INTRODUCTION

At the present time fodder galega (*Galega orientalis* Lam.) is a well-known new fodder crop in Estonia, which has found a certain place among other legume fodder crops. It has a stable growing area and it is approved by farmers.

On the recent years fodder galega has earned a big attention of scientists and agricultural specialists from the areas of former Soviet Union, Europe, USA, Canada and Japan. But the information about galega available in the world is rather dispersed and one cannot get an entire picture about it. Considering the fact that the plant was first introduced at the Estonian Research Institute of Agriculture in 1970ies and these studies are until now, due to a lot of experience, the basic material for researchers and practicians studying galega, the need for recording this collective scientific work has come actual.

The present monograph summarises the scientific research studies made with fodder galega in Estonia. Multidisciplinary approach in galega studies has enabled to create a database about galega`s introduction, its biology, agrotechnology, feeding value, seed growing and breeding. The studies in this field have mainly been carried out at the Estonian Research Institute of Agriculture, under supervision of D. Sc Helmut Raig. The researchers Ph.D Heli Nõmmsalu and Ph.D Jelena Metlitskaja and agronomist Heli Meripõld have worked in the main staff of the research group. Ph.D Peeter Viil, Ph.D Uno Tamm, Ph.D Riho-Jaak Sarand, Helgi Laitamm, D.Sc Paul Lättemäe and some others from the same Institute have also participated in galega studies. The researchers from the Institute of Grassland Science and Botany of Estonian Agricultural University Ph.D Rein Viiralt, M.Sc Toomas Laidna and others have carried out investigations with galega, too.

The approval and support of specialists working in agriculture have had a positive effect on galega`s popularity in Estonia. Their extensive attention has especially been earned by a lot of experience received from plant's agrotechnology when growing it as a fodder crop and also at recultivating it on less fertile soils for increasing the soil fertility.

Proceeding from the novelty of the research work made with fodder galega, the Committee of Discoveries and Inventions of the former Soviet Union granted a patent to galega investigators which deals with galega nodule bacteria preparation. The preparation contains the certain stem of the bacteria *Rhizobium galegae*, separated in Estonia and is being used in galega`s agrotechnology even now. In 1988 just before re-emancipation the State Agro-industrial Committee of the Soviet Union issued a patent to Estonian scientists on galega`s first variety Gale. For presenting the new fodder crop galega and for introducing it into production, the supervisor of this research work Dr H. Raig was awarded a State Prize by the Government of the former Soviet Union in 1984.

The galega field attracts the attention of both people and bees with its beautiful bright lilac flowers already from a distance. Bees and bumblebees and other insects often visit the plants to gather pollen and suck nectar. So galega is a valuable honey plant but also a beautiful decorative plant for growing in a home garden. It surprises us with its indulgence. Many stony slopes turn beautiful and fertile due to growing galega. Galega fields are favourite places for goats. They give the spectator of an unforgettable picture when jumping over plant tops.

1. THE HISTORY OF ADAPTATION AND INTRODUCTION OF FODDER GALEGA

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1.1. Early researches of fodder galega

In the history of almost all civilised countries, there are periods which are characterised by an intensive interest towards the introduction and acclimatisation of natural plant species and populations. But very often these periods were short and disappointing from the aspect of introduction or utilisation possibilities of one or another natural plant. Thus, after some time scientists turned back to already tested plants or gathered new species and genotypes of natural flora and studied them with modern scientific methods.

In the present situation, the production of resistant and persistent leguminous fodder crops for agriculture may become of the utmost importance.

It is important to note that only 5000 out of 250 000 angiosperm species were domesticated and only 150-200 species are widely used. Even among these cultured plants only 20-30 species have a really broad using (Zhucheno, 1999). The usefulness of fodder crops is determined not only by the necessity of fodder production, but also by soil conservation and environment protection.

Among the new crops fodder galega (*Galega orientalis* Lam.) is higly important. It is characterised by high yields of herbage, intensive symbiotic nitrogen fixation, preservation and formation of a healthy soil microflora.

The English name of genus *Galega* is goat's rue. Unfortunately, under that name it is not possible to differentiate the growing and utilisation possibilities of two known species of genus *Galega*: fodder galega – *Galega orientalis* Lam. and *Galega officinalis* L., which is an ornamental and medicinal plant. "ISTA list of Stabilised Plant Names" published by the International Seed Testing Association in 1988 included *G. officinalis* L. under ornamentals, herbs and medicinal plants, but *G. orientalis* Lam. which is a less known field and fodder crop was not on that list.

Based on twenty years of experience with this new crop, the Estonian Research Institute of Agriculture made in 1993 a proposal to ISTA to include *G. orientalis* into the list of field and fodder crops under the specific name of fodder galega (Nõmmsalu et al., 1996). In substance this name corresponds to the purpose of use of the crop, and it avoids all kinds of misunderstandings and confusions with the toxic *G*. *officinalis.*

The studies of fodder value of genus *Galega* started from a *G*. *officinalis*. Now *G*. *officinalis* widely distributed in the nature in Central Europe on Caucasus and in Middle-East. There is a theory that into the countries of Central Europe the plant is brought during commodity exchange from countries of Middle-East and hereinafter it was spread to South America, New Zealand, Northern Africa and Southern Asia (Hegi, 1924; Varis, 1986; Grossgeim, 1930).

The first cultivation experience with *G*. *officinalis* was conducted in the year of 1600 in Germany. The interest was represented first of all by its medicinal properties. In 1773 F. Krause paid attention to the fodder value of *G*. *officinalis* and he proposed to grow it in culture (Raig, 1988).

At the end of the 19th century the analysis of gained experience of cultivating *G*. *officinalis* in France, Germany and Poland was conducted (Golov, 1873; Kalinski, 1873).

It is now established that *Galega officinalis* contains specific compounds such as alkaloids – the guanidine derivatives galegine and 4-hydroxygalegine and the chinazolin-type alkaloid vasicine, which are bitter-tasting and poisonous, and therefore it cannot be used as fodder plant (Schröck, 1941; Schreiber et al., 1964; Barthel, Reuter, 1968; Schäfer, Stein, 1969; Laakso et al., 1990).

Galega orientalis Lam. is more profitable because it does not contain alkaloids or contains them only by steps and can´t be toxic (Nõmmsalu, 1993; Varis, 1986).

Fodder galega as a fodder plant was not known in the countries of Western Europe in the 19th century and so not tested as a crop.

This plant is mainly growing in the area of the Caucasian mountains – in subalpine and in forest belts. There can be find also the districts of joint propagation of both species from genus *Galega – G.orientalis* Lam*.* and *G. officinalis* L. (Figure 1).

For the first time fodder galega was described in the natural habitat in 1908 by H. A. Rollov and he stressed fodder value of this endemic plant (Rollov, 1908). The scientist specified that fodder galega (*G.orientalis*) as against *G. officinalis* had a good edibility.

1.2. Cropping experiments and adaptation of fodder galega

The high estimation of this plant by its fodder value was one of the reasons why it was involved in the studies for using it in field conditions.

Cropping experiments started in Moscow district of Russia in 1920-1930s (Simonov, 1938; Raig, 1988). An extensive and long-term (1931...1970) introduction and selection of galega's natural populations in the Moscow district has been carried out at the former All-Union Institute of Fodder Crops by scientists S. Simonov and Z. Jartijeva. On expeditions to the Caucasus and Armenia the scientists of the above-mentioned institute gathered a lot of natural populations and hybrids. They were compared according to the morphological and biological properties and selected in order to get a more even ecotype of galega.

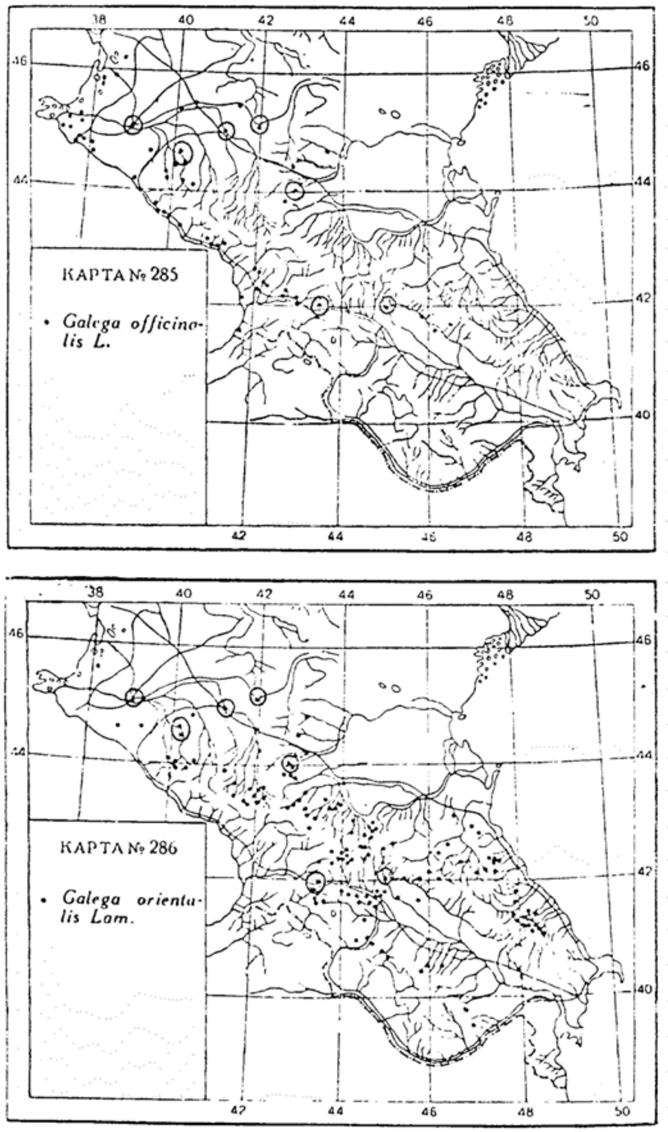

Figure 1. *The natural growing areas of G. orientalis and G. officinalis in the Caucasus (the areas where the both species are growing together are marked with circle). According to Grossgeim, 1930*

In the beginning of 1960s fodder galega was studied on Ukraine (Harkevitš, 1966).

We characterise the studies of fodder galega at 1920-70s as a stage of primary introduction or domestification. In this period the seed material gathered from natural growing areas was used.

Unfortunately, all results of these researches were not put into practice.

In the beginning of 1970s Dr H. Raig obtained galega seeds from the All-Union Institute of Fodder Crops and from All-Union Institute of Plant Production in Sankt-Petersburg, where was a collection of seeds from different parts of the Soviet Union, and an intensive research was started at the Estonian Research Institute of Agriculture.

As a result of mass and individual selection, winterhardy and drought resistant populations were picked out, suitability for mechanised harvesting, lodging resistance and falling resistance of seeds were studied. The agrobiology and agrotehnology for growing the new fodder plant on Estonian soils were also studied, as well as the nutritive value of galega in relation to its cutting time. The given research was carried out at the department of introduction of new fodder crops. The head of the research group was Dr Agr. prof. Helmut Raig. Ph.D. Heli Nõmmsalu and Ph.D. Jelena Metlitskaja worked as researchers, Heli Meripõld as an agronomist. A lot of more researchers from the Institute of Agriculture and other research establishments of Estonia participated also in scientific research of the given plant.

Since 1972 mainly the following problems have been studied:

- agrobiology, possibilities of growing galega for fodder and for seed;
- agrotechnology, pure sowings of galega and mixtures with grasses;
- nutritive value, biochemical composition and use;
- plant breeding and varietal improvement;
- galega as an improver of soil fertility and inhibitor of soil erosion.

The scientific evaluation by Swedish experts was given to this work carried out with a new fodder plant by the above-mentioned research group in the beginning of 1990s. This research project was highly estimated as a unique one and it should be definitely continued with this project due to its interesting potential. It usually takes time to get a new crop introduced and adapted to the different agroecological conditions and uses and Estonian researchers have done this work very successfully.

Estonian farmers met the new fodder crop with interest and approval.

The first seed fields of galega were established in 1976 at the experimental farms of Estonian Research Institute of Agriculture. Galega started to spread into production in 1980. The area under galega fields reached up to 100 hectares in the Estonian collective farms.

Together with re-establishing the independence of the Estonian Republic, in the course of agricultural reform the land was restored to formers owners and many of galega fields got farmers for their new owners. These galega fields produce valuable silage or hay up to the present. Farmers have also enlarged sowing areas of galega and keep it as a supplementary fodder crop among other legumes.

Galega fields have spread all over Estonia and arable land under fodder galega in the republic now reach up to 5000-6000 hectares (Figure 2). The area of galega fields in the farms is on the average 20-30 hectares.

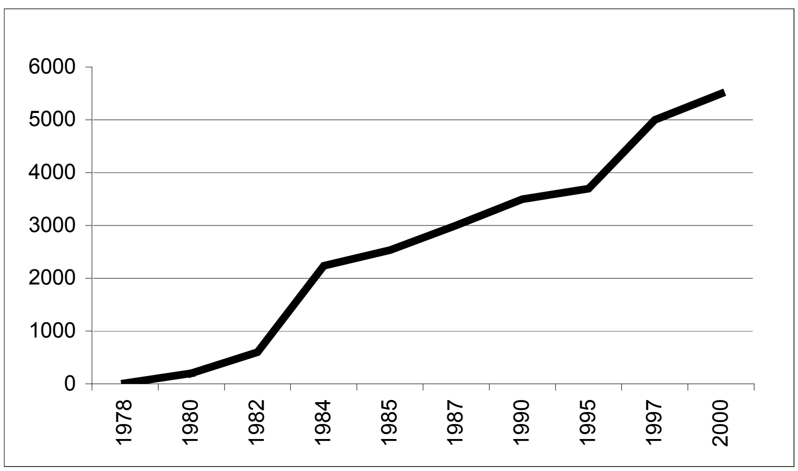

Figure 2. *Arable land (ha) under fodder galega in Estonia*

In one farm in Estonia for example a silage has been made on a 10 hectare galega field for several years running. The quality indicators of this silage are good. This silage contains usually 17.7% of crude protein and 27.8% of crude fibre per DM, silage pH is 4.5 and digestibility of organic matter is 62%. The average milk production in this farm is 8500-9000 kg per year.

The Estonian Research Institute of Agriculture and several Estonian agricultural enterprises have also grown galega seed for export. 4 tons of galega seeds have been sold from Estonia to Canada, the province of Quebeck. 50 kg of galega seeds have been bought by French farmers, 20 kg has been sent to Germany and over 400 kg have been bought by Finnish farmers during the last years.

1.3. Introduction of fodder galega

The first high-productive fodder galega variety Gale has been bred in cooperation between the scientists of the Estonian Research Institute of Agriculture and the former All-Union Institute of Fodder Crops (Moscow district) in 1987.

Variety Gale has many positive qualities: it has high yields, good winterhardiness, good drought tolerance and a stable seed production. Gale is economical and persistent and has a fast regrowth after cutting.

In the end of the 1980s and in the 1990s the seeds of the variety were distributed throughout Estonia, mainly into the northern and north-western part of the former Soviet Union, into the Baltic States and Scandinavian countries.

Possibility for obtaining seed production and propagation of certified seeds enabled in large amounts to extend the acreage under galega on the territory of the former Soviet Union (Figure 3).

The interest towards galega production was the greatest in the northern areas of the former Soviet Union, where the share of leguminous fodder crops was small and there was always a shortage of protein-rich fodder. The northern part of the zone between 40° and 60° of north latitude covers the regions of Volga-Vjatka, the Urals, Siberia and Far-East, as well as regions round St. Petersburg, Yaroslavl, Gorki, Kazan and Ufa. All these regios were characterised by instable seed yields of leguminous fodder crops. The vegetation period in those regions lasts for 80...100 days.

The central and southern parts of the zone have favourable conditions for galega growing. This area covers the Baltic States and Byelorussia, the territories surrounding Pskov, Novgorod, Moscow, Pensa, Vladimir, Kostroma, Kirov, Rjazan and Gorki and also Mordovia, Tatar, Bashkiria, Mari and Chuvash.

All in all, the Estonian Research Institute of Agriculture has sent galega seeds to 33 territories and 6 republics of the former Soviet Union. As feedback, valuable information on the winterhardiness and drought resistance of galega, as well as on the seed and green material yields has been obtained.

Positive results of fodder galega growing have also been obtained from Canada. A lot of studies were conducted across Canada to compare the herbage productivity of fodder galega to that of traditional forage legumes, in order to assess its agricultural potential (Fairey et al., 2000). The average annual dry matter yield of fodder galega was 5,5 t ha^{-1} during the first three production years. The performance characteristics of galega indicated that it could have considerable agricultural potential as an additional, perennial, herbage legume for many regions of Canada.

The Estonian Research Institute of Agriculture has had long-term contacts with Finland in the field of galega research. At the Department of Plant Husbandry of the University of Helsinki, field trials were started in 1978 (Varis, 1986). At the same time the Departments of Microbiology (Lindström, 1989) and Animal and Plant Husbandry commenced microbiological and feeding studies and the department of Pharmacology some alkaloid studies (Laakso et al., 1990).

In Denmark the Plant Breeder of Pajbjergfonden and the Royal Veterinary and Agricultural University and several other research establishments participated in the research work with fodder galega.

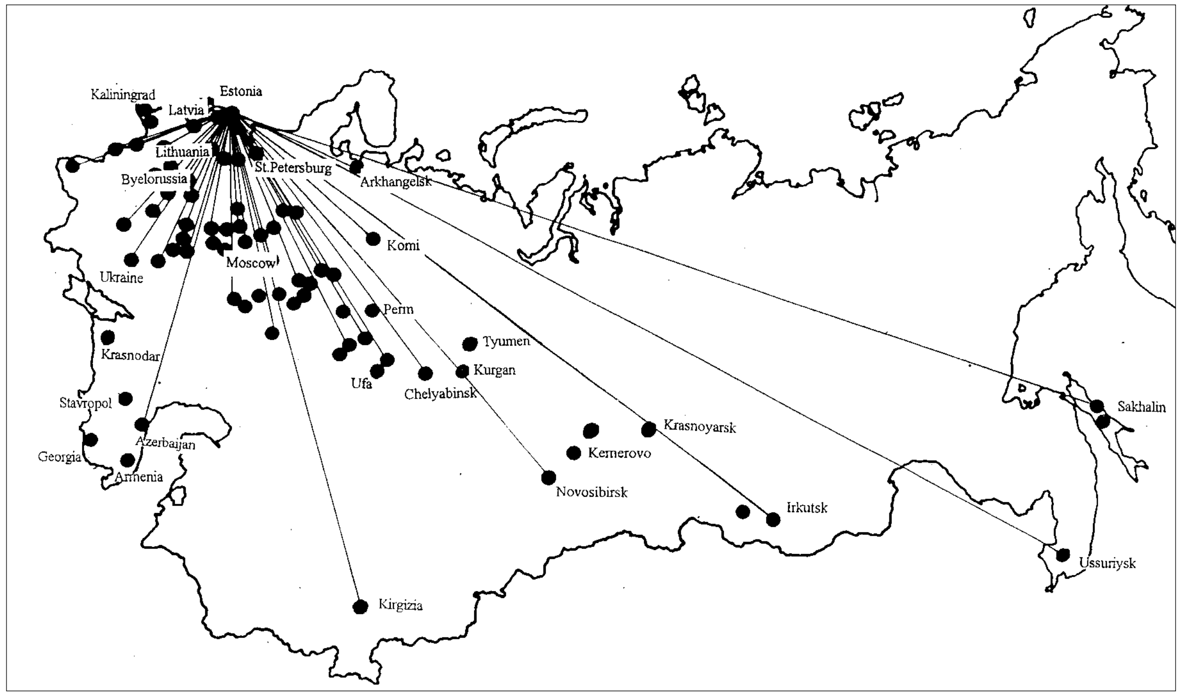

Figure 3. *The main territories and capitals of the former Soviet Union where galega seeds were sent from Estonia in 1980s-1990s*

In 1980s-1990s a lot of experiments with galega were started in different countries (Norway, Sweden, Poland, Yugoslavia, France, Italy, Greenland). In general there was a high interest among farmers to establish smaller fields with this new forage crop. A more intensive introduction and widespread use, especially on poorer sandy soils were being expected. But further field experiments are needed in order to find out the optimal management for galega growing under different soil conditions.

In addition to the above-mentioned countries, experiments with the fodder galega have been carried out also in Germany, Chile, Great Britain, Hungary and USA.

One of the recent collaboration agreements was concluded between Hokuren Livestock Experimental and Training Farm in Hokkaido in Japan and the Estonian Research Institute of Agriculture. The purpose of this agreement is to research, evaluate and pursue studies on the new fodder plant *G. orientalis* and to determine its adaptability under the conditions of Hokkaido as well as the acceptability and consumption of galega's herbage by dairy cattle.

2. BIOLOGICAL CHARACTERISATION OF FODDER GALEGA

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2.1. Botanical characteristics of fodder galega

Fodder galega (*Galega orientalis Lam*.) belongs to the family of legumes (*Leguminosae*) and genus of goat`s rue (*Galega*) (Figure 1).

The genus of goat`s rue consists of 7 plant species and they are spread over Caucasus, Central Asia, the Mediterranian countries, the Balkan countries, Iran, South America and Central Europe. The most well-known and with the broadest spread is *Galega officinalis* L., which grows in nature in all the above-mentioned areas. *Galega orientalis* Lam. originates from the regions of the Caucasian subalpine belt, where it has been found growing as an endemic plant species (Grossgeim, 1930). Its natural growth areas are Armenia, Georgia, Dagestan and Azerbaidzhan (Flora USSR, 1945).

Figure 1. *Fodder galega (Galega orientalis)*

Fodder galega is a perennial tap-rooted herb, which spreads and propagates also vegetatively by underground stolons or rhizomes. The root system of galega consists of several roots: tap-, lateral and additional roots. In the first year the roots are light brown, year by year they get darker together with plant`s ageing. The root system is vigorous but located mostly near surface, penetrating into soil only until 60…70cm. The main root is well developed, with a lot of lateral roots and can reach into the depth of more than a metre. In the depth of 3…7 cm side branches or rhizomes of a stem with 3…4 buds are formed on the main stem. Rhizomes spread in soil horizontally up to 15…30 cm, thereafter they head for ground and form new above-ground shoots (Figure 2). These underground stems are also the place for keeping the gathered food reserves during vegetation period, on which the vegetative propagation and reforming of herbage depends. A lot of buds can also be found on a root crown, from which the development of underground stolons and reforming of herbage is continued. Thus galega propagates and spreads both generatively and vegetatively due to which plant stand will not thin with years but on the contrary, will get thicker.

Figure 2. *New shoots of fodder galega develop also from buds on underground stolons*

Round root nodules are located on galega roots, containing nitrogen fixing bacteria *Rhizobium galegae* (Figure 3). These microsymbionts-bacteria of galega are host-specific and do not belong to any other earlier discovered fast growing species of bacteria situated in root nodules (Lindström, Gyllenberg, 1988).

Figure 3. *The root system of fodder galega with round root nodules and underground stolons*

The height of fodder galega plants varies between 60 and 150 cm. Branch stems are in the middle and upper part of the main stem. The leaves are compound and consist of 5 or 6 pairs of egg-shaped leaflets. There are a few flower clusters on the stem, containing 25 to 60 bright lilac flowers.

Galega fruit is a pod. The pods are 2 to 4 cm long and contain 5 to 8 kidney-shaped seeds. The weight of a thousand seeds is 7.0 to 8.0 g. The seeds are yellowish green in colour, later light brown.

The two most well-known species of the genus of goat`s rue (*Galega*) *Galega orientalis* Lam. and *Galega Officinalis* L. differ from each other botanically. In Table 1 the botanical comparison of the two species is given.

Table 1. *Botanical comparison of Galega orientalis Lam. and Galega officinalis L.*

Characteristic	*Galega orientalis* Lam.	*Galega officinalis* L.
Root	tap-root with rhizomes	tap-root no rhizomes
Stem	erect height 60…150 cm	erect height 50…120 cm
Leaf	compound leaf 5…6 pairs of egg-shaped leaflets	compound leaf 5…8 pairs of lineal leaflets
Stipules	round-leaved	lancet-shaped
Flower	raceme bright lilac	raceme light lilac
Fruits	pods hang	pods erect

Fodder galega does not suffer from any serious fungal, viral or bacterial diseases, or insect or nematode pests at the present time.

For now, according to the data gathered by P. Soobik (Estonian Institute of Agriculture) there are three pathogenic species of fungi specialised strictly on galega: *Pernospora galegae* Sav. et Rayss. (its findings have numerously been collected from the mentioned species at the end of summer), *Ramularia galegae* Sacc. (with considerably conservative frequency) and *Cercospora galegae* Sacc. (there is only one finding for proving the occurrence).

Patogenic fungi of galega are mostly formed by microfungi living on many legumes or several other representatives of cultivated plants. But in local conditions they are of no importance as injurious species since no considerable pathogen occurrences have been found which could disturb galega plants significantly.

2.2. Growth and development characteristics of fodder galega

When solving the adapatation problem of a new fodder crop galega, regional peculiarities of our soil and climatic conditions had to be considered.

The climate of Estonia is moulded by intensive cyclonic activities both in the northern part of Atlantic Ocean and proximate nearness of the Baltic Sea and its bays. Due to that the weather is very changeable. Vegetation period with the temperature over 5°C lasts for 170-180 days and during this time precipitation in the continent of Estonia is 275-330 mm, on the islands and west coast 220-275 mm. The sums of precipitation differ by years and their distribution in spring and summer is irregular. There are often periods with little rainfall (drought) or with too much rain which worsen the growing conditions of field crops a great deal or in a slight degree, complicate sowing and harvesting work and cause big amplitudes in yield.

Although winter is of maritime nature, the absolute minimum of air temperature has been observed from -31°C to -35°C on the islands and coast and down to -43°C inland. The freezing depth of soil depends on the thickness of snow. The snow cover is thicker in February and March, 30-35 cm on the average. Often enough several winter damages of cereals and perennial grasses occur. E.g. lucerne sowings of southern origin are not often winterhardy. Cultural crops are also jeopardised by spring night frosts in vegetation period, especially during blooming. The first early night frost in autumn also ends the growth of plants and damages the yield.

Diversity of Estonian soils is due to the bedrock and relief. Mostly sod-calcareous, sod-podzolic, half-bog soddy and bog soils have spread in Estonia. Sod-calcareous soils of North Central and West

Estonia have been formed on Silurian limestone and on calcerous moraine. South-Estonian sod-podzolic soils have been formed on Devonian loamy red-brown moraine, they are mostly with acid reaction and in several places with hilly relief and also sensitive to erosion.

Since this species originates from mountainous regions of Caucasus and grows in that region starting with 300…400 m up to 2000 m above sea level, it can be assumed that it also grows in colder climate conditions. After the first adaptation experiments it became evident that the plant adapted very well in our conditions and turned out to be more winterhardy than other varieties of fodder galega from southern areas. Galega has been tolerant to winter temperatures of -30°C down to -40°C under snow cover and down to -20°C on uncovered field. During spring growth plant leaves tolerate night frosts of -5°C down to -7°C and at the beginning of flowering down to -4°C.

Winterhardiness of galega depends a lot on its cutting regime. Overwintering is very good when using a two-cut system whereas the second cut is made later in autumn, e.g. at the end of September or beginning of October. There can be no cut at the end of August or beginning of September as in that case by the end of vegetation period the plant will use reserves gathered in underground stolons for regrowth and will not survive well during hibernation.

Galega is well adapted to our soil conditions. It does not grow on acid soils (pH<5.7) since nodule bacteria situated on roots do not tolerate acid reaction of the soil and die. Galega grows well on drought-sensitive sod-calcerous soil on limestone in North and West Estonia and on the islands where it has often shown to be more drought resistant than other leguminous fodder crops (inc. lucernes). Galega grows also well on hilly landscape of South Estonia, where are very variable soils. Its yield is high enough and quite stable compared to other field crops. It also helps to avoid erosion there.

In our conditions, galega starts its growth in spring at the end of April, depending on weather conditions (the average of many years has been about April 27). After 8 up to 14 days the stems will start to grow fast. At the end of May flower buds will start to form, beginning of flowering is about 12-19 of June, the period of full flowering is at the end of June. Depending on weather conditions the seeds ripen usually by the first half of August, sometimes in the beginning of

September. It takes about 114 days from the beginning of growth in spring until harvesting. The average correlation between the development stage of the plant, days and dates needed for passing these stages in our conditions are shown in Table 2.

Table 2. *The average correlation between development stage and days and dates needed for passing the stage (Nõmmsalu, 1993)*

Development stage	Growing days	Dates of passing the stage
Starting the growth in spring	1-9	27.04-05.05
Shooting	10-30	06.05-26.05
Budding	31-46	27.05-11.06
Beginning of flowering	47-54	12.06-19.06
Full flowering	55-65	20.06-30.06
End of flowering	66-74	01.07-09.07
Seed maturing	75-113	10.07-17.08
Seed gathering	114	18.08

Galega herbage renews after cutting mostly by new stolons formed from buds located mostly on a root crown and rhizomes, and the growth of the second cut is fast and good. The yield from the 2^{nd} cut can be approximately one third of the yield gathered during the first cut. The growth of plants is often irregular – e.g. by the beginning of October a part of the plants have formed flower buds already and started blooming, a part of them are in the stage of shooting yet.

Galega is characterised by high percentage of leaves. The role of foliage in green mass is the biggest in the stage of shooting (45-57% on an average), by the beginning of flowering it decreases down to 40-35%. The 2^{nd} cut is with a thicker foliage where the percentage of leaves in green mass is 45-65%, reaching sometimes up to 70%.

The arhitectonics of herbage of galega field and radiation regime have been studied in Estonia in the years 1975-1978 (Tammets, Tooming, 1983). In trial fields the height of the plants was 120-150 cm and density 216-308 stems per m^2. The total assimilation area (leaves+stems) was 14-15 m^2. The assimilation area is the biggest and the phosynthesis and formation of green biomass most intensive in the upper layer at the height of 80-100 cm. By the indicator of assimilation area galega overcame the density of maize grown for green mass.

From the investigations on phytosynthetically active radiation it became out that galega leaves had good light transmission. So the active radiation reaches also the lower, overshadowed leaf layers. Radiation is divided in the herbage between different layers quite evenly and finally is absorbed almost entirely. By that the great production ability of galega can probably be explained.

3. AGROTECHNOLOGY

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3.1. Soil cultivation

Fodder galega can be grown almost on every soil type. Loamy automorphic (non-gleyed) soils are more suitable for galega fields. Good yields are also received on drained gley and alluvial soils. Fodder galega does not tolerate staying surface water, high ground-water level and acid (pH_{KCl} below 5.7) soils. The soil reaction should be close to neutral, like in case of most legumes. Fodder galega grows badly on acid and poor in nutrients soils, the plant cover in this case is weak and is usually become damaged during the first winter.

Fodder galega should be sown early in spring. Therefore the soil cultivation should be done on time and of high quality in autumn. Special attention should be be paid to weed control (stubble disking), especially exploitation and eradication of perennial weeds (common coach grass, field sow thistle, dandelion, etc.). Cleaning the surface layer of soil by eradication of weed sprouts, surface-levelling of the field and preparation the dense seedbed – these are the main objectives of presowing cultivation.

The seedbed must be prepared carefully. The soil must be firmed and free of weeds. A compromise should be made so that the seedbed was neither too fine nor too cloddy. A firm seedbed helps to keep the soil from drying out rapidly and prevents the seed from being planted too deep.

It is essential that the seeds of galega should be sown no more than 1,0...2,0 cm deep into heavy soils and up to 2,5 cm into the lighter ones.

3.2. Fertilisation

Galega needs first of all potassium and phosphorous fertilisers (Table 1).

In the trials established on gley soil with average P and K content and with fertilising doses of $P_{90}K_{120}$, up to 60 t ha^{-1} of fresh material were received from one hectare, in case of unfertilised variant only 24 t ha^{-1}, i.e. more than two times less. Thus growing galega without sufficient amount of P-K fertilisers does not give the desired results. P-K fertiliser has to be given according to their content in soil and the method of establishing galega field. In the sowing year PK-fertilisers are expected to be given also as a reserve fertiliser.

Fertilisation with 30 kg of nitrogen per hectare in the case of pure stand and with 60 kg of nitrogen in the case of a cover crop given at sowing, favours the initial development and growth of galega plants on soils with low fertility and humus content.

In mixtures of galega and grasses 40…60 kg of N given in the second year of utilisation increases the productivity of mixtures. The bigger doses of N-fertiliser decrease the share of galega in plant cover and total protein production.

Acid soils have to be limed before sowing. Better results have been received when giving lime in parts – 2/3 before sowing and 1/3 very close to the sowing before harrowing or rolling (1...2 t ha^{-1}).

The organic fertiliser (40...60 t ha^{-1}) should be given to a preceding crop.

Table 1. *Galega`s need for fertilisation*

Content of nutrients in 100 g soil (mg)	Application	In the year of sowing		In the 2^{nd} and following years of growth
		Without cover crop	Sown under spring cereals	
Phosphorous			P_2O_5-fertilisation (kg ha^{-1})	
4.6 - 11	average	200	275	100
11.1 - 24	small	160	220	80
> 24	very small	70	160	60
Potassium			K_2O-fertilisation (kg ha^{-1})	
5.1- 10	high	360	405	180
10.1 - 20	average	320	325	160
> 20	small	280	295	140
In the year of establishment 30 N				

3.3. Seed preparation

Galega is a leguminous plant which has nodule bacteria on the roots. Plant`s normal development, growth and winterhardiness depend on the existence of nodule bacteria in the soil. When growing galega for the first time, seeds have to be inoculated with a corresponding nodule bacteria. Nodule bacteria are specific, i.e. the ones which are suitable for lucerne and clover, not suitable for soya, melilot and not at all suitable for galega.

Inoculated seeds of galega should be preserved in a cool place, it is even better to sow them out into humid soil (e.g. after raining). If sowing background is favourable, nodule bacteria will multiply in the soil real fast, penetrate into roots through roots` hair and form nodules there. As the source of energy they use carbohydrates from the plant, giving in return fixed compounds of nitrogen. So a useful symbiosis will develop between a plant and bacteria.

The development of nodule bacteria on the roots of galega can be observed already in the second half of summer. The effectiveness of symbiosis between a plant and bacteria will greatly depend on moisture and acidity of soil. There are a few nodules on the roots of galega plants in fields with late sowing time and fields suffered from drought. Plants are weak and light green and die during over-wintering. Dark green vigorous plants certainly prove that nitrogen is fixed intensively (Figure 1).

Figure 1.*The influence of inoculation on the development and growth of galega plants: 1 - not inoculated; 2, 3 - inoculated*

In a trial established on sod-calcerous soil on limestone the influence of seeds` inoculation on galega's productivity was studied, depending on the number of bacteria in a bacterial preparation (Table 2). The trial results show that growth and development of galega depends directly on inoculation of seeds and quality of bacterial preparation. The influence of the preparation with a small number of bacteria was close to the control variant.

Table 2. *The effect of inoculation on galega's dry matter yield and its quality on the sowing year*

No of bacteria per one seed	Dry matter yield	Crude protein content
	t ha^{-1}	%
200 000	6.13	14.9
40 000	5.77	15.4
2 000	1.91	10,5
control	0.84	10.8

Bacterial preparations and pesticides must not be used together.

Scarification is also an important method in preparing seeds for sowing. Quite a high percentage of seeds (50...68%) is covered with a hard seed cover. Scarification favours the germination of seeds in the sowing year.

Scarification can take place 5...7 days before sowing and it should be done with a special for this purpose made machine.

3.4. Sowing rate and row space

Sowing rate and row space are depend on the purpose of galega growing, quality of seeds, sowing method and other conditions.

Galega fields are usually established with the narrow row space of ca 10…30 cm for getting fresh material for green fodder or making silage and with the wide row space of ca 45…60 cm for getting seeds.

The production of fresh material and seeds depends directly on density of plant cover. Sowings with low density and with a good lighting regime give high seed yield but maximum herbage are received from sowings with higher density.

It is also practical to establish galega field sometimes with a wide row space (45…60 cm) for producing green fodder. Tillering between the rows is carried out in the sowing year in every case, which favours the growth and development of underground stolons and controls weeds. As galega spreads and multiplies also vegetatively this plant is capable to regulate the density of plant cover by itself by vegetative propagation. Because of the vegetative propagation the multiplication coefficient of galega is extra high.

Sowing rate depends on the purpose of use the field: for green fodder with the narrow row space – 20…30 kg ha^{-1}, for establishing seed fields with the wide row space – 6…8 kg ha^{-1}.

In order to find out how row space influences the herbage production, pure sowings with the row space of 12.5 cm, 25.0 cm and 50 cm with sowing rates accordingly 40, 20, 10 and 15 kg ha^{-1} were established. For investigation the vegetative propagation and spread of galega, the tillering between the rows was not used. It became evident that the growth density and herbage yield practically equalised on the 4th year of use, irrespective of sowing method. Nevertheless in sowings with wide row space (50 cm) 21…27% of dry matter was not received.

Table 3. *The influence of sowing depth on emergence of galega seeds on clays (Raig1980)*

Size of seeds	Mass of a 1000 seeds, g	Percentage of seeds` emergence Sowing depth, cm			
		1	2	3	5
Big	7.39	63.7	56.9	25.2	
Small	7.04	31.2	22.2	-	-
Not sized	7.30	45.2	46.2	16.5	14.2

The germination of galega seeds depends on the size of the seed. Bigger, well developed seeds germinate better than the small ones. The optimum sowing depth is 1…2 cm depending on soil texture and humidity (Table 3). Pre- and after-sowing rolling creates favourable germination conditions for seeds.

It is also possible to sow galega under cover crop. In sowings under cover crop (for example early summer barley) it is possible to improve lighting regime by decreasing the sowing rate of a cover crop by 25…50% and regulating the row space. Good results have been achieved by every other row sowing, with the row space of 20…35 cm. It is important to decrease the sheltering effect of cover crops.

3.5. Sowing time

Galega's growth and development depends on sowing time. Although the seed`s optimum germination temperature is 10…12°C, it does not mean that sowing could be delayed in spring and wait for optimum temperature.

In trials the best results were received from the variants with sowing time in May. Galega plants which were sown in June, but especially in July and August, started to develop and grow slowly, plant cover remained thin and got infested with weeds, plants were weak and pale green.

Overwintering of galega plants depended also on sowing time. Of stands sowed in May, overwintered 95…100%, of stands sowed at the end of July – 52% and in August, only 12.8%. Late sowing time did not favored the vigorous growth of galega plants on the next year, i.e. from stands sowed in August it was received 0,5…2,4 t ha^{-1} of dry matter only. Although in the third year of growing the yields started to conform between the different sowing times due to vegetative propagation and spread of galega, the yield losses were due to late sowing time, as an average of 4 years, very big, reaching in stands sowed in July up to 11.5…32.9% and in stands sowed in August up to 23…28.3%. Dry matter yields of galega and the changes in the production depending on the year of growth are shown in Table 4.

On the basis of a long-term experience it can be confirmed that galega needs early sowing, e.i. sowing on the first opportunity. All presowing activities – field selection, soil cultivation, weed control and fertilisation have to be carried out already in autumn; so the necessary preconditions for early sowing will be established.

Table 4. *The effect of sowing time on dry matter yield of galega ($t\ ha^{-1}$) (Raig, 1980)*

Sowing time	Year of growth					5-year average	%
	1.	2.	3.	4.	5.		
17.05	5,8	9,3	11,3	7,1	8,6	8,4	100
17.06	5,7	7,9	10,9	6,6	9,1	8,0	95
17.07	1,3	6,1	9,2	6,1	8,1	6,2	73
10.08	4,8	6,9	9,9	7,0	8,4	6,5	78

3.6. Sowing under cover crop

Galega plants in pure stands have more favourable growth and development conditions, but a lot of annual weeds could be found there. Sowing under cover crop enables the better control of weeds on galega field on the first year of growth.

In order to study the effect of cover crop and fertilisation on the growth of galega plants the field trials were established with different fertiliser applications. The cover crop spring barley Otra was sown on May 17 with the row space of 10.5 cm, galega was also sown on the same day. Barley shoots were cut for fodder on June 26 in some variants. Also the weeds grown in the upper layer were cut in the variant without a cover crop. By that time galega in a pure stand had developed into 4…5 true leaves. Barley in full maturity was harvested on August 13 and the growth and development of galega were the worst in this variant (Table 5). Plants grown under barley were weak and bright green.

The yield of barley depended on fertilisers. 3,2 $t\ ha^{-1}$ was received at fertilisation with 120 kg of P_2O_5 and 120 kg of K_2O and no nitrogen per hectare, 5,2 $t\ ha^{-1}$ with the same fertilisation rate + 40 kg of nitrogen and 5,6 $t\ ha^{-1}$ with the same fertilisation rate + manure. The trial results indicated great positive effect of mineral fertilisers and manure on barley yield (extra yield being 2,1…2,4 $t\ ha^{-1}$), which in turn had bad influence on under sowed galega. Winterhardiness of galega diminished in this case.

The effect of a cover crop and fertilisation on galega's dry matter yield in the above mentioned trials is shown in Figure 2. From that we can see that the dry matter production of galega stand from the first year was so much higher the less competition could be found for the growth place in the plant cover. The higher dry matter yields were received from pure stands of galega. The differences between variants decreased at the following years. The highest total dry matter yield of 6,6-7,2 t ha^{-1} was received due to the use of PK-fertilisers and no N application.

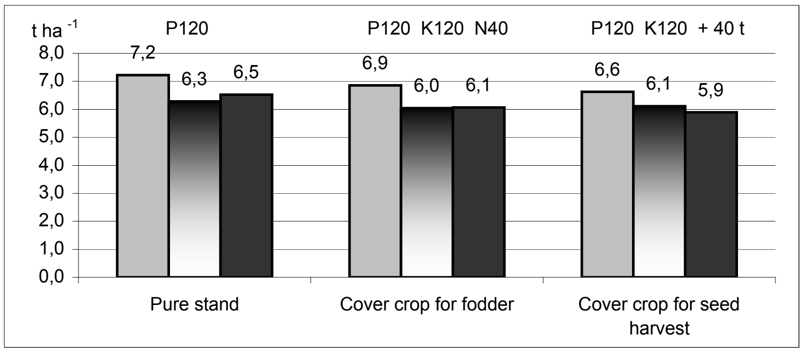

Figure 2. *The effect of a cover crop and fertilisation on dry matter yield of galega (on the average of 1975…1978)*

Table 5. *The effect of a cover crop and fertilization on galega's dry matter yield (t ha $^{-1}$) (Raig, 1980)*

Sward	Cut	$P_2O_5$120 K_2O120						$P_2O_5$120 K_2O120 N40						$P_2O_5$120 K_2O120 + 40t manure					
		1975	1976	1977	1978	sum	mean	1975	1976	1977	1978	sum	mean	1975	1976	1977	1978	sum	mean
Pure stand	1.	4,5	3,8	6,5	3,7	18,5		2,9	3,4	6,5	3,7	16,4		4,2	3,4	6,1	3,9	17,7	
	2.	-	3,7	2,4	4,3	10,4		-	2,2	2,0	4,6	8,7		-	2,3	2,3	3,8	8,4	
	Total	4,5	7,4	8,9	8,0	28,9	7,2	2,9	5,6	8,4	8,3	25,1	6,3	4,2	5,7	8,5	7,7	26,1	6,5
Cover crop	1.	3,9	4,1	6,2	3,6	17,8		2,5	2,1	6,7	3,8	15,1		3,4	2,6	6,6	3,8	16,4	
for fodder	2.	-	2,5	2,6	4,6	9,6		-	2,2	2,6	4,3	9,1		-	1,8	2,4	3,8	7,9	
	Total	3,9	6,6	8,7	8,2	27,4	6,9	2,5	4,3	9,2	8,1	24,2	6,0	3,4	4,4	9,0	7,5	24,3	6,1
Cover crop for seed harvest	1.	4,1	3,2	6,0	3,3	16,6		1,6	3,0	6,5	4,3	15,4		2,3	2,9	6,4	4,3	16,0	
	2.	-	3,5	1,9	4,5	9,9		-	1,5	2,3	5,2	9,0		-	2,3	3,5	3,5	9,4	
	Total	4,1	6,7	7,9	7,9	26,5	6,6	1,6	4,5	8,9	9,5	24,4	6,1	2,3	5,3	9,9	7,8	25,3	5,9

3.7. Treatments on galega field

The initial development and growth of galega plants is slow. Therefore it is of relevant importance to apply several treatment methods here.

Seeds need moisture for germination. The field has to be rolled just after sowing for improving the contact between seeds and soil. The weight of the roller is chosen according to moisture content of soil. By rolling, the soil is surface-levelled.

Due to slow development speed of galega plants pure stands of galega suffer from infestation with weeds at the first year of growing. The productivity of galega in stands sowed under cover crop decreases considerably in the first and second years of growing, but suppression of weeds is more effective there. Chemical weed control has to be carried out both in pure stands and stands with a cover crop.

For controlling annual weeds like *Sinapis arvensis* L., *Viola arvensis* Murr., *Thlaspi arvense* L., *Polygonum* spp., *Tripleurospermum inodorum* L. the herbicides MCPA-1.0 l ha^{-1}, Basagran (contains 480 g l^{-1} of bentazone as active ingredient) 3.0-4.0 l ha^{-1} or MCPB 2.5-3.8 l ha^{-1} are being used. Tank mixtures with Stomp (330 g l^{-1} of pendimethalin) are also well suitable: Stomp 1.5-2.0 l ha^{-1} + MCPA 0.5 l ha^{-1} or MCPB 1.5-2.0 l ha^{-1} or Basagran 1.0-2.0 l ha^{-1}. Basagran 1-2 l ha^{-1} in the mixture with MCPA 0.5 l ha^{-1} or MCPB 1.5-2.0 l ha^{-1} will also do. Mixtures of different herbicides are better since the effect on different weeds usually increases. The impact range of MCPA is similar to MCPB, Stomp improves the effect on hemp nettles, field pansy and fumitory, Basagran on corn mayweed and goose grass. Galega must be in the stage of 2-3 true leaves at the time of treatment.

Starting from the second or third year of use, galega will, unlike the other perennial legumes (lucerne, clover, etc.), phase out from its thick upper layer of plant cover into lower layer such perennial weeds like *Tussilago farfara* L., *Cirsium arvense* (L.) Scop. but not *Elytrigia repens* (L.) Desv. For coach grass herbicides Agil (100 g l^{-1} of propaquizafop) 1.0 l ha^{-1}, Zellek Super (108 g l^{-1} of haloxyfop-R methyl ester) 2.0 l ha^{-1} and Fusilade Super (125 g l^{-1} of fluazifop-p-butyl) are used.

Since the third year of use, the galega field with normal density is almost free of weeds. It is due to vigorous growth of galega and shading of lower layers. In older galega fields (more than 8 years) the spread of perennial weeds like *Aethusa cynapium* L., *Cirsium arvense* (L.) Scop, *Artemisia vulgaris* L., *Urtica dioica* L. has been observed. For controlling the weed centres the herbicide Roundup (360 g l^{-1} of glyphosate) with overall control effect or its analogues – Glialka (360 g l^{-1} of glyphosate), Glyfos (360 g l^{-1} of glyphosate) etc. should be used locally.

3.8. Irrigation

The series of irrigation trials were established on drought-sensitive sod-calcerous soil on limestone in 1975, 1976 and 1980. Ground water from a drilled well (9…10°C) and water warmed up in a reservoir (13.5°C, 17°C and 21°C) was used. The fertilisation rate was 120 kg of P_2O_5 and 120 kg of K_2O per hectare. The weather of trial years was drier than the long-term average. The difference from the precipitation rate was 30 mm in 1975, 147 mm in 1976 and 23 mm in 1980, therefore irrigation was effective at these years (Table 6).

Each mm of irrigation water gave an extra dry matter yield of 17...22 kg. When using cold water from drilled well and warmed reservoir water, the warmer water gave the 10...23% increase in the productivity.

Table 6. *The effect of irrigation on galega's productivity on sod-calcerous soil on limestone (Raig, 1980)*

Year	Irrigation rate	Temp. of water for irrigation	Dry matter yield	Extra yield due to irrigation		Yield of nonirrigated variant
	mm		t ha^{-1}	t ha^{-1}	%	t ha^{-1}
1975	96	10	11,2	2,1	23	9,1
	93	17	12.1	3,0	33	
1976	97	9	8.6	1.6	23	7,0
	97	13.5	10,2	3,2	46	
1980	24	10	8,4	0,4	5	8,0
	24	21	10,0	2,0	25	

For example at Adavere large-scale farm irrigated grasslands have been established on slightly podzolized and leached loamy sands and loams. Irrigated area (317 ha) give usually 2...4 cuts. Seed mixtures for establishing irrigated grasslands included also galega. Mostly mixtures with galega, cocksfoot and red clover are dominating. Grass swards rich in bastard lucerne and smooth bromegrass are also used. Irrigation rates which have been used are very different yearly: from 30 mm up to 193 mm. The 11-year average irrigation rate is 78 mm and the number of irrigations 2.5.

Use of irrigation can be one possibility in galega fields to increase the production. The extra yields due to irrigation and stability of production can confirm it.

3.9. Some peculiarities of mixtures' agrotechnology

The choice of components for mixture, their share in the sward and sowing rate depend on soil characteristics, its water regime and also on the utilisation of sward.

Galega does not usually survive in the fields which locally suffer from surface water or have variable texture and acid reaction. Grasses are more resistant in these conditions and growing them together with galega will increase the production stability of sward.

Smooth bromegrass (*Bromus inermis* L.), meadow foxtail (*Alopecurus pratensis* L.) and reed canary grass (*Typhoides arundinacea* L.) are the grasses which development and growth are suitable for growing together with galega on moist areas. Of drought-resistant grasses timothy (*Phleum pratense* L.), meadow fescue (*Festuca pratensis* Huds.) and cocksfoot (*Dactylis glomerata* L.) should be included in mixtures.

The share of galega in the mixture is usually 40...60%, the sowing rate is 15...20 kg ha^{-1} and row space is 20...25 cm. Grasses can be sown vertically with galega rows.

Mixtures are also less infested with weeds in the year of sowing.

4. SEED GROWING

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Seed growing of fodder galega is much more simple in Estonian weather conditions and getting seed is more stable when in case of lucerne and clover. Although it is possible to obtain seed from swards intended for growing fresh material, the lighting conditions, etc. are better in specially established seed fields with a wide row space and the obtained seed yield in this case is significantly higher.

In 1976 fields for harvesting seed yield with a row space of 60 cm, sowing rate of 10 kg ha^{-1} on three types of soil were established: Variant 1 – sod-calcerous soil on limestone, variant 2 – sod-podzolic soil, variant 3 – leached sod-calcareous soil. As an average of 10 years, 230...420 kg of seeds were received per one hectare. PK fertilizer (90 kg of P_2O_5 and 60 kg of K_2O) was given every year since establishing the seed field. The yield results are given in Table 1.

Table 1. *Seed yields (kg ha^{-}1) of galega in long-term large-scale trials, 1977…1986 (Raig, 1988)*

Year	Var.1 Sod-calcerous soil on limestone	Var.2 Sod-podzolic soil	Var.3 Leached sod-calcareous soil
1977	236	201	780
1978	427	182	339
1979	240	265	700
1980	207	198	652
1981	204	210	266
1982	450	420	400
1983	430	363	330
1984	130	275	0
1985	415	100	353
1986	316	200	416
average of 10 years	305	241	424

The seed yield depends essentially on soil, temperature during the flowering time and precipitation. Higher yields were received on soils with high lime content (var. 1&3). In 1984, in the beginning of June, at the time of flowering the night frost (from -1 down to -2°C) damaged flowers and decreased the seed yield considerably (var. 1) and caused total failure of seed yield (var.3).

Comparing the seed yield of galega to the seed yield of hybrid lucerne, which Estonian statistical average seed yield is 70 kg ha^{-1}, the seed yields of galega are 3...6 times higher.

It also became evident that by using the above-mentioned sowing rate (10 kg ha^{-1}) the plant cover of these fields was too dense as a result of which the light regime became worse, plants lodged and the yield decreased in total. In order to find out the optimum sowing rate, supplementary trials with the sowing rates of 4-6-8-10 kg ha^{-1} and with the row space of 62.5 cm were established. In the second trial there were different row spaces - 12.5; 25.0; 37.5; 62.5 cm. The sowing rate was 40 kg ha^{-1} and sowing depth was 2.0 cm.

The vegetation period of 1989 started early, the average air temperatures of May and June were +1...+1.7°C degrees higher than the usual ones, the amount of precipitation in June was 75 mm, i.e. 129% of the norm. The highest seed yield – 690 kg ha^{-1} – was obtained in 1989 with a wide row space (62.5 cm) and the sowing rate of 4 kg ha^{-1} (Table 2). Analogical results (654 kg ha^{-1}) were received with the wide row space and a relatively high sowing rate (40 kg ha^{-1}) (Table 3). In the following year, i.e. in 1990, galega's seed yield decreased. In spring the growth and development of plants were slow due to frequent night frosts. The amount of precipitation in May and June was lower, i.e. 51% of the norm. As galega has a strong root system, the summer drought did not considerably affect the seed yields of the variants. The trial results indicated that in the 3rd year (1991) the seed yield did not depend on the sowing rate, but still depended on the row space. The plant cover density of the swards sowed with wide row space (62.5 cm) was still thinner and yields amounted to 270.9 and 378.1 kg ha^{-1}.

The trial results of 1993 were very much affected by the night frosts in June (-1...-3°C). Galega was then at the stage of flowering; therefore the seed yields remained lower – 120...149 kg ha^{-1}.

Table 2. *The dependence of galega's seed yield on sowing rate (Meripõld, 1994)*

Var	Row space	Sowing rate	Seed yield, kg ha^{-1}					5-year ave-rage
			1989	1990	1991	1992	1993	
1	62.5	10	619.0	270.9	289.8	214.0	149.6	308.5
2	62.5	8	647.0	378.0	327.6	228.0	148.2	345.7
3	62.5	6	612.0	365.4	378.1	269.0	120.6	349.0
4	62.5	4	690.0	428.9	302.4	221.0	144.1	357.0

Table 3. *The dependence of galega's seed yield on row space (Meripõld, 1994)*

Var	Row space	Sowing rate	Seed yield, kg ha^{-1}					5-year ave-rage
			1989	1990	1991	1992	1993	
1	12.5	40	401	283.5	220.5	234.0	128.9	253.6
2	25.0	40	563	303.0	239.4	152.0	120.0	275.5
3	37.5	40	570	306.9	264.6	231.0	131.7	300.8
4	62.5	40	654	294.1	270.9	193.0	120.0	306.4

In conclusion, according to the field trial results, the average seed yield of 5 years was 253...357 kg ha^{-1}. The highest seed yields (612...690 kg ha^{-1}) were obtained in the 2nd production year with a wide row space (62.5cm). The optimum sowing rate was 4...6 kg ha^{-1}.

Sowing rates over 6 kg ha^{-1} did not increase seed yields. The fact that seed yields have become more homogenous over years is caused by intensive vegetative propagation of galega as well as by self-regulation of plant stems density.

For now the great advantages of fodder galega compared with other leguminous crops concerning the obtaining of seed yields have become obvious. It is very important that fodder galega is able to give a stable seed yields in regions where it is not possible to obtain a good seed yield from lucerne (Raig, 1993; Nõmmsalu, Meripõld, 1996).

Seed yield of fodder galega depends significantly on establishment and field work. Lime-rich mineral soils with normal moisture regime are suitable for seed growing. Sowings without a cover crop with a wide row space (45...60 cm) should be preferred, which will give seed already at the next year. Sufficient sowing rate is 4...6 kg of seed per hectare.

The seed`s pre-sowing inoculation with a special bacterial fertiliser is essential.

The soil should be well cultivated and levelled and made dense by a land roller pre- and after sowing in order to get the even sowing depth (1-2 cm). P-K fertiliser should be given according to soil characteristics in the proportion 1:1 both before establishing the seed field and early spring or autumn of the each growing year.

With the object of weed control, the field should be treated with herbicides in the sowing year. Also tillering can be used between the rows or weeds can be controlled by cutting. Using the tillering between the rows for thinning the plant cover, it has to be continued also at the following years, usually in spring.

The seed yield must be cleaned from the seeds of foreign species and weeds, which seeds are distinguished from the others.

Galega starts blooming at the end of May or in the beginning of June, depending on spring, and it lasts for 1...2 weeks. Due to large open blossoms, bees and bumblebees like to visit galega plants and it helps in increasing the seed yield.

5. BREEDING OF FODDER GALEGA

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5.1. The potential for breeding an improved fodder galega

Fodder galega is a "young" crop (domesticated only about 70 years ago) which does not have a prolonged cultivation and breeding history (Rollov, 1908; Simonov, 1938; Raig, 1988; Nõmmsalu, 1993).

The first galega variety Gale was produced in Estonia by the specialists of the Research Institute of Agriculture (H. Raig, J. Metlitskaja) and All-Russian Institute of Fodder Crops (S. Simonov, Z. Jartieva) by using mass selection. In Estonia the variety Gale has been on the official variety list since 1988.

In 1985...1990 official trials of variety Gale were carried out in 65 cultivar control stations which situated in areas with different climatic conditions on the territory of the previous Soviet Union. The obtained research results indicated that galega variety Gale was in the north-western and northern region of Europe not inferior, and by some parameters even superior to the basic fodder crop lucerne. The superiority of Gale in seed production was especially evident in northern growing areas (Metlitskaja, 1992).

The variety Gale is used not only as a forage plant but also as a crop for soil improvement (Raig, 1994).

The galega possesses a high intensity of symbiotrophic nitrogen nutrition due to the symbiosis with root nodule bacteria (*Rhizobium galegae*). In Estonia the *Rhizobia* inoculation can improve galega yield by 80%, while N fertilization – only by 35%.

An important task now is to improve the existing variety and breed new varieties with the improved, economically valuable characteristics. Therefore, studing the initial material for the selection of galega and working out the methodological foundations for selection process are of great significance. The aim of our work was to investigate the symbiotic polymorphism of galega plants and their selection for N_2 -fixing activity with a view to increase yields, seed production and land reclamation purposes.

The collection of galega specimens was studied in the trial fields of the Estonian Research Institute of Agriculture in 1984...1987. The institute is situated in the northern agroclimatic district of Estonia, approximately 15 km from Tallinn. The weather was characteristic to the given district during the research period. Compared with the average of several years, the trial years can be characterised as follows: 1984 and 1985 – cold, with excess moisture; 1986 – moist, relatively warm; 1987 – cold, with excess moisture.

The specimens were obtained mostly from the former All-Union Institute of Plant Production, but also from the other experimental establishments from the previous Soviet Union. During the investigation period we studied 17 specimens of galega. The geographical origin of specimens was the following: 6 from Krasnodar territory, 2 from Stavropol area, 2 from Armenia, 1 from Georgia, Mordovia, Komi, Moscow and Leningrad districts. The collection contained 6 local and 11 wild specimens (Table 1).

Table 1. *The collection of galega specimens studied in Estonia (1984...1986)*

No	Specimens	Origin of specimens	Year of the collection of seeds	Reproduction
9494	wild	Krasnodar territ., Maikop	-	1979
11911	wild	Armenia, Loori hayfield	-	1978
13306	wild	Krasnodar territ., forest	1932	1979
16568	wild	Stavropol, Železnovodsk	1933	1979
16586	wild	Stavropol, Pjatigorsk	1933	1970
16942	wild	Krasnodar, Toply kluts	1934	1979
17185	wild	Krasnodar, Bely kluts	1934	1979
17188	wild	Krasnodar, Beloretsensk	1934	1972
24864	wild	Krasnodar, Suntuk	1935	1979
28670	wild	Armenia, Sarvangai	1950	1979
33157	wild	Krasnodar, Tulski distr.	1953	1979
33784	local	Moscow distr., Institute of Fodder Crops	1974	1978
39342	local	Mordovia, Research Station	1974	1981
44240	variety Gale	Estonian Research Institute of Agriculture	1983	1983
46800	local	Komi, Ural Research Centre	1982	1982
46801	local	Georgia, Bakurian Botanical Garden	1981	1981
46802	local	Leningrad distr., Kirisi	1983	1983

Specimens were planted by seedlings (50×50 cm) in 4 replications. There were two variants used for investigation: one for green plant material, the other for seed. Totally 1640 individual plants were studied, 40 in each specimen. The registered variety Gale was used as a standard. In order to study and pick out the valuable genotypes from the population of the variety Gale, it was planted by seedlings (100×100 cm) in the nursery garden. Before sowing the seeds were inoculated with *Rhizobium galegae*, containing the active strain 740 R.

The breeding program included studing of intraspecific variation, initial material for breeding and search of possibilities for increasing the symbiotic efficiency of galega. The nitrogen-fixing activity was determined in three independent microvegetative trials (under sterile conditions) by using the acetylene reduction assay (Hardy et all., 1968), 1145 plants were screened.

Research of specimens by the basic selection parameters

There were significant differences both between years and specimens **in the lenght of growing period** and in that of development stages. The beginning of growth in spring was 4...6 days earlier in case of local specimens from Mordovia (k-39342), Komi (k-46800), the variety Gale from Estonia (k-44240), from Moscow (k-33784) and Leningrad districts (k-46802). Among wild specimens the ones from Krasnodar (k-9494) and Stavropol (k-16586) territories had an early emergence. According to the duration of vegetation period, the specimens were divided into groups. Wild specimens from Krasnodar (k-24864, 33157, 13306) and Armenia (k-11811) had a short vegetation period (93...95 days). The variety Gale (k-44240), the local varieties from Komi (k-46800), Mordovia (k-39342), Moscow (k-33784) and Leningrad (k-46802) districts, and the wild specimens from Krasnodar (k-17185, 17188, 9494) and Stavropol (k-16586) territories had a medium-long vegetation period (96...99 days). A longer period (100...103 days) was characteristic to the local specimen from Georgia (k-46801) and of wild specimens from Krasnodar (k-16942) and Stavropol (k-16586) territories.

As to **the height of plants** in the sowing year, the local specimens from Komi (k-46800) and Mordovia (k-39342) exceeded considerably that of the standard variety Gale (37±3.3 cm). On the same level with the standard were the specimens from Moscow (k-39342) and Leningrad (k-46802) districts. The wild specimens from Krasnodar (k-11811, 13306, 16942) and the local specimens from Georgia (k-46801) were considerably shorter. The height of plants on the 20th day after the beginning of vegetation varied in 1985...1986 between 44 and 68 cm. On the same level with the standard (63...68 cm) were the local specimens from Mordovia (k-39342), Komi (k-46800), Moscow (k-33784) and Leningrad (k-46802), the wild specimens from Stavropol (k-16586, 16568) and Krasnodar (k-16942) territories. As to the height before the first cut, there were no considerable differences. On the average of years the local specimens from Leningrad (k-46802), Komi (k-46800) and Mordovia (k-39342) were on the level of the standard variety (102...105 cm). In our trials the height of plants on the 20th day after the first cut reached 41...57 cm. The tallest (55...57 cm) were the local specimens from Leningrad (k-46802) district and the wild specimens from Armenia (k-28670). On the same level as the standard variety were the local specimens from Moscow (k-33784), Mordovia (k-39342), Komi (k-46800), Georgia (k-46801) and the wild specimens from Stavropol (k-16586, 16568) and Krasnodar (k-9494, 16542) territories. Before the second cut, a group of local specimens from Mordovia (k-39342), Komi (k-46800), Leningrad (k-46802) and Moscow (k-33784), as well as the wild specimens from Armenia (k-28670, 11811), Krasnodar (k-18185, 16942) and Stavropol (k-16586) were taller (63...75 cm).

The number of stalks per m^2 varied in the year of sowing between 17 and 36, the average number being 23.7 stalks/m^2 The wild specimens from Krasnodar (k-9494, 17188, 24864, 33157, 17185) and Stavropol (k-16586) territories, the local specimens from Leningrad (k-46802) and Komi (k-46800) had in the sowing year a thick stand of stalks, i.e. 25...36 stalks/m^2. In the following years the stand of stalks was thickest, i.e. 46...57 stalks/m^2, in case of the specimens from Mordovia (k-39342), Komi (k-46800) and Leningrad (k-46802), as well as the wild specimen from Stavropol (k-16568) territory. On the standard level (42...45 stalks/m^2) were the local specimens from Moscow (k-33784) and the wild specimens from Krasnodar (k-17188, 17185, 13306) territory and Armenia (k-28670).

The percentage of leaves in the sowing year was 46...71%. The percentage of leaves was highest on the local specimens from Leningrad (k-46802), Komi (k-46800), Mordovia (k-39342) and the wild specimens from Krasnodar (k-33157, 17185, 24864, 17188, 13306) and Stavropol (k-16568) territories. The highest percentage of leaves (48...56%) in 1985...1986 was on the wild specimens from Armenia (k-28670, 11811), Stavropol (k-16586, 16568) and Krasnodar (k-33157, 9494, 13306) territories. In the second cut all specimens had a high percentage of leaves (52...65%). This parameter was the highest on the specimens from Georgia (k-46801).

According to **the thickness of stalks** on the level of the 4th internode, the specimens could be divided into two groups. To the first group belonged the specimens with thin stalks, i.e. 3,5...4,0 mm in the first cut and 2.5...2.8 mm in the 2nd cut. These were the wild specimens from Krasnodar (k-9494, 24864, 16942) and the local specimen from Georgia (k-46801). The local specimens from Mordovia (k-33784), Komi (k-46800) and variety Gale from Estonia made up the 2nd group of specimens with thick stalks, i.e. 4.8...5.7 mm in the 1st cut and 2.9...3.3 mm in the 2nd cut.

Biochemical analyses indicated a difference in the dry matter content and in its composition (protein, ash, fats, crude fibre). In the year of sowing the content of dry matter varied between 19...26%. In the following years the dry matter content in the 1st cut was 18...26%, in the 2nd cut 28...34%. The green material, which was left after seed harvesting, contained 36...43% of dry matter. Of all samples the protein and dry matter contents were the highest on the variety Gale (k-44240) and the local specimens from Moscow (k-33784), Leningrad (k-46802) districts and Komi (k-46800) and Mordovia (k-39342).

By the **yield of fresh material** in the year of sowing, we picked out specimens which were able to give a yield of full value already in the 1st year. Their yielding ability was between 110...150 g/m^2, which was 164...224% of the standard. To this group belonged the local specimen from Komi (k-46800), the wild specimens from Krasnodar (k-24864, 9494) and Stavropol (k-16586) territories and Armenia (k-28670). By the yield of fresh material (two cuts, average of three years), the specimens could be divided into three groups: the group of specimens with high yielding capacity, i.e. 1950...2332 g/m^2 (88...106% of the standard). To this group belonged all local specimens: from Estonia, Komi, Mordovia, Moscow and Leningrad (k-44240, 39342, 33784, 46800, 46802). The wild specimens from Krasnodar (k-9494, 33157) and Stavropol (k-16586) territories and the local specimen from Georgia (k-46801) made up the group of low productivity - 983...1316 g/m^2 (45...60% of the standard). All other specimens belonged to the group of medium productivity, 1483...1759 g/m^2 (67...80% of the standard).

By seed yields the best (33.2...42.1 g/m^2) turned out to be the variety Gale from Estonia (k-44240), the local specimens from Mordovia (k-39342), Komi (k-46800), Moscow district (k-33784) and the wild specimens from Krasnodar territory (k-24864, 17185). The trial years (1985...1987) were on the whole favourable for seed production.

As to **the winterhardiness**, the galega specimens differed considerably. The main selection for winterhardiness took place in the very cold winter of 1984...1985. The most winterhardy specimens (92.5...92.8%) were the variety Gale from Estonia (k-44240) and the local specimen from Mordovia (k-39342). The local specimens from Komi (k-46800) and Moscow (k-33784), the wild specimens from Krasnodar (k-17185, 17188) and Armenia (k-28670, 11811) had a winterhardiness on the level of 70.0...82.5%. Overwintering was bad (40...55%) in the case of the specimens from Krasnodar (k-9494, 33157) territory. In the following winters of 1985...1986 and 1986...1987 the differences diminished, the average overwintering being 90.5...100%.

The characteristics of the best specimens of galega are given in Table 2.

Biometrical analysis of biological and morphological characteristics of galega

As it was shown earlier, the galega specimens studied in Estonian conditions, differed considerably in their morphobiological parameters. It is of primary importance to study the order of intraspecific organization of species, which facilitates the selection of initial material. Therefore, the aim of the next stage in our research was to systematise the information about the genetic polymorphism of galega by the basic morphobiological parameters.

The data about the individual variability of basic morphobiological parameters of galega specimens, studied in the field conditions in 1984...1987, were grouped on the basis of geographical origin of plants. The studied specimens were divided into 5 groups, being evolutionally formed in different geographical conditions: I – Krasnodar, II – Stavropol, III – Armenia, IV – Georgia, V – Moscow.

Table 2. *Characteristics of the best specimens of galega studied in Estonia in 1984...1987*

No	Speci-men	Origin	Winter-hardi-ness, %	Fresh material 2 cuts, kg/m^2	Number of stalks per m^2	% of leaves	Height of stalks, cm		Seed yield, g/m^2	Dry matter content,%	Crude protein content,%
							1st cut	2nd cut			
44240	Variety Gale	Estonia	93	2.21	44.7	46.5	108.3	69.3	31.5	25.8	20.8
39342	Local	Mordovia	93	2.33	56.5	46.1	102.0	71.3	36.2	21.5	21.6
46800	Local	Komi	83	1.98	53.3	47.0	104.7	71.3	34.0	25.0	20.6
33784	Local	Moscow distr.	75	2.17	42.3	45.8	101.3	72.0	33.2	25.0	22.4
17185	Wild	Krasnodar territ.	80	1.76	46.7	47.7	96.7	65.7	34.0	24.5	19.2
46802	Local	Leningrad distr.	65	1.95	45.7	40.1	105.0	74.0	25.7	25.5	17.6

Within the groups the data about biometrical variability of populations were put together and standardised. The parameters inside the groups were aggregated into one parameter G. For that different functions were used which expressed the dimension of all characters averages under G1 and G2 on different groups in equal system of XY coordinators.

Bigger differences on horizontal level have group centres from Krasnodar (1.25) and Moscow (-0.20). On vertical level the group of populations from Armenia (3.12) was different (Table 3).

Table 3. *Cluster analysis of geographical groups of of galega specimens*

Groups	Origin of specimens	Function X_{G1}	Function Y_{G2}
1	Krasnodar	1.25	-0.09
2	Stavropol	0.20	-0.98
3	Armenia	1.14	3.12
4	Georgia	-0.03	-0.84
5	Moscow district	-0.20	0.18

The first and second group presented wild specimens which had been collected in the foothills of the North Caucasus, the Armenian group presented wild specimens from the mountains of Armenia, the Georgian specimens were obtained from the botanical garden of Georgia. The Moscow group included specimens obtained from the seeds of the All-Union Institute of Fodder Crops.

Table 4 gives the comparison of the group of wild specimens from the North Caucasus (k-9494, 13306, 16942, 17185, 17188, 24864, 33157, 16568, 16586) and that of specimens (k-33784, 39342, 44240, 46800, 46802), the initial material of which has passed selection of many years in the conditions of Moscow district.

Analysing the data concerning the beginning of growth period in spring, we could distinguish considerable differences between the two groups. In the group of specimens, originating from Moscow district, early emerging plants were dominating, whereas the majority of wild specimens from Krasnodar territory was characterized by a later emergence. As to the dates of flowering, early flowering plants were more characteristic of the wild specimens of Krasnodar.

Comparing the coefficients of correlation, we distinguished considerable differences in several parameters between the two groups. These differences indicate a genetic determination in the groups (Table 5).

The group of specimens from Armenia was not presentable for futher statistical analysis. But our data about this group could still help to prove the theory of mr. Simonov about the existence of a mountainous ecotype of galega in the vicinity of Lori.

The analysis of the results showed that the described specimens were representing the North-Caucasian, the mountaineous Trans-Caucasian (by Simonov Lorian) and the Moscowian ecotypes.

In order to determine the range of variability of several morphological parameters of galega in its natural growing environment, and in order to select out the most valuable genotypes, we studied the Idzhevaiski district in Armenia, the Maikop and Apseron districts in Krasnodar territory. All in all, we described 12 cenopopulations of galega in their generative state. Such parameters as the height of generative stalks, the number of internodes on the stalk, the length of leaves were characterized by low variability (v%) – 7.8...17.6%. The thickness of stalks was characterized by medium variability - 20.9...21.4%. More variable (35.2...45.7%) were the parameters of the generative parts of stalks – the number of pods in cluster and the length of cluster. On the whole the variability of parameters was lower in the natural growing environment than in the conditions of introduction.

Table 4. *Comparison of morphobiological parameters of two groups of galega: wild specimens from the North Caucasus and introduced specimens from Moscow district*

Parameters	Results					
	$x \pm M_x$	t-st	lim	σ	V %	t-st
Beginning of growth in spring, points	1.35±0.06 / 1.82±0.07	5.11**	1-3 / 1-3	0.56 / 0.64	42±3.2 / 35±2.7	1.68
Height at 1st cut, cm	119.1±1.76 / 107.6±1.72	4.67**	66-160 / 70-140	16.6 / 17.1	14±1.1 / 16±1.2	1.23
Number of stalks per plant	24±0.93 / 23±1.25	0.64	2-54 / 2-113	8.81 / 12.36	37±3.1 / 53±4.1	3.12**
Weight of fresh material,1st cut, g	946.6±39.51 / 640.2±33.96	5.87**	100-2000 / 25-1820	374.9 / 336.2	40±3.0 / 53±4.1	2.55**
Weight of fresh material, 2nd cut, g	491.1±21.55 / 398.2±18.70	3.25**	150-1360 / 50-980	204.4 / 185.1	42±3.2 / 46±3.6	0.83

Note: Numerators indicate the results of the Moscowian group, denominators of North-Caucasian group
* $p < 0.05$ ** $p < 0.01$

Table 5. *Comparison of biomorphological parameters of North-Caucasian and Moscowian groups of specimens*

Comparable parameters	Coefficients of correlation		
	North-Caucasian group	Moscowian group	t-st
Beginning of vegetation – beginning of flowering, points	-0.38**	-0.15	1.59
Beginning of vegetation, points – Height on the 20th day of vegetation, cm	-0.24*	-0.51**	1.86
Beginning of flowering, points – Weight of green material, 1st cut, g	0.1	0.24*	0.86
Beginning of flowering, points – Thickness of stalks, 1st cut, mm	0.03	0.31**	1.87
Height of 1st cut, cm – Weight of green material, 1st cut, g	0.46**	0.44**	0.16
Height of 1st cut, cm – Weight of 2 cuts, g	0.39**	0.42**	0.23
Weight of 1st cut, g – Beginning of vegetation	0.33**	0.01	2.13*
Height of 2nd cut, cm – Height on the 20th day after cut	0.06	0.38**	2.18*
Number of stalks – Weight of 2 cuts, g	0.19	0.68**	4.08**
Weight of 1st cut, g – Number of stalks	0.44**	0.66**	2.07*

* $p < 0.05$ ** $p < 0.01$

5.2. Evaluation and perspectives of the selection of fodder galega

The ecological and economic laws give many important arguments in favour of developing the ecological approaches in plant production. An increasing role of fodder crops in agriculture demonstrates a necessity to use bioenergetic criteria in plant breeding to increase efficiency of utilisation of natural resources by plant. The beneficial interactions between plants and microbes are of high importance for sustainable agriculture.

A domination of symbiotrophic over combined type of nutrition may related to the fact that galega is a "young" crop, which does not have a prolonged breeding history. A domination of the combined type of N nutrition over symbiotrophic one is typical for the "old" legumes crops (pea, lucerne), possibly due to an impoverishment of germaplasm in the "symbiotic" genes resulted from the plant cultivation under conditions of a sufficient combined N supply (Provorov, 1999). For improving symbiotic nitrogen fixation (SNF), breeding both interacting organisms – plants and nodule bacteria, is required.

Still, selection of fodder galega by the ability to symbiosis has not been carried out before. The aim of this work was to investigate symbiotic polymorphism of fodder galega plants and their selection for SNF activity with a view to increase fresh material and seed production and nitrogen fixation for agricultural and land reclamation purposes.

The individual variability of the fodder galega variety Gale by the N-fixing capacity in sterile experiment conditions (total 1145 plants were screened) was studied. The following *Rhizobium galegae* strains were used: commercial strain 740 and wild type strain 812. The N-fixing activity was determined in three independent micro-vegetative trials by using the acetylene reduction assay (ARA).

The breeding program included studying of intraspecific variation of the initial material for breeding and search of possibilities for increasing the symbiotic efficiency of galega.

Variety Gale possessed a high level of variability for symbiotic nitrogen fixation. For the acetylene reduction activity, the coefficient of variation of individual plants was 77.8-127.3%.

A pronounced skewness (As=+1.02...+1.69) for nitrogenase activity was revealed demonstrating that a majority of plants possessed a low level of nitrogen fixation. A similar asymmetric distribution of individual plants for nitrogen-fixing activity was revealed in alfalfa and sweet clover (Provorov, Simarov, 1990). As much as 14.8% of galega plants did not display a nitrogen-fixing activity (Fix^-).

Plants with maximal nitrogen-fixing ability (Fix^{++}) and good morphological parameters as well as Fix^- plants were picked out and replanted into the field conditions. The selected Fix^{++} plants when compared with Fix^- plants demonstrated a good development in the first year (Table 1), yielding ability and velocity of entering the generative stage at the second year (Table 2). A possibility to improve plant´s growth via selection for acetylene reduction activity was revealed previously in alfalfa (Barnes et al., 1984) and pea (Tikhonovich et al., 1987).

The Fix^{++}plants are included as an initial material for the further selection. The obtained data are used for developing the methodological basis for breeding new highly-productive and symbiotically active varieties.

Table 1. *Growth of fodder galega plants selected according to their nitrogen fixing activity in field trial (first year)*

Plant growth	Number of plants		
	Fix^{++}	Fix^-	Total
1 stalk (4-10 cm)	35	46	81
1-2 stalks (11-15 cm)	22	26	48
3-4 stalks, shrub (1620cm)	31	27	58
5-8 stalks densely shrugged (20-25cm)	29	10	39

Difference between Fix^{++} and Fix^- is significant (χ^2=9.90; P_o<0,05)

This method is most suitable at initial breeding stages for excluding genotypes with poor symbiotic nitrogen-fixing activity. Application of ARA at the next stages is more complex because it does not always correlate to the plant´s yield. The ARA is a more effective selection criteria when plants are screened from a defined plant population than from a collection of diverse genotypes.

Table 2. *Growth of galega plants differing in nitrogen fixing activity under field conditions (second year)*

Traits	Group of plants		
	Fix^{-}	Fix^{++}	t_{St} (P_0)
DM yield (air-dried) g/plot	2195 ± 250.5	4025 ± 463,5	3,52(P_o<0,05)
Height of plants, cm	54,8 ± 3,14	70,3 ± 3,89	3,10(P_o<0,01)
% vigorously developed plants	35,0 ± 7,54	62,7 ± 6,57	2,74(P_o<0,01)
% of plants in generative stage	52,5 ± 7,90	82,3 ± 5,34	3,12 (P_o<0,01)

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