

Review Article

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Plantago lanceolata – An overview of its agronomically and healing valuable features

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Abstract: This article gives an overview of the widely distributed herb ribwort plantain (*Plantago lanceolata*). Currently, this plant is mostly grown in grasslands, rarely in arable land, and its secondary metabolites are used in medicine. Studies cited in the article indicate its very rapid growth and deep rooting in the soil, which results in high drought tolerance and uptake of valuable nutrients from deep soil layers. An intensive symbiosis with various mycorrhizal fungi is characteristic of plantain for a high capacity for nutrient and water appropriation. It is also characterized by different contents of iridoid glycosides like aucubin and catalpol in shoots and roots of different varieties. The use of *P. lanceolata* is discussed on permanent and non-permanent grasslands where agriculturally specific varieties have been developed for grazing animals showing positive health effects in them. Information is provided on the cultivation of ribwort plantain, including studies on sowing and fertilization, the yield and infestation of the plant with pathogens, and the occurrence of iridoid glycosides in the plant. In addition, information is included on pests that threaten the plant's cultivation.

Keywords: arable land, cultivation, grassland, medical properties, ribwort plantain

produced [1], but also in terms of preserving soil fertility and water quality, the targeted promotion of biodiversity, and climate protection in order to be classified as sustainable cropping systems [2]. To achieve these goals in arable farming, priority is given to technical measures such as reduced tillage, targeted use of fertilizers and pesticides by means of digitalization and precision farming, and by providing new varieties through breeding [3]. Actually, innovations can possibly also be achieved for the development of sustainable arable farming systems through the targeted integration of plant species that have not previously been used in farming systems or have only been used to a limited extent.

Ribwort plantain (*Plantago lanceolata* L.) is a crop primarily grown in grasslands for feeding animals or in arable fields for manufacturing drugs for medicinal purposes, e.g. cough syrup and herbal candies [4]. In addition, in the last 10 years, a number of articles have been published highlighting the special services of ribwort plantain in grasslands for the environment and for livestock [5,6] and also in the arable field as main and intermediate crop [7–9]. To sum up, the aim of this article is to summarize the exceptional features and services of ribwort plantain for animals and humans and to illustrate its importance in farming systems.

1 Introduction

Farming systems must meet extensive requirements not only in terms of yield and quality of the crop products

2 Characteristics of ribwort plantain

Plantago lanceolata, narrow-leaved plantain [10], is one of over 250 species of genus *Plantago* L. (Plantaginaceae) [11]. It is common in roadside grassland [12] with a world-wide distribution, perennial, rarely annual or biennial plant, with a mass of surface fibrous roots (5–10 cm long) and often a few deep roots, and is wind-pollinated. The above-ground part of the plant is characterized by alternate basal leaves up to 40 cm long including the petiole. The blades of the leaves are in lanceolate to lance-oblong shape (0.5–3.5 cm wide) entire or slightly

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toothed. Moreover, ribwort plantain has several scapes, which are visibly higher than the leaves (up to 45 cm), spikes are densely flowered, ovoid conic at first, and at maturity becomes cylindric and 2–8 cm long. It has scarious corolla lobes (2.0–2.5 mm long), four stamens, and capsules up to 4 mm long, which can hold 1–2 ellipsoid brown or shiny black seeds [13]. Ribwort plantain requires long days to induce flowering and takes place from May to August (seasons in the Northern Hemisphere), but it can even flower in April and continue till the first frosts [14].

According to Bond et al. [14], ribwort plantain prefers soils with a pH from 6.5 to 7.3, among vegetation that is mown or grazed, for fine - to medium-textured soils, moderately rich in organic matter. Ribwort plantain can be also grown in very poor quality soils; for example, serpentine soils, containing high concentrations of heavy metals such as Zn, Ni, and Cr. Thanks to the high tolerance of eco-physiological conditions, ribwort plantain may have also potential use in the recultivation of soils contaminated with heavy metals [15]. Due to the possible occurrence of *P. lanceolata* in many soil environments, increasing the stomatal density and, in the meantime, reducing the stomatal opening width in leaves was the plant's response to environmental stress observed. Therefore, these special properties of ribwort plantain can be used as a bioindicator [16].

The ability of *P. lanceolata* to take up nutrients and water from the soil is largely determined by the rooting depth and the rooting intensity of the soil. The limited studies available to date on the root growth of *P. lanceolata* in arable land show that this plant has a rapid and very deep rooting ability. Reiter et al. [17] used sole-cropped ribwort plantain as a reference crop for estimating symbiotic N_2 fixation of red clover; this plant was sowed on 1 April each year, was cut on three dates, and recorded rooting after around 125 days of growth each time. On this long-term arable land, a plowed loess soil (Haplic Luvisol) near Goettingen, Germany, a total root length of ribwort between 8.5 and 8.7 km per m^2 down to a depth of at least 1 m was found (Figure 1).

For herbaceous plants including ribwort plantain, it is very important to maintain mutualistic relationships with arbuscular mycorrhizal fungi [19]. It is based on the fact that the host plant provides carbon to the fungus in return for supplying water, phosphorus, and trace elements from the soil [20]. This is possible because plant roots that are in symbiosis with mycorrhizal fungi have a larger surface area and so they are relatively thicker than normal roots and can effectively penetrate the soil and ultimately provide the plant with valuable nutrients [21]. Associations of plants with fungi also often result in increasing plant growth and reproduction [20]. In addition,

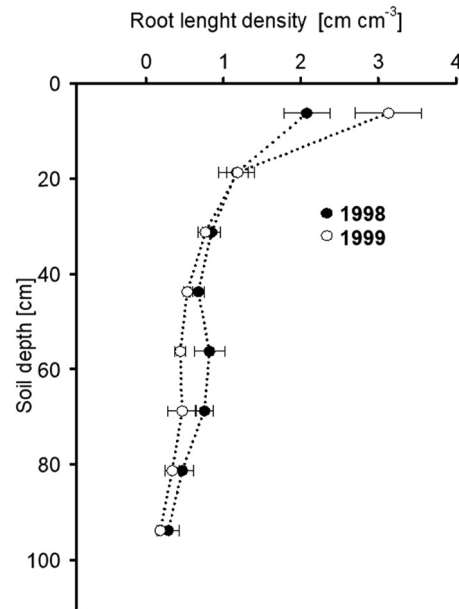


Figure 1: Root length density and the total root length in sole cropped *P. lanceolata*, determined by taking 2 soil columns down to 1 m, rinsing the roots over a close-meshed sieve, and recording the root length with an image analysis system [17] in loess on August 4 in 1998 and August 2 in 1999 [18].

P. lanceolata symbiosis with vesicular-arbuscular mycorrhizal fungi affects changes in the chemical composition of the plant including secondary metabolites [22].

Under natural conditions, ribwort plantain grows in clearings, pastures, roadside strips, and meadows [23], and it is the most common on neutral to alkaline soils [13]. It prefers light and airy soils, loamy-sandy, or black earth [23], and its occurrence is estimated up to 800 m above sea level [14]. This plant occurs in New Zealand and is often used as a component of mixed pastures [24].

3 Cultivation and utilization of ribwort plantain

3.1 Utilization as a medicinal and aromatic plant

It is worth mentioning that *P. lanceolata* is nowadays mainly used for medical purposes [4] and has a wide range of applications in many aspects. Currently, about 45 patents are registered based on the potential of plantain leaves, but still, only a few of them are in use [25].

The unusual properties of medicinal products made of ribwort plantain leaves were known in antiquity and

were considered as a remedy for different ailments [26]. Nowadays, they are used mainly in inflammation of the upper respiratory tract and accelerate skin regeneration, showing bactericidal and anti-diarrheal effects (Table 1). It can also be used against insect and snake bites, toothaches, or as an immunity enhancer [25–29]. Haddadian et al. [30] also mentioned that the World Health Organization based on clinical data recommended the *Plantago* genus for use in reducing blood sugar that has increased after a meal, irritable bladder syndrome, diverticulitis, constipation caused by the duodenal ulcer, hemorrhoids, and to reduce the risk of coronary heart disease as an adjunct to diet in treating hypercholesterolemia. Thanks to the known above-average medicinal properties of *Plantago*, Fons et al. [31] summarized 20 years of experiments under experimental culture conditions concluding the potential use of these plants as future drug candidates.

The plant parts that interest pharmaceuticals the most are husks, or shredded or fully dried leaves [25]. Herbal substances and herbal preparations of ribwort plantain are widely available in Europe and have an established position in the market. They are common in many forms: dried leaf, whole or comminuted or powdered, dry extract, liquid extract, soft extract, expressed plant sap, scape, herbal substance, and syrup. Moreover, leaves of *P. lanceolata* also have a very wide medicinal use in a mixture with other herbs, such as *Salviae folium*, *Liquiritiae radix*, *Thymi herba*, *Sambuci nigrae flos*, *Matricariae flos*, *Foeniculi fructus*, *Polygonii avicularis herba*, *Serpylli herba*, and *Foeniculi aetheroleum*. All the possibilities of this plant have been very well documented in traditional use [32].

The unusual properties were also observed in veterinary medicine. Studies conducted so far have indicated the possibility of using this plant as an additive to rainbow trout (*Oncorhynchus mykiss*) feed. After 90 days of basic diet with the addition of plantain’s methanol extract and fulfillment of required breeding and experimental criterias, positive health effects were noted. Scientific results of the

experiment proved the positive effect of the plant extract feed supplement on the growth and immunostimulatory properties in rainbow trout breeding [28]. In addition, according to Olumi et al. [33], ribwort plantain water-soluble extract made of aerial plant parts can be used medicinally as an ointment ingredient in burros (*Equus asinus*) tendinitis caused by bacterial collagenase. The ointment was characterized by an anti-inflammatory effect against this disease and it accelerated the healing of tendons owing to acteoside, a phenylethanoid, which inhibits arachidonic acid in the cyclooxygenase pathway. Their special properties have also been appreciated in the cosmetics industry. There are studies conducted by many European companies proving the wide possibilities of application in various products: lotions, creams, and solutions for spa use. Research conducted by German scientists proves that the water extract containing *P. lanceolata* has antibacterial, anti-inflammatory properties, and reduces existing skin impurities; at the same time, it optimizes the appearance of skin [25].

Besides, essential oil components can also be produced from the ribwort plantain material, which are used in the food industry as food flavourings. The essential oils constituting the plant leaves were extracted by hydrodistillation, and the aromatic compounds were then studied by GC-MS and GC-FID techniques. The main aromatic constituents of ribwort plantain leaves are apocarotenoids 1.5–2.3%, which have intense aroma, fatty acids 28.0–52.1% (of which palmitic acid is 15.3–32.0%), oxidized monoterpenes 4.3–13.2% (linalool 2.7–3.5%), aldehydes and ketones 6.9–10.0% (pentyl vinyketone 2.0–3.4%), and alcohols 3.8–9.2% (1-octen-3-ol 2.4–8.2%) [34].

It is necessary to underline that during the growth ribwort plantain produces defence metabolites, including aucubin, catalpol, and two iridoid glycosides [35]. According to Bowers et al. [36], genotypes of *P. lanceolata* have a significant impact on the iridoid glucosides concentration in the plant leaves. A trial conducted in the experimental garden clearly indicated that among the five vegetatively

Table 1: Documented health benefits of ribwort plantain

Effect	Tested population	Reference
Inflammation of the upper respiratory tract	People	[28]
Accelerate skin regeneration	People	[26]
Anti-bactericidal	People	[25]
Soothes the effects of insect and snake bites	People	[25]
Toothaches	People	[29]
Immunity enhancer	People and animals	[25]
Feed ingredient that helps growth properties	Animals	[28]

propagated genotypic cultivars of ribwort plantain (collected outside Providence, RI, USA), each had a different concentration of iridoid glycosides. A similar study was conducted by Al-Mamun et al. [37], where 25 ecotypes of ribwort plantain were collected in northern Japan and two commercial varieties, Grassland Lancelot and Ceres Tonic, both obtained from New Zealand. The results showed that the content of aucubin concentration in leaves in commercial cultivars was for Grassland Lancelot 0.65% and Ceres Tonic 1.78%. This was comparable or even lower with the 25 ecotypes used in the trials in which the value varied between 0.98 and 4.18%. The concentration of catalpol was only 0.004% in Grassland Lancelot, while none was detected in Ceres Tonic. The highest concentration of this component was found in one of the other 25 tested ecotypes and was only 0.121%. In comparison, Tamura and Nishibe [38], in their study conducted on the previously mentioned commercial varieties, obtained slightly different values. From spring to autumn, aucubin concentration in ribwort plantain leaves was from 1.0 to 2.7% in Ceres Tonic and from 2.1 to 4.8% in Grasslands Lancelot. Over the season, these increases were gradual but, during midsummer, the content was relatively constant. The level of acteosides over the course of the growing season ranged from 1.5 to 4.1% in Ceres Tonic and from 3.5 to 7.1% in Grasslands Lancelot. During the summer, the content was steady and decreased to 1.9% in Ceres Tonic and to 2.5% in Grasslands Lancelot. In the cultivars, the concentration of catalpol during the growing season was low, fluctuating between 1 and 2% of dry matter (DM). According to Al-Mamun et al. [37], the discrepancy in the concentrations of aucubin and catalpol in the same *P. lanceolata* cultivars might be due to the different ages of plant parts and the extraction methods. A significant difference in aucubin and catalpol contents in the dry matter of ribwort plantain leaves was shown in an experiment conducted by Dietz et al. [39], who compared two different cultivars: Libor and Arterner. During the trial period from June to the end of September, the Arterner variety showed a higher maximum value in the aucubin content at 3.5% DM. The maximum content of this component in Libor cultivar was 0.7% lower. In both cases, the leaf content of catalpol was below 1% DM. The authors also mentioned that the main allelochemicals (aucubin and catalpol) of ribwort plantain are also present in roots, but so far, not enough comparative studies have been made on different varieties (Table 2).

Due to the special features of defence metabolites, they provide the plant against an herbivore deterrent and pathogens protection because of toxins present in its biomass. In addition, they can be an oviposition stimulant for specialized insects [35]. The amount is stimulated by environmental factors in accordance with Miehle-Steier et al. [40];

Table 2: Fooder varieties of *P. lanceolata* L. available in the world seed market [42]

Variety	Breeder
Agritonic	Grasslands Innovation (NZ)
Boston	Norwest Seed (NZ)
Ceres Tonic	PGG Wrightson Seeds (NZ)
Ceres Tonic Plus	PGG Wrightson Seeds (NZ)
Endurance	Seed Force (NZ)
Grasslands Lancelot	Grasslands Innovation (NZ)
Hercules	Pastoral improvements (NZ)

for *P. lanceolata*, light and nutrients are the most important. Data obtained from greenhouse experiments showed a direct interaction between the factors mentioned and the occurrence of aucubin in leaves. It was also noted that nutrients were not affected by the aucubin concentrations in the roots (Table 3). In addition, the concentration of aucubin in leaves was approx. 4 times higher, while the catalpol concentration was 2 times higher under good light conditions. It was also noted that during bad light conditions, catalpol was reduced to half despite the high nutrient treatment. Moreover, the high availability of nutrients with light conditions did not affect the production of catalpol. The occurrence of legumes together in plots with *P. lanceolata* did not have any effect on the total iridoid glycosides, aucubin, or catalpol concentrations in leaves. Additionally, light and availability of nutrients were most important in obtaining a high dry matter yield. Both of these factors had a positive effect on the biomass obtained from leaves and roots. By excluding positive lighting conditions, all the above-ground and underground parts of the plant, despite the supply of adequate nutrients, produced less biomass.

The main herbal ingredients in ribwort plantain are i.a. iridoid glycosides (2–3%) containing major compounds such as aucubin and catalpol. Their content depends on the maturity of leaves. Young leaves contain up to 9% of iridoids but older ones had very small amounts [32] and was around 2 times less [36]. In the young parts of the plant, the dominant component is catalpol, while in the older parts, it is aucubin [32,41]. The maximum content of aucubin in *P. lanceolata* occurs

Table 3: Minimum and maximum concentrations of aucubin and catalpol in leaves and roots of ribwort plantain depending on light and nutrient availability [40]

Plant part	Aucubin (mg/g DM)	Catalpol (mg/g DM)
Leaves	4.1–17.9	5.5–12.3
Roots	2.6–21.2	0.9–7.5

in autumn, the lowest before the flowering period (catalpol up to 1% and aucubin from 1 to 3%) [25].

3.2 Permanent and non-permanent grassland

Ribwort plantain is a popular agricultural crop in New Zealand, where the most intensive research is being carried out on its use and influence of its presence in permanent grassland sward. Thanks to the discovered potential of this plant's presence in a grassland sward, breeding lines were selected and currently registered as fodder varieties [42]. In 2016, seven of them were registered (Table 2) and were characterized by a better concentration of mineral components, yield, dry matter, and properties facilitating its mechanical harvest [43] compared to the common plants of this species. Nowadays, ribwort plantain varieties are also components of seed mixtures for the renovation and establishment of permanent grasslands. Moreover, they are also used on arable land in pure stands [42].

The mixture with ribwort plantain can be also a richer source of nutrients for the diet of pasture animals [44] because of the higher digestibility of the organic matter and metabolizable energy content. In addition, it also had a lower fiber content. A diet based on a mixture of herbs, including ribwort plantain and red clover, supported the lamb weight gain in spring, summer, and autumn (average gains were around 250 g per day). In comparison, in the summer, the daily growth of lambs in the same period of time based on the conventional diet with ryegrass/clover mixture was only around 80–150 g per day. So, the daily gain of lamb weight was approx. 70–100 g when fed a diet with ribwort plantain [45]. A similar diet during the dry summer including 20% of this species resulted in higher growth rates of dairy heifers than those fed on pasture [46].

Farmers from New Zealand use ribwort plantain in mixed sward with cyocoria (*Cichorium intybus*), red clover (*Trifolium pratense*), white clover (*Trifolium repens*), and other legumes [5,9,44]. The combination of these plants is a high-quality substitute for ryegrass/white clover pasture, which has a comparable annual production of dry matter. In the Manawatu region (New Zealand), the mixture of seeding rate of 0–60% of ribwort plantain, 20–40% of chicory, 5–20% of red clover, and 0–10% of white clover produced 9–15 t DM/ha a year. A mixture of herbs containing ribwort plantain showed a greater tolerance to drought, which often results in an increase in the production of green

forage during the summer period than a mixture of ryegrass and white clover.

Ribwort plantain leaves are a very good addition to livestock feed, characterized by above-average health values. They can also be used as a substitute for hay in sheep and a replacement for vegetables in animal diets. The results of a study carried out by Guil-Guerrero [47] provide detailed data of the composition of 100 g of fresh young ribwort plantain leaves collected in southeastern Spain (Table 4).

Compared to other fodder crops, ribwort plantain can create more plant material during summer and autumn, which cannot always be used. To solve the problem of excess yield, the plant can be preserved as silage and used later as a supplementary fodder in times of shortage [48]. In order to obtain silage of high quality, it is very important to ensure, e.g. anaerobic conditions and at the same time an appropriate pH [49], which prevents the growth of yeasts and bacteria. An important factor in obtaining good quality silage is also an appropriate harvest time. Delaying it may result in a decrease in the nutritional value of the plant, i.e. in crude protein content [48]. Bariroh [48] also reported that the metabolic energy content of good silage should be higher than 10 MJ ME/kg of DM. Moreover, the crude protein content should be between 16 and 20%, and the digestibility value more than 70%. In the study, the author managed to obtain silage made of *P. lanceolata* with slightly higher digestibility and energy content (MJ/kg DM). Arslan Duru et al. [49] proved that ribwort plantain shows ensiling potential without the addition of other crops as all parameters obtained from its silage show desirable levels in terms of crude nutrient contents and fermentation properties. The

Table 4: Composition of 100 g of ribwort plantain fresh leaves collected in southeastern Spain (mean \pm SD)* [47]

Tested indicators	Results
Moisture (g)	86.6 \pm 13.21
Protein (g)	2.12 \pm 0.27
Available carbohydrates (g)	2.81 \pm 0.44
Fibre (g)	3.71 \pm 0.55
Lipids (g)	0.33 \pm 0.06
Ashes (g)	2.67 \pm 0.59
Vitamin C (mg)	13.6 \pm 1.3
Carotenes (mg)	6.77 \pm 2.7
Nitrate (mg)	34 \pm 4.0
Oxalic acid (mg)	88.2 \pm 39
E (kJ)	92.0 \pm 84

*Mean and standard deviation (SD) are across five different locations; E (kJ): energy content in kilojoules.

authors also stated that ribwort plantain silages contain sufficient lactic acid. Because water-soluble carbohydrates blocked the ammonia formation by preventing proteolysis for the production of lactic acid, resulting in a decrease of pH to 4.0; also a suitable fermentation atmosphere was provided by ribwort plantain.

4 Agricultural management practice of ribwort plantain

The seed sowing rate is approximately 2 kg per ha [21] and according to Rumball et al. [50], the weight of 1,000 seeds of the Ceres Tonic variety is from 1.6 to 1.8 g; therefore, using the sowing rate given by Sadowski [23], around 111 seeds per m² should be sown in the field. Schmidtke [51] and Reiter et al. [17] sowed 800 germinable seeds of ribwort plantain per m² for pure stands and 800 germinable seeds per m² were also used for undersowing of ribwort plantain in potatoes [7]. In a three-year experiment carried out by Kołodziej and Wiśniewski [52] under the conditions of Central and Eastern Europe in Poland (Lubelskie Voivodeship) with a sowing rate of 2–8 kg per ha, the number of leaves per plant varied from 16 to 41, while the average height of inflorescence was from 41.5 to 67.5 cm. The detailed results of this experiment are presented in Table 5.

In this experiment, the amount of dry matter yield of the herb was between 1.6 and 11.7 t/ha, and the amount of harvested plant seeds ranged from 0.25 to 1.14 t/ha (Table 6). The obtained results show that the most optimal sowing rate of ribwort plantain is between 6 and 8 kg per ha.

However, so far, no systematic results are available on the optimal seeding rate of ribwort plantain in pure stands as the main crop or for intercropping in the field as well as for cultivation in pure stands or mixtures with,

e.g. forage legumes. This also applies to the reseeding of ribwort plantain in grasslands [53]. The seeds are often sown in rows every 30–40 cm [23], but Reiter et al. [17] and Schmidtke [51] cultivated ribwort plantain in row spaces of 24 and 18 cm. No light is required for fresh seed germination [13,53]. For rapid establishment and good properties of the plant, the best sowing depth is 1 cm [54], or from 0.5 to 1.0 cm as given by Sadowski [23]. Seed sowing takes place in late March or early April and plant emergence starts after 2–3 weeks [23]. The herbal material consists of leaves and stems. Harvesting can begin in the first year and due to the weak development of plants, it probably should be done only once. In subsequent years, during the flowering period from May to June, harvesting can be done 2–4 times [17,51]. Due to the small size of the leaves and the location near the ground, harvesting is done manually in some experiments [23]. For varieties with upright leaves (e.g. Grassland Lancelot, Ceres Tonic) and intended grazing animals [56], mechanical harvesting is well suited for these genotypes selected for cutting use [17,51]. The leaves should be free of fungal diseases, fully formed, and without petioles. The plantation can be maintained for 4–5 years [23]. Commercial *P. lanceolata* varieties were produced and adapted to New Zealand climatic conditions. In a study by Skinner and Gustine [56], it was proved that none of the improved varieties used in the study, Ceres Tonic and Grassland Lancelot, had sufficient winter hardiness to survive the conditions of the northeastern USA.

Genotypes of ribwort plantain naturally adapted to low temperatures served as materials for the development of experimental lines to select a component of perennial pasture mixtures in temperate regions of the United States. The research resulted in the selection of the PG733 variety having higher frost tolerance properties than the New Zealand varieties. It was then evaluated for release as a commercial variety [57].

Table 5: The length and number of leaves as well as the length of the inflorescence in ribwort plantain depending on the seed sowing rate and cultivation year [52]

Seeding rate (kg/ha)	Number of leaves per plant			Average length of leaves (cm)	Average height of inflorescence (cm)	
	I year (II times harvested-average value)	II year (III times harvested-average value)	III year (II times harvested-average value)		II year	III year
2	26	33	18	23.1	49.5	46.9
4	28	36	16	22.5	58.3	41.9
6	34	41	21	22.6	64.5	52.4
8	26	39	20	23.1	65.5	45.4
10	26	38	20	24.9	67.5	41.5

Table 6: Yields of ribwort plantain depending on the sowing rate and cultivation year [52]

Seeding rate (kg/ha)	DM of herb (t/ha)			Weight of seeds (t/ha)	
	I year (harvested II times)	II year (harvested III times)	III year (harvested II times)	II year	III year
2	5.4	9.6	1.8	0.88	0.25
4	6.4	10.0	1.9	0.91	0.33
6	7.6	11.1	2.2	0.96	0.36
8	8.0	11.6	2.5	1.1	0.44
10	8.0	11.7	2.8	1.14	0.49

Fertilizer applied: 60 kg N, 40 kg P₂O₅, and 80 kg K₂O.

In order to increase the yield of a crop, required doses of fertilizers have to be applied. According to Kołodziej [26], the most optimal doses of fertilizers on medium-rich brown soil were 60 kg N, 40 kg P, and 80 kg K per ha per year, which led to an increase in the shoot yield by 72, 43, and 94% (in relation to control). During the experiments, seeds bought from Seed Central Office in Bydgoszcz (Poland) were treated with Dithane M-45 preparation and were sown at 6 kg/ha, at a row distance of 30 cm to a depth of 1.5 cm. Half of the nitrogen fertilizer dose (in the form of ammonium nitrate) was applied in early spring and after the first leaf harvest. Phosphorus and potassium fertilizers (in the form of single superphosphate and 50% potassium salt) were applied in the first year in autumn and in the following years in early spring. Increased doses of N, P, K fertilizers than that recommended by the author for three years of cultivation resulted in only slightly higher yields. But the crops were more contaminated by pathogenic fungi, which had a negative impact on the profitability of production. The share of the diseased raw material at the fertilizer dose recommended, during the first year of cultivation, was 6.5%. After increasing the fertilizer dose to 90 kg N/ha, 60 kg P/ha, and 120 kg K/ha, it was 11%. It should be emphasized that under the conditions of Central and Eastern Europe, the cultivation of *P. lanceolata* was most profitable in the first and second years of growing. In the third year, there was a drastic reduction in the shoot yield. At the recommended dose of fertilizers, yields of air-dry matter of leaves were total in the first year with 9.4 t DM/ha; in the second year, 10.2 t DM/ha; and in the third year it was only 4.5 t DM/ha (Table 7) [26].

Similar results were obtained by Kołodziej and Wiśniewski [52]. In spite of the application of diverse sowing norms, while maintaining an adequate fertilizer dose, the yield of ribwort plantain in the third year of

cultivation was significantly lower in comparison with the first and second years (in the third year, there was more than a fourfold reduction in the yield compared to the second year and threefold reduction compared to the first year; Table 6). This study confirms other cited results that the most profitable is the two-year cultivation of *P. lanceolata*.

The cultivation of the plant on brown soil, without the use of additional fertilizers, resulted in lower yields of leaves in the following years of cultivation. However, ribwort plantain showed the highest amounts of active substances without increasing the fertilizers.

Kołodziej [26] also mentioned that the iridoid content of aucubin in leaves collected during the first harvest with no fertilizers was 2.58% DM, and using the recommended fertilizer dose, it was 0.26 percentage points less. The plant yield was also characterized by the lowest weight and the lowest number of inflorescence shoots and leaves; it also had shorter leaf blades but it was less infected by the pathogenic fungi (0.5% diseased raw material).

According to Sazońska [58], the cultivation of organic ribwort plantain under Central and Eastern European conditions had occasionally observed plant changes due to powdery mildew (*Sphaerotheca plantaginis* (Cast.) L. Junell.), downy mildew (*Peronospora alta* Eckl.), and grey mold of plantain (*Phyllosticta plantaginis* Sacc.). The author also emphasized that no mass occurrence of the aforementioned diseases has been observed to date. However, Stewart [55] reported that a wide range of fungal and bacterial diseases was found globally on ribwort plantain. Diseases such as *Aschochyta* leaf spot, *Phoma* sp., and *Stemphylium* sp. were reported in older leaves. Root rot was also occasionally reported in the second-year seed crops. Under New Zealand conditions, the most dangerous insects that fed on the leaves of ribwort plantain were the weevils (*Gymnetron pascuorum* Gyllenhal), flea beetles, gall midges, and plantain moth as reported by Gerrard et al. [59]. The plant had good tolerance to New Zealand grass grub (*Costelytra zealandica*) and poor acceptability to leaf-feeding snails [58]. Under European conditions, Sazońska [58] reported that beetles were the biggest threat to the crop, in addition to aphids (feeding on leaves and ground parts of the plant).

5 Conclusion

Plantago lanceolata exhibits good adaptation for greater agricultural use in terms of constituents and growth

Table 7: Content of N-total, P, and K in leaves (% of DM), yields of air-dry matter of leaves (t/ha), the share of diseased raw material (%), and aucubin content (% of DM) collected during the first harvest in ribwort plantain leaves depending on fertilizer doses in successive years of cultivation [26]

Fertilizer dose	Content	I year (average % of DM)	II year (average % of DM)	III year (average % of DM)	Year	Yield (t DM/ha)	S (%)	Aucubin (% of DM)
N ₀ P ₀ K ₀	N-total	1.55	1.42	1.28	I	2.97	0.5	3.20
						2.47		
	P	0.40	0.35	0.35	II	2.45	1.8	2.24
						1.77		
						2.80		
	K	3.02	2.87	3.04	III	1.57	2.5	2.30
						0.68		
N ₁ P ₁ K ₁	N-total	1.62	1.70	1.97	I	4.92	4.5	2.70
						4.44		
	P	0.44	0.37	0.37	II	2.8	6.5	2.05
						3.76		
						3.59		
	K	3.10	3.39	3.43	III	1.92	7.7	2.20
						2.54		
N ₂ P ₂ K ₂	N-total	1.62	1.88	1.65	I	5.37	11	2.60
						5.18		
	P	0.89	0.57	0.4	II	3.31	13.5	1.90
						4.12		
						4.31		
	K	3.18	3.55	3.5	III	1.94	18.5	2.20
						2.98		

N₀P₀K₀ – 0 kg N, 0 kg P, 0 kg K (control object).

N₁P₁K₁ – 60 kg N, 40 kg P, 80 kg K (fertilizer dose recommended by the author).

N₂P₂K₂ – 90 kg N, 60 kg P, 120 kg K (max. fertilizer dose used by the author).

Yield – yields of air-dry matter of ribwort plantain leaves, I and III year – harvested 2 times, II year – harvested 3 times.

S – share of diseased raw material (III years of cultivation – % value).

Aucubin – aucubin content from the ribwort plantain leaves collected during the first harvest.

properties. The advantages of this plant for crop production lie in its high content of valuable substances for human and animal consumption. At the same time, ribwort has a deep and strong root system and a symbiosis with mycorrhiza, which gives it a very good appropriation of water and nutrients, especially from the subsoil. Therefore, by integrating ribwort plantain into grassland stands, and also into arable forage stands, the resilience of cropping systems to changing climatic conditions can presumably also be increased in Central Europe. However, this would also require the provision of cultivars of ribwort suitable for the growing conditions in Central Europe, which, in addition to good overwintering ability and persistence for use in grassland, have good suitability for cut use with upright leaves or tread tolerance for grazing. Ribwort varieties for forage production would also need to have high digestibility and good suitability for silage in order to be competitive with common forage grasses. Furthermore, studies must be carried out under Central European conditions in order to establish ribwort plantain

efficiently in existing grassland stands through targeted seeding. The aim should be to make greater use of the positive effects of ribwort plantain on the environment in Central Europe, analogous to the newly developed strategies for its use in forage production in New Zealand [6,60]. Furthermore, ribwort plantain also offers new possibilities in intercropping to reduce nitrogen losses in arable farming [7,8].

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