttings with a container-grown system, the most troublesome weeds are the common liverwort (*Marchantia polymorpha* L.), the procumbent pearlwort (*Sagina procubens* L.) and the marsh cudweed (*Gnaphalium uliginosum* L.).

The use of herbicides in forestry

In Poland, at the end of 2018, 2224 plant protection products placed on the market, of which herbicides accounted for 41.1%, including 0.5% of herbicides used in forestry (Fig. 1). At the same time, 4.0% of herbicides were allowed to be used in minor crops. In this group, only 0.3% are herbicides for use in minor forest crops, that is, in nurseries, renewals, afforestation and seed plantations of forestry species of coniferous and deciduous trees.

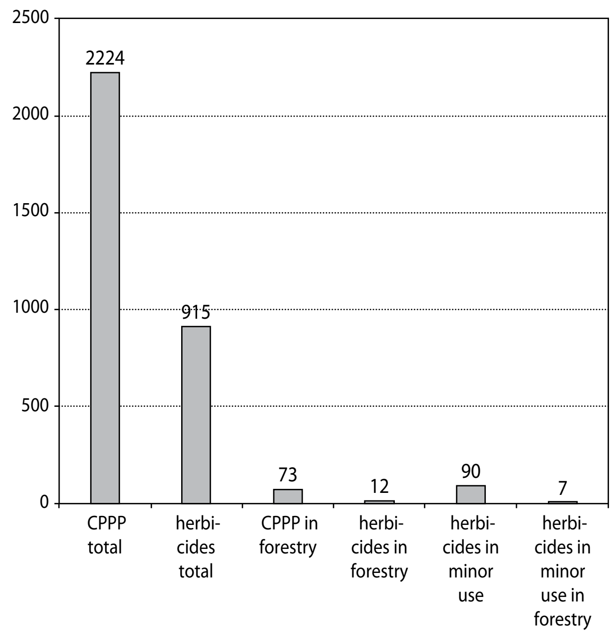

Figure 1. The number of chemical plant protection products (CPPP) with particular emphasis on herbicides used in forestry (as on 31/12/2018)

In forests, most herbicides were used in the 1960s and 1970s. At the time, herbicides were used, among others in beech stands (*Fagus sylvatica* L.), when in the years of seed sowing, it was necessary to prepare the soil (Gorzelak 2000; Vasic et al. 2012). Herbicides were also used in poplar plantations, as well as in coniferous and deciduous conifers, mainly for the elimination of sprouts or young natural regeneration of birch (*Betula pendula* Roth.) and poplar (*Populus tremula* L.). Sometimes during the cleaning of late or early thinning chemically, single deciduous trees were removed by applying a herbicide in the form of the so-called toxic ring of the herbicide (Gorzelak 1994). The above chemical treatments using herbicides are currently not performed and have largely been replaced by the mechanical removal of weeds.

Currently, the scale of using herbicides in forests is small compared to the agricultural sectors. This is possible due to the fact that the integrated protection of forest crops against weeds includes various mechanical and biological treatments that significantly reduce the need for using herbicides (Łukaszewicz 2013). The aim of the chemical treatment is not to completely eliminate herbaceous plants, but to limit them so that seedlings could go beyond their level of growth and are not drowned out. Decisions on the use of herbicides are made when it is not possible to apply mechanical (proper soil preparation before planting or mowing) or biological (use of cover crops) methods of weed control. The chemical control of weeds in the preparation of soil for cultivation is applied in heavily weedy areas (over 60% of the area). This method of weeding the surface usually takes place in the year preceding the renewal, which results in the optimal development of seedlings of forest trees, especially within two years after planting (Dixon and Clay 2004). However, the control of weeds in existing crops is recommended in the case of direct threat to the growth and life of trees, especially by monocotyledonous grass, air raids and tree and bush growth.

In addition to land designated for forest nurseries or crops, weed control sometimes occurs on post-fire areas due to the emergence of species of expansive grasses: true sedges (*Carex* spp.) and purple moor-grass (*Molinia caerulea* (L.) Moench.), whose development inhibits growth seedlings of forest trees (Gorzelak 1994).

Active substances of herbicides used in forestry

Herbicides are very numerous and diverse group of compounds, both in terms of chemical structure as well as impact on plants; hence, their classification is complex (Forouzesh et al. 2015). They can be divided according to various criteria, for example (Vencill and Ambrust 2002):

- date of use for the crop: pre-sowing, pre-emergence and post-emergence herbicides;
- way of picking up weeds: herbal, foliar, soil and foliar herbicides;
- selectivity: non-selective herbicides destroying all plants and selective: damaging monocotyledonous or dicotyledonous plants;
- chemical structure: organic and inorganic herbicides from 75 chemical groups;
- displacement in the plant: systemic and contact herbicides;
- mechanism of action: interfering with or blocking life processes of plants;
- their main purpose: defoliants (to destroy leaves), desiccants (to dry leaves and stalks) and arboricides (to destroy trees and shrubs).

In the 60s and 70s of the last century, the active substances of herbicides were derivatives of hydrocarbons, nitrile compounds, carboxylic acids, aryl-fatty acids and carbonic acids as well as phenols and amines (Holm et al. 1997).

New generations of herbicides are characterized by a higher efficiency of action, the use of lower doses applied per unit of weed areas, which in turn allowed for organizational and technical improvement of chemical weed control, its higher effectiveness and safety of use (Matyjaszczyk and Sobczak 2017). There is also a tendency to use mixtures of herbicides (multicomponent herbicides), which is related to the desire to broaden the range of weed species to be controlled and to increase the safety of crops and the environment.

According to the HRAC (Herbicide Resistance Action Committee), as of 31/12/2018, 281 active substances of herbicides belonging to 63 different chemical groups are known (https://hracglobal.com/tools/classification-lookup, access December 31, 2018). From this in Poland, 119 active substances are included in 52 chemical groups (Matyjaszczyk and Sobczak 2017; Regulation 540/2011).

Nowadays, herbicides are among the most commonly used pesticides. Statistical Yearbook of Agriculture (2017) states that in 2016, more than 26,400 tons of plant protection products were sold in Poland (calculated as active substances), including about 12,693 tons (52%) of herbicides, growth inhibitors and moss killers.

In the last 20 years, 13 active substances of herbicides belonging to 11 chemical groups were used in forestry, of which 8 active substances are used up to now (Tab. 1).

Table 1. Chemical characterization of herbicides used in Polish forestry in the years 1999–2019

Chemical group	Active substance	Year of		
		registration in the world	registration in Poland	withdrawal or in use
Acetamides	dimethenamid	1996	2000	in use
Aminophosphonates	glyphosate	1974	1979	in use
Benzonitriles	dichlobenil	1960	1973	2009
Chloroacetamides	metazachlor	1976	1985	in use
Diphenyl ethers	aclonifen	1983	2018	in use
Imidazolinones	imazapyr	1981	1990	2003
Naphthoquinones	quinoclamine	2003	2014	in use
Derivatives of bipyridils	paraquat	1958	1967	2007
Aryl phenoxypropionic acid derivatives	fluazifop-P-butyl	1980	1984	in use
	propaquizafop	1987	1996	in use
Sulfonylureas	foramsulfuron	2002	2002	in use
	iodosulfuron-methyl-sodium	1999	2000	in use
Triazines	simazine	1955	1965	2007

Herbicides used in forestry have many different mechanisms of action related to metabolism and the growth and division of cells (Vasič et al. 2012). Benzonitriles are inhibitors of cell wall synthesis, acetamides and chloroacetamides – fatty acid synthesis inhibitors, arylphenoxypropionic acid derivatives – lipid biosynthesis inhibitors, and sulfonylureas – aminoacid synthesis inhibitors. The metabolism of plant cells is also associated with imidazolinones that inhibit the action of ALS/AHAS synthase, aminophosphonates inhibiting the action of 5-endopyrogrone-3-phosphosemic acid synthase (EPSP) and biphenylethers, which are inhibitors of protoporphyrinogen oxidase. Bipyridyl and triazine derivatives are associated with the inhibition of photosynthetic systems. The mechanism of action of quinochlamine belonging to the naphthoquinones is not yet known.

The oldest active substance – triazines and bipyridyl derivatives – were discovered in the 1950s and were used until 2007 (Ainsworth 1981; Holm et al. 1997; Vencill and Ambrust 2002; Adamczewski 2011). Benzonitriles were withdrawn 2 years later, while imidazolinones, placed in the market in the early 1980s, were withdrawn less than 10 years later, due to the negative impact on the environment. Active substances synthesized chemically or discovered by studying the phenomenon of allelopathy in the 1970s: chloroacetamides and aminophosphonates, 1980: diphenylethers, imidazolinones, arylphenoxypropionic acid derivatives, 1990: sulfonylureas and acetamides, and in 2000: sulfonylureas and naphtoquinones still remain in use.

Quantitative analysis of active substances of herbicides used in the years 1999–2019 in forestry showed that glyphosate was the most commonly used during all these years (Tab. 2). Quinochlamine was used for

Table 2. Herbicides recommended for use in Polish forestry in the years 1999 – 2019

The name of the active substance	The name of herbicide
Aclonifen	Bandur 600 SC
Quinoclamine	Mogeton 25 WP
Dichlobenil	Casoron 6,75 GR
Fluazifop-P-butyl	Fusilade Super 125 EC, Fusilade Forte 150 EC Trivko
Foramsulfuron + iodosulfuron-methyl-sodium	Logo 310 WG
Glyphosate	agrofosat 360 SL, Agrosar 360 SL, Avans 330 SL Avans Premium 360 SL, Glifocyd 360 SL, Glifogan 360 SL, Glifoherb 360 SL, Glifopol 360 SL, Glyfos 360 SL, Perzocyd 280 SL, Resolva Total, Rodeo 360 SL, Roundup 360 SL, Roundup Active 360, Roundup Flex 480, Roundup Max 2, Roundup Powermax 720, Roundup Ultra 360 SL
Imazapyr	Arsenal 250 SL
Metazachlor + dimethenamid	Butisan Duo 400 EC
Paraquat	Tarol 200 SL
Propaquizafop	Agil 100 EC, Galeon 100 EC
Simazine	Azotop 50 WP

13 years (2004–2009, 2012–till date), and for 11 years (1999–2009) dichlobenil and propachizafop were used. For the shortest used active substances should be simazine (only in 2004) and paraquat (2004 and 2006–2007) and formasulfuron (2015–2017), as well as imazapyr (2002–2006). Two-component herbicides have only been used since 2018.

In the years 1999–2019, a total of 31 herbicides were registered for use in forestry (Tab. 3). Two of them contained a combination of two active substances, the others contained one active substance, 18 of which were based on glyphosate. These agents were SL formulations (water-soluble concentrates), WP (powders for aqueous suspension), GR (granules), WG (granules for preparing an aqueous suspension), EC (concentrates for making an aqueous emulsion).

Over the past 20 years, 2 to 16 herbicides have been registered each year (Tab. 3). The highest number of these preparations was held by the State Forests in 2004–2006. In the subsequent years, until 2014, a gradual decline in the number of herbicides used in forestry was observed, which should be related to the adoption by Poland of EU legal regulations (including Directive 91/414/EWG), which significantly increased the requirements for pesticides in terms of impact on human and animal health and the natural environment (Matyjaszczyk 2011a, b; Karmiłowicz et al. 2018). This resulted in a large increase in costs associated with the

Table 3. Number of herbicides including active substances used in forest protection in Poland in the years 1999–2019

Year	Systemic							Contact		Contact – systematic		Unknown	Total
	glyphosate	fluazifop-P-butyl	imazapyr	propaquizafop	foramsulfuron	metazachlor + dimethenamid	foramsulfuron + iodosulfuron-methyl-sodium	paraquat	aclonifen	dichlobenil	simazine	quinoclamine	
1999	2	1	0	0	0	0	0	0	0	1	0	0	4
2000	2	1	0	0	0	0	0	0	0	1	0	0	4
2001	3	1	0	0	0	0	0	0	0	1	0	0	5
2002	4	1	1	0	0	0	0	0	0	1	0	0	7
2003	4	1	1	0	0	0	0	0	0	1	0	0	7
2004	11	0	1	0	0	0	0	1	0	1	1	1	16
2005	11	0	1	1	0	0	0	0	0	1	0	1	15
2006	11	0	1	1	0	0	0	1	0	1	0	1	16
2007	8	0	0	1	0	0	0	1	0	1	0	1	12
2008	8	0	0	1	0	0	0	0	0	1	0	1	11
2009	6	0	0	1	0	0	0	0	0	1	0	1	9
2010	5	0	0	1	0	0	0	0	0	0	0	0	6
2011	4	0	0	1	0	0	0	0	0	0	0	0	5
2012	4	0	0	2	0	0	0	0	0	0	0	1	7
2013	3	0	0	1	0	0	0	0	0	0	0	1	5
2014	2	0	0	1	0	0	0	0	0	0	0	1	4
2015	2	0	0	1	1	0	0	0	0	0	0	1	5
2016	3	0	0	0	1	0	0	0	0	0	0	1	5
2017	6	2	0	0	1	0	0	0	0	0	0	1	10
2018	8	2	0	0	0	1	1	0	1	0	0	1	14
2019	8	2	0	0	0	1	1	0	1	0	0	1	14

introduction of a plant protection product on the market and use. As a consequence, the availability and diversity of these agents authorized for use in Poland has significantly decreased (Karmiłowicz et al. 2017; Matyjaszczyk et al. 2019; Skrzecz and Perlińska 2018). This was accompanied by a reduced interest of producers in introducing funds for marketing and use in forest areas, which constitute a much smaller market, in comparison with agricultural crops (Skrzecz and Perlińska 2018). Since 2014, there has been an increase in the number of herbicides introduced for use in forestry. The reason for this increase is the introduction in 2009 of Regulation (EC) No 1107/2009 of the European Parliament and of the Council, which gave the opportunity to apply for the extension of the authorization of a plant protection product registered in a Member State for minor uses not yet covered by this authorization (Matyjaszczyk 2017). On this basis, the State Forests in the recent years have obtained permission to use several plant protection products, including herbicides, in minor crops, that is, in nurseries, seed plantations of forest trees and in renewals and afforestation (Skrzecz and Perlińska 2018).

Summary

The scale of use of herbicides in forests is small compared to the agricultural sectors. It is caused due to the fact that in the integrated protection of forest crops against weeds, first of all, there are various mechanical treatments that limit the need to use herbicides. Chemicals are used primarily in forest nurseries and before preparing the soil for forest crops, and less frequently in forest crops – only in the case of direct threat to the trees by weeds, especially monocotyledonous grass (sand reed or turf dandelion). In the case of conifer species, it is recommended to use chemicals during soil preparation before cultivation, rather than during its growth.

In the years 1999–2019, 31 herbicides were registered in the forestry, including 13 active substances. Two herbicides contained two active substances, 29 each, of which 18 were based on glyphosate. At that time, 2 to 7 active substances and 4 to 16 herbicides containing these were registered each year. The lowest number of herbicides (4–5) were recorded in 1999–2001 and 2013–2016, while the highest in 2004–2006. The increase in the herbicide range for use in forests was observed in 2017 – 201 results from the possibility of their registration for minor crops, which include nurseries and forest crops as well as seed plantations of forest trees.

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