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# THE EFFECT OF *LATHYRUS JAPONICUS* ON SOIL FERTILITY IN ICELAND

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## ABSTRACT

Nitrogen is the most limiting nutrient in agriculture and degraded land. Biological fixation of atmospheric nitrogen by legumes is an efficient process that supplies large amounts of nitrogen to soil. This study focuses on assessing the effectiveness of Purple beach pea in improving the fertility of degraded soils in the Hekluskógar area in South Iceland. The objectives were to determine the effects of Purple beach pea on (i) selected soil chemical properties such as C, N, P, Ca, Mg, K and pH, and (ii) the growth rate of the ryegrass *Lolium xhybridum* in soils where Purple beach pea has grown compared to soil where Purple beach pea is absent in a greenhouse experiment. Soil samples were collected at 0-5 cm and 5-15 cm at randomly selected sites where Purple beach pea has been growing for the last 15 years (treated) and control sites (untreated) at Hekluskógar. Soil samples were analysed for carbon and nitrogen using the Dumas method. Other measurements included phosphorus, calcium, magnesium, potassium, pH, and C:N ratio. The top 15 cm of soil was collected from both treated and untreated sites and used in a greenhouse experiment, where 25 seeds of ryegrass were seeded in eight separate pots for each treatment. The height of ryegrass was measured and the biomass was measured after drying in an oven. The results showed that treated sites had significantly ($p < 0.05$) higher total soil nitrogen and carbon content in 0-5 cm compared to the untreated sites. Also, the oven-dried biomass of the ryegrass was significantly ($p < .0015$) higher in the treated soil than untreated soil. This study thus demonstrated the beneficial effects of Purple beach pea on soil nitrogen and carbon plus beneficial effects on growth rates of ryegrass. This clearly shows that Purple beach pea could be important in revegetation of eroded land in Iceland

**Key words**: legume, soil, fertility, nitrogen, ryegrass

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## 1. INTRODUCTION

Soils form fundamental natural resources and provide the basis for all life on terrestrial ecosystems. Degraded soils are typically of poor quality with regards to physical, chemical and biological properties (Arnalds & Kimble 2001). Iceland, since the human settlement around AD 874, has suffered from major land degradation and soil erosion (Arnalds et al. 2001). The main contributing factor has been the heavy utilization of terrestrial sources, primarily by extensive removing of natural woodlands and grazing by domestic livestock (Gísladóttir et al. 2011). The degraded soils are typically characterized by the low capacity to retain water, few sources of macro-elements, rich in volcanic glass and low amounts of allophane clay and organic carbon compared with vegetated areas (Arnalds 2015). The main soil types in Iceland are Andosols, Vitriols, and Histosols (Arnalds 2015). The characteristics of the Vitrisols are sandy and shallow as well as dominated by the volcanic glass containing low organic carbon (0.39%) (Óskarsson et al. 2004).

Carbon and nitrogen cycling through soil organic matter can improve soil fertility (Drinkwater et al. 1998). Restoring soil carbon is thus essential to enhance soil quality and improve soil productivity, maintain clean water, and reduce atmospheric $CO_2$ (Lal 2004). Carbon is critical to soil functioning and productivity, and a main component of and contributor to healthy soil conditions. The C:N ratio is a quick way to evaluate the balance between carbon and nitrogen present in the soil that are essential for soil and vegetation growth as well as microbial health. Also, the C:N ratio shows the degradation rate of organic matter, which is the main source of carbon in soil (Swangjang 2015).

Studies have shown that the biological fixation of atmospheric nitrogen is an efficient process that supplies large amounts of nitrogen by legumes to produce high crop yields rich in protein content, provide forage for livestock and to be used for purposes of restoration of degraded soils (Goff 2014; Vaz Patto & Rubiales 2014). Legumes can also be very effective for reclamation of large unproductive areas, such as *Lupinus nootkatensis* (Nootka lupine) which has been widely used in Iceland for reclamation of large barren areas, increasing vegetation cover and soil fertility (Magnusson et al. 2002).

Hekluskógar is one of the largest restoration projects that is now under way near the volcano Mt. Hekla in a highly eroded area in south Iceland. The eroded areas have limited ecosystem function such as a low nutrient content of the soil, low water holding capacity and less vegetation cover, and also lack important soil organisms (Aradottir 2007; Arnalds & Kimble 2001). The Hekluskógar area is being restored by native birch and willow woodlands as well as shrublands on more than 900 $km^2$ of eroded land surrounding the Mt. Hekla volcano (Óskarsson 2009). Native legume species have also been introduced in the Hekluskógar area (Aradottir 2007).

*Lathyrus japonicus* (Purple beach pea) is a legume that is found in Iceland. Purple beach pea is a long-lived perennial legume that is native to the temperate coastal area of northern and Arctic zones. The typical habitat of Purple beach pea is sandy or stony seashores and other coastal locations (Asmussen 1993). Purple beach pea has a different growth form than lupines, and spreads easily with rhizomes. Purple beach pea could be a candidate for use in reclamation in Iceland to improve soil nitrogen content of soil similar to that of lupine. This study focuses on assessing the effectiveness of Purple beach pea in improving the fertility of degraded soils in the Hekluskógar area where Purple beach pea has grown for a long time (treated area) and where Purple beach pea is absent (untreated area).

### 1.1 Main goal

To determine the effect of *Lathyrus japonicus* (Purple beach pea), a native legume, on soil fertility at an eroded site in Hekluskógar in South Iceland.

### 1.2 Specific objectives

To determine the effects of Purple beach pea on:

a) selected soil chemical properties: C, N, P, Ca, Mg, K, and pH
b) growth rate of the ryegrass *Lolium xhybridum* in soils where Purple beach pea has grown compared to soil where Purple beach pea is absent.

## 2. LITERATURE REVIEW

Various *Lathyrus* species are used to increase vegetation cover, produce green manure, controlling soil erosion, and to reclaim degraded land. *Lathyrus* species have traits that render them valuable for agricultural production. These have been evaluated for the high potential to be used as organic fertilizer. These include *L. sylvestris* (flat pea), *L. tingitanus* (tangier pea), and *L. sativus* (chickling vetch) (Wright 1985; Drouin et al. 1996). The genus *Lathyrus* commonly establishes effective nitrogen fixation symbiosis with *Rhizobium leguminosarum* in different geographical locations (Mutch & Young 2004; Han et al. 2010). *Lathyrus* species have been used to improve soil nitrogen content (Vaz Patto & Rubiales 2014).

Purple beach pea has a wide range of potential uses which include restoration of denuded areas and possibly agronomic functions. This species occurs in coastal dunes that are known to be very dynamic systems. In these environments, succession starts from plants that are highly tolerant to sand accumulation, salinity, and low nutrient content to less disturbance-tolerant and stress-tolerant and supposedly more competitive species. Purple beach pea often grows along stabilized dunes (Houle 1997).

In Iceland Purple beach pea forms large, green patches with grasses and are sometimes seen in sand dunes near the sea, for instance in Hornstrandir in the northwest of Iceland, where Purple beach pea has established itself. It is palatable to sheep but vulnerable to continuous grazing (Kristinsson 2005).

Revegetation of degraded soils using nitrogen-fixing species has become a progressively important tool in the rehabilitation of natural landscapes that are affected by land degradation (Dollard & Carrington 2013). Given the distribution of Purple beach pea in Iceland it is likely that it could become important in revegetation in Iceland, especially since it has shown to enhance recovery of degraded lands in the Hekluskógar area.

## 3. METHODS AND MATERIALS

To determine if Purple beach pea has positive effects on soils, a site was selected at Hekluskógar where Purple beach pea has been growing for the last 15 years (MH Jóhannsson, May 2018, Soil Conservation Service of Iceland, personal communication). Soil samples were taken to analyze the nutrient content of the soil and to conduct a greenhouse experiment with soil from treated and untreated sites.

### 3.1 Description of the study area

This study was conducted at Hekluskógar (64°02' N, 019°50' W) in a highly active South Iceland seismic volcanic zone, near Mt. Hekla. Hekluskógar is a big reclamation area with a total size between 900 and 1000 $km^2$. Erosion is extensive in the Hekluskógar area, eroded landscapes providing less than 33% vegetation cover (Aradottir 2007). The soils are classified as Vitric Pumice Brown Andosol (O Arnalds, 20 August 2018, Soil Conservation Service of Iceland, personal communication). These soils are largely influenced by the volcanic activities of Mt. Hekla (Arnalds 2015), which has erupted approximately 23 times since the settlement of Iceland in 874 AD (Thordarson & Larsen 2007). Due to the frequent eruptions, volcanic tephra (ash) has been deposited and is easily moved by wind and water. This can cause extensive disturbance and damage to ecosystems and has been coupled with anthropogenic activities such as clear-cutting of natural woodlands and overgrazing (Aradottir 2007). In this area, the natural woodlands were already gone by 1882 when the remaining poor vegetation and soil were blown away in a big storm (Olafsdottir et al. 2001).

The Hekluskógar project has been using native tree birch (*Betula pubescens)* and willow (especially *Salix phylicifolia* and *S. lanata*), Lymegrass (*Leymus areanarius*) and other grasses (*Festuca* spp. and *Poa pratensis*) (Aradottir 2007) for reclaiming land.

In 2003, the legume Purple beach pea was introduced experimentally into barren areas with little vegetation cover at Hekluskógar (MH Jóhannsson, May 2018, Soil Conservation Service of Iceland, personal communication). In 2018, the total cover of Purple beach pea in treated areas was about 31%, non-vascular (lichens and mosses) plants cover about 17%, but vascular plants covered about 80% with very little barren soil or about 3%. However, where Purple beach pea was absent (untreated areas) the cover of vascular plants was about 20%, but 30% cover of non-vascular plants. The barren soil area was close to 50%. The average growth height for all plants in the untreated area was about 0.7 cm but about 7.9 cm in the treated site (MH Jóhannsson, August 2018, Soil Conservation Service of Iceland, personal communication). Data from the Icelandic Meteorological office for 2006 to 2018 report an annual average temperature of 4.8°C, with a lowest temperature of 17.6°C, and a highest temperature of 27.6°C at Hella, near Hekluskógar (unpublished data).

Soil sampling sites were selected by choosing one location at each of four sites where Purple beach pea was abundant and a control site 5-10 m outside the Purple beach pea area, as shown in Figure 1.

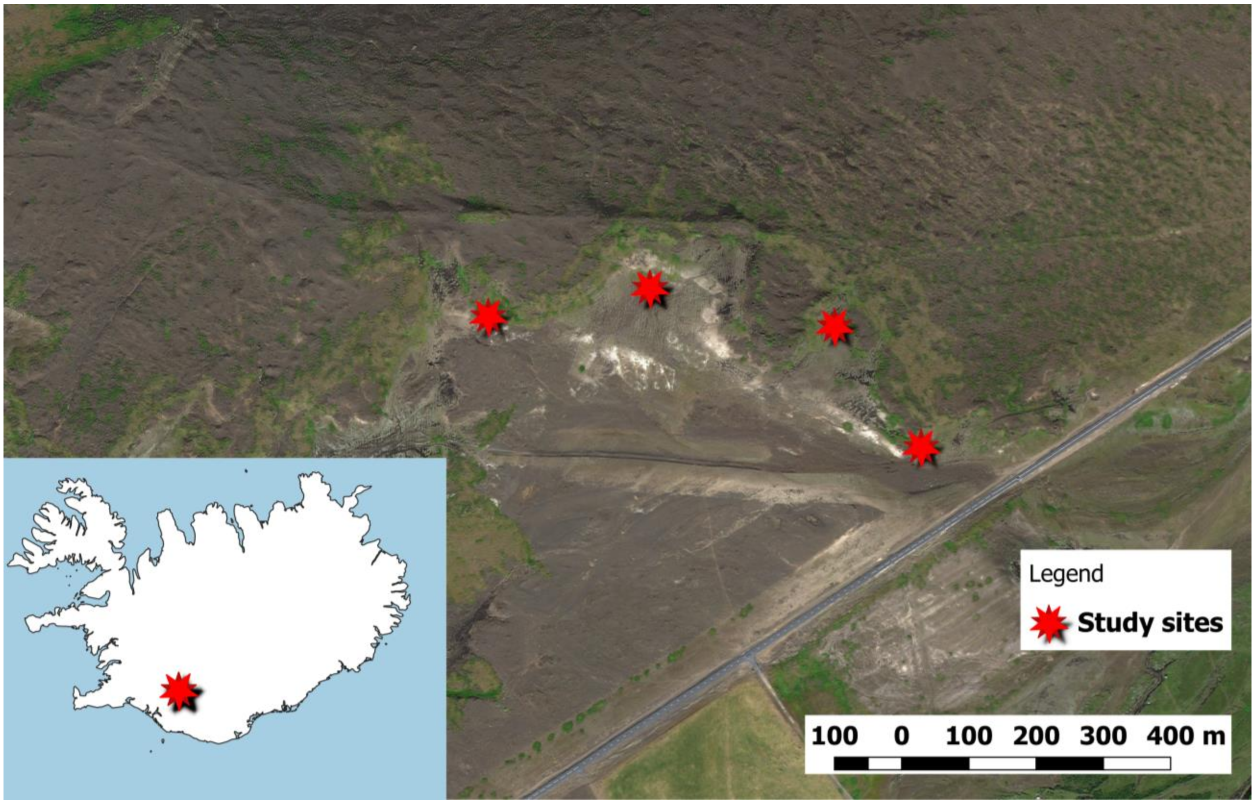


Figure 1. Location of the study site at Hekluskógar in south Iceland.

### 3.2 Sampling and data collection

The soil samples were collected at 0-5 cm and 5-15 cm depth at randomly selected points using a 5 cm diameter handheld auger with five replications at each of the four sites where Purple beach pea (treated sites) has been growing for the last 15 years and nearby four control sites (untreated sites). Each soil sample included five soil cores mixed into a single composite sample (Fig. 2). Soil samples were dried at 40ºC in an oven for 48 hours. The dried soil samples were sieved (≤ 2mm) before analysing. For analysis of Phosphorus (P), Calcium (Ca), Magnesium (Mg), and Potassium (K) elements, the two depths of the soil were combined into one.

In addition, the top 15 cm of soil was collected from both treated and untreated sites and used in a greenhouse experiment, where 25 seeds of ryegrass (*Lolium xhybridum*) were seeded in eight separate one-liter pots for each treatment combination, for a total of 64 pots. The greenhouse was unheated and had natural light. Watering of the plants took place two times per day at 06:00 AM and 20:00 PM for five minutes each time. The emergence of ryegrass was identified in ten days after sowing seeds. The growth rate of the ryegrass and its dried biomass was measured. The height of ryegrass was measured three times every 10 days and at 50 days before collecting the biomass. Biomass was collected by cutting the aboveground biomass at soil level and dried 105 ºC in an oven for 24 hours and then weighed. The collected soils were sieved (≤ 2mm) before seeds were planted in it.

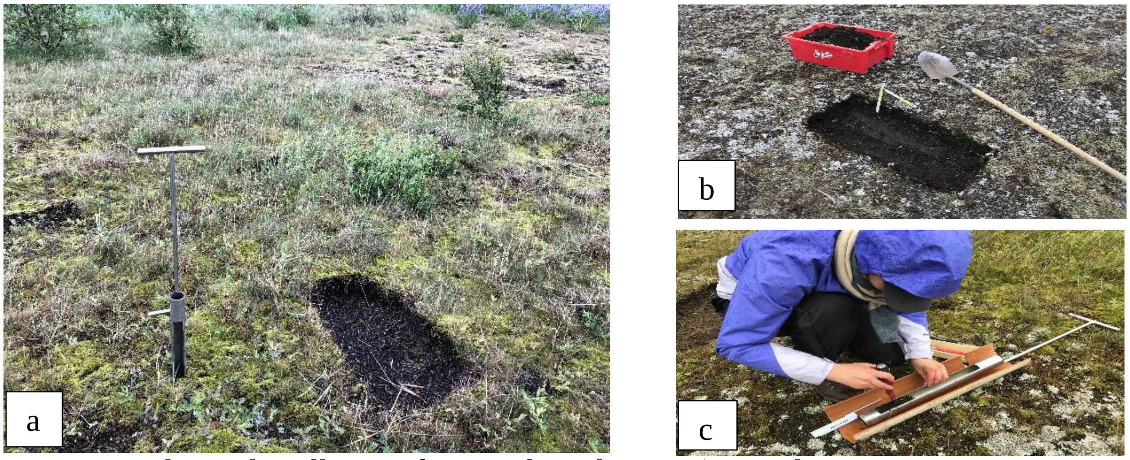


Figure 2. Soil sample collection from each study site. a) Sampling using an auger, b) soil collection for a greenhouse experiment, and c) dividing soil samples into 0-5 and 5-15 cm depth. (Photos: B.Battogtokh, Magnús H. Jóhannsson, June 2018).

## 3.3 Soil chemical properties analysis

### *3.3.1 Measuring carbon and nitrogen*

Dried and sieved (2 mm) soils were ball-milled. The soil carbon and nitrogen were determined by the Dumas method (International Organization for Standardization 2016), a high-temperature combustion with high purity oxygen in a high purity Helium carrier. Detection of the formed $CO_2$ and $N_2$ was with TCD (thermal conductivity detector).

The C and N were then calculated on a dry matter basis by using the C and N values and the dry matter (of the milled sample) value.

### *3.3.2 Analysing the minerals P, Ca, Mg and K*

Around 0.1 g of each soil sample was digested in a mixture of nitric acid ($HNO_3$), hydrochloric (HCl) and hydrogen peroxide ($H_2O_2$) in a microwave oven under pressure. The digested sample solution was diluted to mark, shaken and filtered with a syringe filter. Minerals were analysed using inductively coupled plasma atomic emission spectrometry (ICP-OES; Spectro Ciros Vision). As for C and N, the mineral content was then calculated on a dry matter basis by using the mineral values and the dry matter (of the milled sample) value.

### *3.3.3 Soil pH*

The methodology described by Blakemore (1987) was used to measure pH. The soil was dried and sieved (2 mm) and 10 g of soil samples were placed in a 50 ml centrifuge tube with 25 ml de-ionized water, mixed vigorously and shaken for five minutes 350 rpm. Samples were left standing overnight and then measured with a pH electrode in the water phase.

### 3.4 Statistical analysis

Data were analysed by ANOVA procedure using JMP version 13.1 (SAS Inst., 2016). Two-way analysis of variance (ANOVA) was used to detect effects of treatment and soil depths on soil chemical properties (TN, TC, C:N ratio and pH). One-way analysis of variance was used to detect for differences between treatments on soil minerals (P, Ca, Mg and K). Height and biomass of the ryegrass were compared between treated and untreated soil by one-way analysis of variance (ANOVA). Differences with $p < 0.05$ were considered statistically significant.

## 4. RESULTS

### 4.1 Soil chemical properties

The total soil nitrogen (TN) content was significantly higher in the treated sites at the 0-5 cm depth. However, there was no significant difference in TN content between untreated and treated sites at the 5-15 cm depth (Table 1). Also, total soil carbon (TC) content was significantly higher in the treated sites at 0-5 cm depth but not at 5-15 cm depth (Table 1).

**Table 1.** Two-way ANOVA results showing the mean (M) and standard error (SE) of the measured variables (total soil nitrogen (TN), total soil carbon (TC), C:N ratio and pH) between treatments, soil depth (SD), and their interaction. Different superscripts indicate significant differences between means ($p < 0.05$), “ns” indicates a non-significant difference between means, n = 4.

| **Treatments, (T)** | **Soil depth (cm)** | **Soil chemical properties (M ± SE)** | | | |
|---|---|---|---|---|---|
| | | TN (%) | TC (%) | C:N ratio | pH |
| Untreated | 0-5 | $0.04 \pm 0.08^{a}$ | $0.71 \pm 0.16^{b}$ | $15.1 \pm 0.98^{ns}$ | $6.3 \pm 0.11^{ns}$ |
| Treated | 0-5 | $0.07 \pm 0.08^{b}$ | $1.23 \pm 0.19^{a}$ | $16.8 \pm 0.62^{ns}$ | $6.2 \pm 0.07^{ns}$ |
| p-value | | 0.0002 | 0.0002 | 0.18 | 0.72 |
| Untreated | 5-15 | $0.02 \pm 0.00^{ns}$ | $0.24 \pm 0.07^{ns}$ | $11.0 \pm 1.44^{ns}$ | $7.1 \pm 0.05^{a}$ |
| Treated | 5-15 | $0.02 \pm 0.02^{ns}$ | $0.34 \pm 0.04^{ns}$ | $14.3 \pm 0.68^{ns}$ | $6.7 \pm 0.11^{b}$ |
| p-value | | 0.68 | 0.26 | 0.08 | 0.01 |
| T x SD interaction (p-value) | | 0.12 | 0.15 | 0.44 | 0.09 |

No significant difference was found in the C:N ratio of the untreated and treated sites in the both 0-5 and 5-15 cm depth (Table 1). Soil pH was significantly higher at the untreated site in the 5-15 cm than at treated sites, but no significant difference was found in pH in the 0-5 cm (Table 1). The interaction between the treatment (T) and soil depth (SD) was not significant for any of the variables tested (Table 1).

There were no significant differences found in total P, total Ca, total Mg and total K between the untreated and treaded sites (Table 2).

**Table 2.** One-way ANOVA results showing the mean (M) and standard error (SE) of the soil Phosphorus (P µg/g), Calcium (Ca µg/g), Magnesium (Mg µg/g) and Potassium (K µg/g) between treatments. "ns" indicates a non-significant difference between means ($p > 0.05$), n = 4.

| Treatments | Soil depth (cm) | Soil chemical properties (M ± SE) | | | |
|---|---|---|---|---|---|
| | | P (µg/g) | Ca (µg/g) | Mg (µg/g) | K (µg/g) |
| Untreated | 0-15 | 699.2 ± 41.7$^{ns}$ | 4311 ± 203.6$^{ns}$ | 3424.5 ± 212.3$^{ns}$ | 334.5 ± 63.9$^{ns}$ |
| Treated | 0-15 | 649.1 ± 41.7$^{ns}$ | 4100± 470.7$^{ns}$ | 2715.8 ± 205.5$^{ns}$ | 297.9 ± 50.9$^{ns}$ |
| p-value | | 0.4 | 0.52 | 0.05 | 0.67 |

## 4.2 The greenhouse experiment

### *4.2.1 Ryegrass emergence and height*

The emergence of ryegrass was not significantly different ($p < 0.32$) between treated (87%) and untreated (90%) soil. However, the height of ryegrass measured at 10, 30 and 50 days after sowing was significantly higher in treated soil than untreated (Fig. 3 and 4).

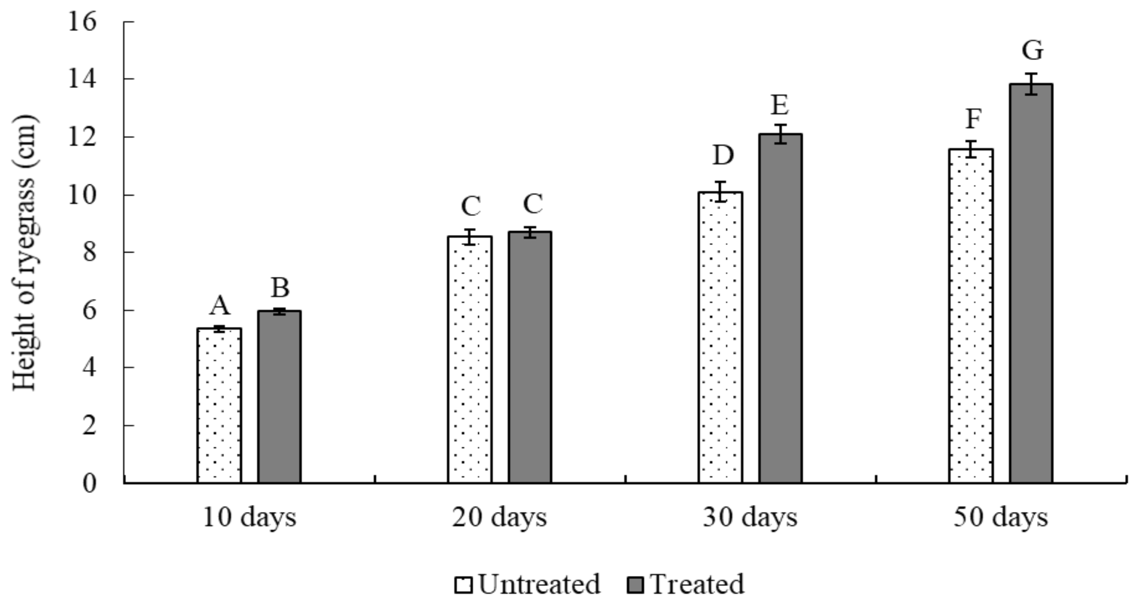


Figure 3. The height of the ryegrass in the untreated and treated soil. Different letters above the columns indicate a significant difference, n = 4.

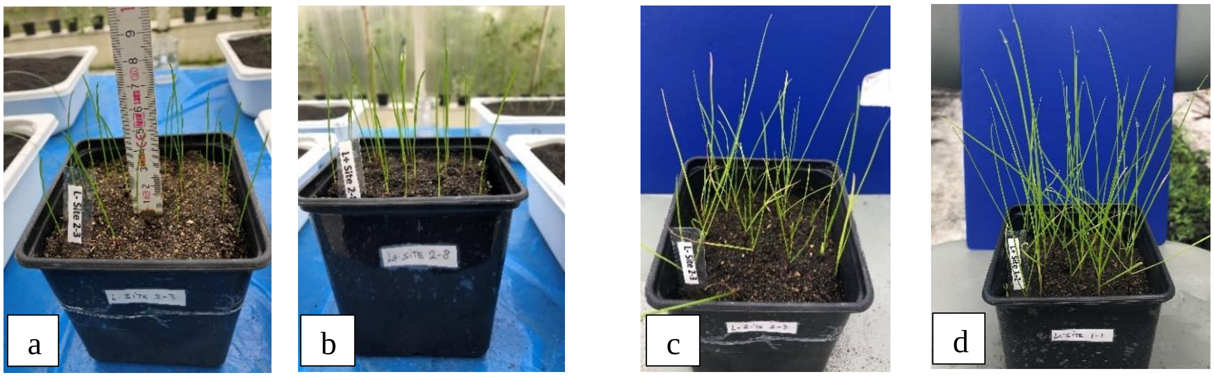


Figure 4. The height of ryegrass in the greenhouse, a) emergence of the ryegrass in untreated soil at 10 days, b) emergence of the ryegrass in treated soil at 10 days, c) height of ryegrass in untreated soil at 50 days, d) height of ryegrass in treated soil at 50 days. (Photos: B. Battogtokh 19 June and 31 July 2018).

### *4.2.2 Biomass of the ryegrass*

The oven-dried biomass of the ryegrass was significantly higher ($p < .0015$) in the treated (0.21 ± 0.02 g) than untreated (0.16 ± 0.02 g) soil.

## 5. DISCUSSION

### 5.1 Nitrogen and carbon

This study found that the nitrogen-fixing Purple beach pea had a significantly positive effect on total nitrogen and carbon content in the top layer (0-5 cm) of the soil, thus showing clear benefits to the soil. The treated site with 0.07% TN and 1.23% TC was significantly higher than the untreated control site with 0.04% TN and 0.71% TC. The values for the untreated site were similar to the 0.05% TN and 0.7% TC values reported by Gretarsdottir et al. (2004). Also, the values for the untreated site were similar to 0.03% TN and higher than the 0.43% TC reported by Arnalds et al. (2013). There were no beneficial effects of Purple beach pea in the treated site at the lower soil depth (5-15 cm), showing that the effects were limited to the upper layer of soil. Furthermore, since the cover of Purple beach pea was only 31%, the effect on other vegetation was positive, resulting in an almost 100% vegetation cover compared to about 50% where Purple beach pea was lacking. In addition, the average height of the vegetation was greater (7.9 cm vs. 0.7 cm).

The greenhouse experiment in this study showed clearly that ryegrass grown in treated soil grew faster than in untreated soil and thus had greater biomass. Again, showing the clear benefit of Purple beach pea to the soil it grows in.

### 5.2 C:N ratio

The C:N ratio in this study did not vary significantly by treatment or depth. However, the trend seemed to be that the soil C:N ratio was slightly higher in the top layer of the soil (0-5 cm) than in the lower layer (5-15 cm) (Table 1) which was similar to what Lou et al. (2012) reported where the C:N ratio declined with increasing soil depth.

### 5.3 Soil pH

The non-significant difference in pH between treated and untreated sites in the upper layer of soil might indicate that there was sufficient root activity in the untreated site that affected the pH level. In contrast, at the treated sites where there was more vegetation and thus more root activity, it seemed to affect the lower layers which root activity in untreated sites did not. A common average pH for Vitrisols is pH 7, as reported in Arnalds (2004).

### 5.4 Soil minerals (P, Ca, Mg and K)

This study found no significant differences in total P, total Ca, total Mg and total K between untreated and treated sites. It is therefore evident that Purple beach pea had no vital impact on soil minerals (P, Ca, Mg and K). These results agree with Ritter (2007) who found that vegetation did not change soil total P in Icelandic soil.

### 5.5 The overall effect of Purple beach pea on soils

This study has shown that Purple beach pea has a significant positive effect on soil TN and TC content in the top layer (0-5 cm) of vitrisols in Hekluskógar, South Iceland. Nitrogen is the most limiting nutrient in agriculture and degraded land in Iceland. This is why chemical fertilizers are used extensively for cropland in Iceland (Arnalds 2015). The results from this study clearly show that Purple beach pea could be important in restoration work since it fixes nitrogen. Not only does it fix nitrogen for its own purposes, but obviously some of it is released into the soil by decomposition and/or root turnover. Also, soil organic carbon is important for soils and increases nutrient and water holding capacity. The nitrogen-fixing Purple beach pea could, therefore, provide a sustainable and cost-effective method of improving soil TN and TC for land reclamation purposes. This would be accompanied by the obvious advantage of reduced import of nitrogen fertilizers.

## 6. CONCLUSIONS

The beneficial effects of Purple beach pea on soil nitrogen and carbon plus beneficial effects on growth rates of ryegrass clearly show that Purple beach pea could be important in revegetation of eroded land in Iceland.

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