Seasonal Trends of Foliar Nutrients in Seven Plant Species in a Subalpine Meadow, Northern Mexico

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Abstract

As an approach to understand and characterize plant nutrient trends in seven plant species, determinations of plant nutrients (µmol gdw^{-1}) in leaf tissue, were evaluated (following a repeated measures experimental design) in *Lupinus cacuminis*, *Astragalus purpusii*, *Senecio madrensis*, *Poa muelleri*, *Euphorbia furcillata*, *Pinus culminicola*, and *Pinus hartwegii* at four-week intervals between May and October, 2001. These plant species represented a variety of life forms in the subalpine meadow environment in the summit of Cerro Potosi, Nuevo Leon, Mexico, which has been declared as a natural state protected area and subjected to a conservation program. Results have revealed significant differences (p<0.001) among plant species in all studied plant nutrients. Maximum (1058) and minimum (187) Ca concentrations were achieved by *L. cacuminis* and *P. hartwegii*, respectively. Higher concentrations of K (809) and Mg (108) were observed in *S. madrensis* and *A. purpusii*, while *P. hartwegii* and *P. culminicola* acquired lower values (81 and 31, respectively). Higher (65) and lower (45) P concentrations were found in *S. madrensis* and *P. hartwegii*, respectively. N content (%) ranged from 3.08 (*A. purpusii*) to 1.30 (*P. culminicola*). *A. purpusii* achieved higher concentrations of Cu (0.20), Fe (18.70) and Mn (11.68), while levels of 0.07 (Cu), 2.58 (Fe) and 0.81 (Mn) were detected in *P. hartwegii*. Maximum (1.22) and minimum (0.71) leaf Zn concentrations were observed in *P. culminicola* and *L. cacuminis*, respectively. Results provide substantial evidence to support the physiological plasticity among plant species and their responses to resources availability. In addition, implications of these results for understanding subalpine function, dynamics and competitive interactions between plant species are discussed.

1. Introduction

One of the most interesting ecological boundaries found in the southern region of the state of Nuevo Leon (northern, Mexico) are the alpine and subalpine meadows of the summit of Cerro Potosi. As has been previously reported (Billings, 1989), alpine and subalpine meadows located in high-mountain summits consists mainly of dwarf shrubs and perennial herbaceous plants. Under this type of environmental conditions, plant species face intense solar radiation, low temperatures, snow, and strong blowing winds which restrict growth and plant reproduction. However, in spite of the well documented studies on plant diversity and plant community structure (Beaman and Andresen, 1966; Garcia-Arevalo and Gonzalez-Elizondo, 1991), up to date there are not basic ecophysiological studies which relate plant function in terms of plant nutritional status in this particular region, which has been declared in November 2000 as a state natural protected area. For instance, studies on plant nutrition are important to understand the mechanisms of how nutrient uptake and accumulation are regulated, as well as, are essentials for analysing the growth performance of plant tissue. In this regard, it has been well established, that leaf tissue analysis of plant minerals has been employed as an indicator not only of nutrient stress but it has also been used to compare the potential productivity among vigorous and poor plant species and consequently ecosystem productivity (Drechsel and Zech, 1991). In addition, plant nutrients not only play an important role in the physiological processes but they also determine the yield and quality of forage for wildlife or range livestock (Ramírez et al., 2006). Therefore, this ecological boundary provides an opportunity to investigate the relationship between physiological responses and changes in resource availability. Thus, the main objective of the present study was to characterize and compare the nutritional status of seven plant species that grow in the subalpine meadow in the summit of Cerro Potosi in order to understand and characterize the seasonal trends of macro- and micro-nutrients.

2. Materials and Methods

The present study was carried out on the summit northern slope of Cerro Potosi (24º50´35´´ and 24º53´16´´ N; 100º13´12´´ and 100º15´12´´ W). Cerro Potosi is the highest peak of the state of Nuevo Leon, northern Mexico, reaching 3670 m elevation, and it is located between the west flank of the Sierra Madre Oriental Mountain and the Mexican High Plateau (García-Arevalo and Gonzalez-Elizondo, 1991). Geologically, it is formed of limestone rock, of sea sediments origin, with gypsum and lutite or siltsone, belonging to the lower Cretaceous, Mesozoic age. Mean monthly air temperature ranges from -1.5ºC (January) up to 7.5ºC (August) and a mean annual total precipitation of 400 mm. The northern slope is usually covered with snow from November to mid April. Soils are shallow (less than 10 cm in depth) with a high organic matter content (20%). Some physical and chemical properties of the soil at a profile depth of 0-10 cm are shown in table 1. At the research site, seven plant species, which represented a variety of growth and life forms (perennial herbaceous, dwarf or prostrate and tree types), were chosen randomly from a previously established plot of 20 x 20 m^2 (Plate 1). Studied plants species were: *Lupinus cacuminis* Standl. (Fabaceae, herb), *Astragalus purpusii* M.E. Jones (Fabaceae, herb), *Senecio madrensis* A. Gray (Asteraceae, herb), *Pinus culminicola* Andresen & Beaman (Pinaceae, dwarf shrub), *Pinus hartwegii* Lindl. (Pinaceae, tree), *Poa muelleri* Swallen (Poaceae, grass), and *Euphorbia furcillata* H.B.K. (Euphorbiaceae, herb). The present study was undertaken between May and October, 2001. During this period, eight sampling dates (May-01, May-31, Jun-20, Jul-11, Aug-07, Sep-05, Oct-02, and Oct-31) were carried out at the experimental plot in the subalpine meadow in order to collect leaf tissue from current-year shoots (three replicates per plant species and sampling date) to perform determinations of plant nutrients. Leaf tissue samples were oven-dried for 48 h at 60ºC, ground in a Wiley mill to pass a 1-mm screen, stored in pre-labeled plastic vials at room temperature, and subsequently used for elemental analyses. Weighed (0.5 g) leaf samples (dry weight material) were digested in concentrated nitric acid. Determinations (µmol gdw^{-1}) of macro [calcium (Ca), potassium (K)

Table 1: Some physical and chemical properties of the soil at the experimental plot in the subalpine meadow of the summit of Cerro Potosi, northern Mexico

Soil Property	Value
Physical	
Particle size	
Sand (g kg^{-1})	525.0
Silt (g kg^{-1})	475.0
Clay (g kg^{-1})	0.0
Water Retention (kg kg^{-1})	
–0.03 MPa	0.805
–1.50 MPa	0.636
Available Water Capacity (kg kg^{-1})	0.149
Chemical	
pH	6.80
Electrical Conductivity (µS cm-1)	154.00
Organic Matter (%)	20.96
Ca (mg kg^{-1})	5,892.60
K (mg kg^{-1})	907.90
Mg (mg kg^{-1})	84.60
N (%)	1.39
P (mg kg^{-1})	28.47
Cu (mg kg^{-1})	5.33
Fe (mg kg^{-1})	26.32
Mn (mg kg^{-1})	176.41
Zn (mg kg^{-1})	12.33

Plate 1: Panoramic view of the sub-alpine experimental plot at the research site.

and magnesium (Mg)] and micro elements [copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn)] were estimated using an atomic absorption spectrophotometer with an air/acetylene (Mg, Cu, Fe, Mn, and Zn) or nitrous oxide/acetylene (Ca and K) flame. The instrument used for this purposes was a Varian, Model SpectrAA-200. Total nitrogen (N) content (%) was determined by applying the Kjeldahl method to 0.5 g dry weight material digested in selenous sulphuric acid. Due to technical reasons, N content was only determined and statistically analyzed in three sampling dates (May-01, Jul-11, and Oct-31) out of eight. Total phosphorus (P) concentration (µmol gdw^{-1}) was determined colorimetrically by applying the molybdo-vanadate method to 0.5 g dry weight material digested in concentrated nitric acid. The instrument used for P analyses was a Perkin-Elmer UV-Visible spectrophotometer, Model Lambda 1A. All plant nutrient analyses were performed as described in AOAC (1996) and following the instruction manual of each instrument used. To determine if differences existed between plant species (PS), sampling dates (SD) and their interaction (I_{PS*SD}) on foliar nutrient concentrations, analysis of variance (ANOVA) with repeated measures (rm-ANOVA) (Ott, 1993) was used, with plant species nested as subjects with three replications. Assumptions of normality for each plant nutrient data were tested using the Kolmogorov-Smirnov test (Steel and Torrie, 1980). Mean differences between plant species, when appropriate, were determined by one-way ANOVA and ranked by Tukey's honestly significant differences (HSD) procedure test at p=0.05 (Steel and Torrie, 1980). All applied statistical methods were according to the SPSS (Statistical Package for the Social Sciences) software package (standard released version 9.0 for Windows, SPSS Inc., Chicago, IL, USA).

3. Results and Discussion

3.1. Seasonal trends of macro- and micro-nutrients

In all sampling dates, rm-ANOVA detected a highly significant (p<0.001) effect of plant species (PS), sampling dates (SD) and their interaction (I_{PS*SD}), indicating that statistical differences in nutrients among plant species have varied among sampling dates (table 2). The seasonal trends of plant nutrient values for Ca, P, K, Mg, Cu, Fe, Mn, and Zn among plant species are illustrated in figure 1. On an average basis for all sampling dates, the following nutrient concentration quantities were observed: mean Ca concentration was 478.83±6.03 µmol gdw^{-1} and *L. cacuminis* and *P. hartwegii* achieved the highest (1,058 µmol gdw^{-1}) and the lowest (187 µmol gdw^{-1}) Ca concentration in foliar tissue, respectively, (figure 1(a)). With respect to K (figure 1 (b)), mean K concentration was 301.44±3.38 µmol gdw^{-1} and *S. madrensis* had the maximum concentration (809.8 µmol gdw^{-1}) while *P. hartwegii* had the minimum (143.3 µmol gdw^{-1}) concentration. *A. purpusii* and *S. madrensis* acquired higher Mg concentration values (108.9 and 102.5 µmol gdw^{-1}, respectively), in contrast, lower levels were detected in *P. muelleri* and *P. culminicola* (61.0 and 59.7 µmol gdw^{-1}, respectively) (figure 1(c)). Mean Mg concentration for all plant species and sampling dates was 79.87±1.19 µmol gdw^{-1}. P concentration of the seven plant species and eight sampling dates averaged 51.99±0.77 µmol gdw^{-1}. *S. madrensis* had the highest P concentration (65.4 µmol gdw^{-1}), in contrast, *P. hartwegii* the lowest (45.13 µmol gdw^{-1}) (figure 1(d)). Among plant species and sampling dates, mean Cu, Fe and Mn concentration values were

Table 2: Mean squares values derived of the repeated measures ANOVA (rm-ANOVA) to detect significant differences for plant nutrients determined in leaf tissue of seven plant species studied at the experimental plot in the subalpine meadow of the summit of Cerro Potosi, northern Mexico. Main effects were Plant Species (PS) and Sampling Dates (SD). Mean, standard error (SE) and coefficient of variation (CV, %) values are provided

Plant Nutrient	Between Plants		Within Plants		Mean ± SE	CV (%)
	PS	Plant	SD	I_{PS*SD}		
Ca	1820184.20***	5347.8	701773.10***	145708.30***	478.83 ± 6.03	27
K	1306764.30***	1797.2	13807.20*	9858.30*	301.44 ± 3.38	26
Mg	7775.20***	221.2	7237.00***	1168.70***	79.87 ± 1.19	17
N	4.00***	0.2	0.08^{NS}	0.48***	1.96 ± 0.08	15
P	1195.80***	93.1	397.80***	235.20***	51.99 ± 0.77	12
Cu	0.04***	0.08	0.03***	0.02***	0.13 ± 0.002	24
Fe	649.40***	14.9	156.80***	51.70***	6.13 ± 0.31	74
Mn	245.80***	4.3	13.20***	16.50***	4.97 ± 0.16	40
Zn	0.68***	0.07	0.84***	0.12^{NS}	0.96 ± 0.02	34

^{NS}Not Significant; p≥0.05); *p<0.05); **(p<0.01); ***(p<0.001)

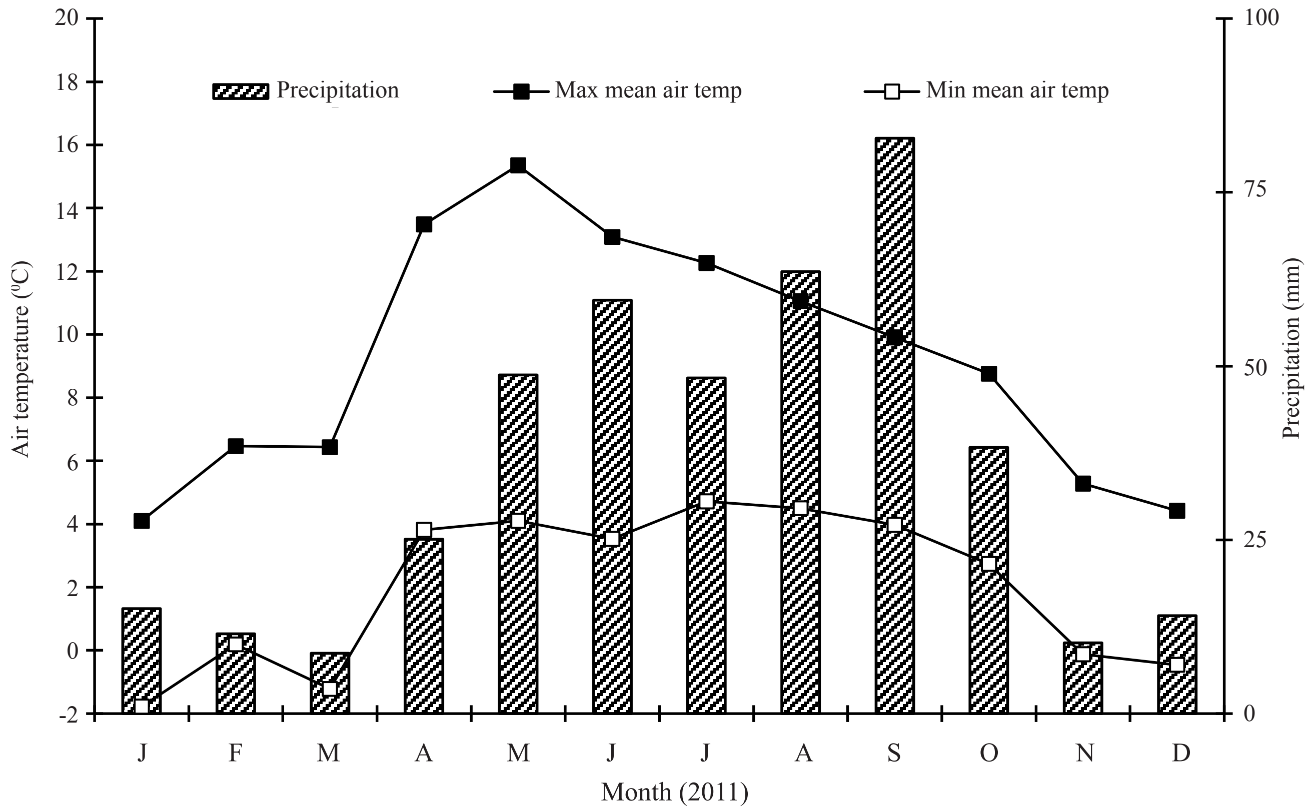

Figure 1: Monthly maximum and minimum mean air temperature and cumulative monthly precipitation at the research site

0.13±0.002, 6.13±0.31, 4.97±0.16 µmol gdw^{-1}, respectively. Higher concentrations of Cu (0.20 µmol gdw^{-1}), Fe (18.70 µmol gdw^{-1}) and Mn (11.68 µmol gdw^{-1}) were observed in *A. purpusii*, in contrast; lower concentrations of Cu (0.07 µmol gdw^{-1}), Fe (2.58 µmol gdw^{-1}) and Mn (0.81 µmol gdw^{-1}) were attained in *P. hartwegii* (figures 1(e), 1(f), and 1(g), for Cu, Fe, and Mn, respectively). Mean Zn concentration of the seven plant species and eight sampling dates was 0.96±0.02 µmol gdw^{-1}. Maximum (1.22 µmol gdw^{-1}) and minimum (0.71 µmol gdw^{-1}) Zn concentrations were registered in *P. culminicola* and *L. cacuminis*, respectively (figure 1 (h)).

Averaged N content across plant species and sampling dates was 1.96±0.02 %. Higher N content levels at May-01 (3.08±0.04 %), Jul-11 (2.85±0.76 %), and Oct-31 (3.27±0.08 %) observed in *A. purpusii* were significantly (p<0.001) different than those values (1.30±0.06, 1.39±0.16, and 1.60±0.09 %, respectively) detected in *P. culminicola* during the same sampling dates (figure 2 & 3).

3.2. Relationships among plant nutrients

Cu foliar concentration values showed a significant (p<0.01) and positive correlation with Mn (r=0.517), Fe (r=0.392), K (r=0.384) and P (r=0.244) levels. Similarly, Mn was significantly (p<0.01) and positively correlated with Fe (r=0.719), Zn (r=0.200) and K (r=0.195) foliar values. A significant (p<0.01) association was found to exist between Ca and Mg (r=0.300), Mg and K (r=0.332) and K and P (r=0.602). Conversely, a weak but significant (p<0.01) and positive correlations were observed between Mn and K (r=0.195), Fe and Zn (r=0.190) and Fe and Mg (r=0.189) (table 3).

Since at the research site, studied shrub species belong to different growth forms and functional types, their rates and patterns of growth as well as their allocation of essential nutrients among leaf and other plant tissue differ among them.

Plant nutrient absorption in cold climates has been shown to be strongly limited by nutrient availability rather than by low temperature (Chapin III, 1983). In this regard, nitrogen availability in turn is influenced by a range of abiotic and biotic factors which result from indirect effects of low temperatures such as slow chemical weathering, poor soil aeration and slow organic matter decomposition (Chapin III, 1983). In relatively open meadows of sub-alpine environments, the organic matter content of the surface soils is found to be high due to the slow rate of decomposition and mineralization (Gibson, 1991; Badía Villas et al., 2002) and they show a low water retention capacity (Badía Villas et al., 2002), in agreement with the results found in this study. According to Laffan (2001), soils in alpine environments are generally shallow and extremely stony, and they often occur in association with bare rock fields and scree slopes. In

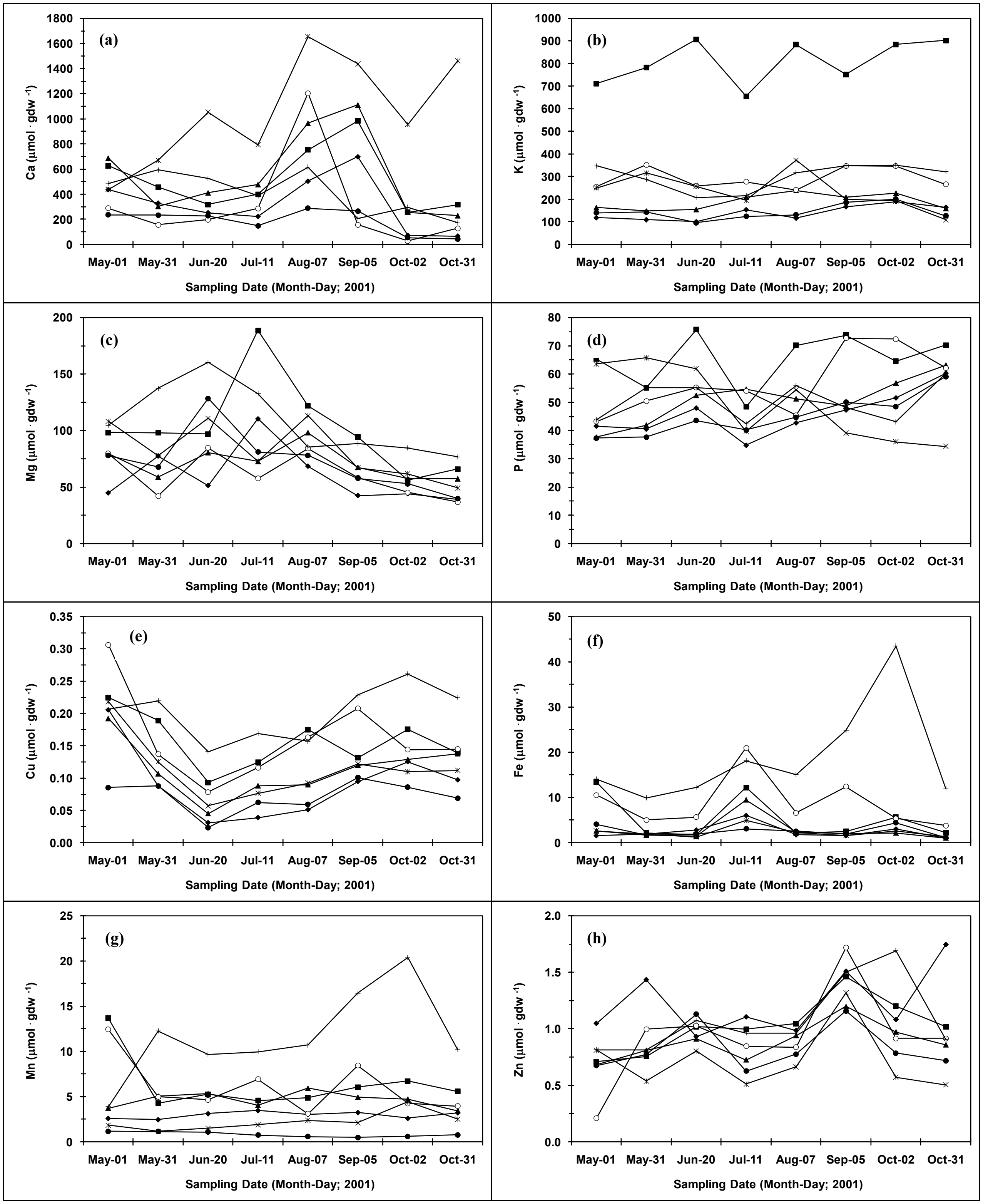

Figure 2: Seasonal patterns of Ca (a), K (b), Mg (c), P (d), Cu (e), Fe (f), Mn (g), and Zn (h) determined in leaf tissue of seven plant species studied in the subalpine meadow of the summit of Cerro Potosi, northtern Mexico. Values are means (n=3). *Astragalus purpusii* (+), *Euphorbia furcillata* (▲), *Lupinus cacuminis* (✱), *Senecio madrensis* (■), *Pinus culminicola* (◆), *Pinus hartwegii* (●), and *Poa muelleri* (○).

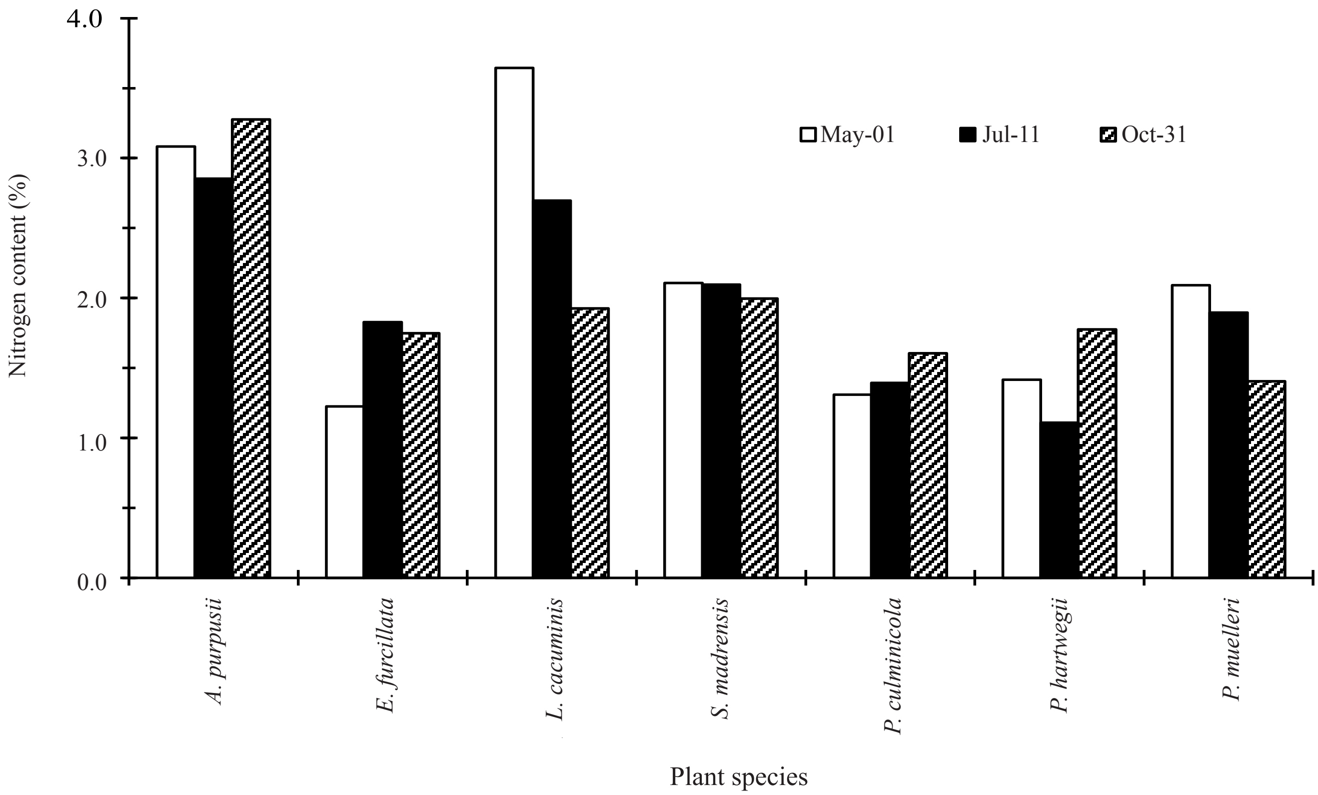

Figure 1: N content in leaf tissue of seven plant species at three sampling dates (May-01, July-11 and October-31, 2001) studied in the subalpine meadow of the summit of Cerro Potosi, northern Mexico. Values are means (n=3)

Table 3: Pearson´s correlation coefficient values among different plant nutrients determined in leaf tissue of seven plant species studied in the subalpine meadow of the summit of Cerro Potosi, northern Mexico. Correlation coefficient values are denoted below the diagonal line while their respective *p*-values are shown above. n=168 for Cu, Fe, Mn, Zn, Ca, Mg, K, and P. n=81 for N.

	Plant nutrient								
	Cu	Mn	Fe	Zn	Ca	Mg	K	P	N
Cu		0.001	0.001	0.231	0.914	0.079	0.001	0.001	0.001
Mn	0.517		0.001	0.004	0.265	0.074	0.005	0.609	0.110
Fe	0.392	0.719		0.006	0.057	0.006	0.333	0.665	0.022
Zn	0.083	0.200	0.190		0.048	0.954	0.063	0.006	0.723
Ca	0.008	-0.078	-0.132	-0.137		0.001	0.218	0.042	0.287
Mg	0.122	0.124	0.189	0.004	0.300		0.001	0.240	0.001
K	0.384	0.195	0.067	0.129	0.086	0.332		0.001	0.001
P	0.244	0.036	-0.030	0.190	-0.141	0.082	0.602		0.001
N	0.365	0.179	0.255	0.040	0.120	0.377	0.348	0.395	

addition, surface layers frequently comprise organic loams or fibrous peats overlying shallow brown or grey coloured loamy subsoils with abundant rock fragments. Furthermore, it has been stated that humus accumulation is a synergistic effect of increased litter input and decreased organic matter mineralization rates due to cooler conditions under the scrub canopy in sub-alpine ecosystems (Dirnböck et al., 2008). These described features of this type of soils are in agreement with the observed characteristics of the soil system in the sub-alpine meadow of this study. The physical, chemical and biological properties of the soils in the summit of Cerro Potosi and the high altitude areas in particular remain unexplored and open new research lines, specifically in terms of organic matter decomposition rate and litter quality deposition patterns.

Other studies have indicated that plant nutrient contents in leaf tissue depend not only on soil nutrient availability, but also on the efficiency and rate of nutrient uptake, and on nutrient partitioning within the plant structures, as well as on the growth rates of the plant (Chapin III et al., 1986).

The positive effects of high internal nutrient availability on foliar biomass investment in leaves becomes buffered by concomitant increase in plant size that reduces biomass in foliage. Whether high or low nutrient content in leaf tissue of different plant species is related to plant size remains to be resolved under the sub-alpine environmental conditions of the summit of Cerro Postosi (Niinemets et al., 2002). In addition, this study provides a useful baseline reference data for future researches in these smaller group of species or for investigations related to long term effects of climate change on growth, phenology and nutritional status of plant communities characteristic of the sub-alpine meadow. A study has shown that warming open-top chambers using the International Tundra Experiment protocol in the Australian Alps produced earlier budding, flowering and seed set in several alpine species. In addition, species also altered the timing of these events, particularly budding, in response to year-to-year temperature variation. Besides, some species responded immediately, whereas in others the cumulative effects of warming across several years were required before a response was detected (Hoffmann et al., 2010). In this regard, whether high foliar contents of Ca in *L. cacuminis*, Mg and K in *S. madrensis*, and Mg, Fe and Mn in *A. purpusii* are associated to flowering and seed set demands due to nutrient allocation from root or other tissue sources or to alternations in phenological events such as leaf flushing, budding, flowering and seed maturation among sub-alpine species due to temperature needs remains unresolved in the present study.

4. Conclusion

It provides a substantial evidence to support the physiological plasticity among plant species and their responses to resources availability. Further results helps in understanding subalpine function, dynamics and competitive interactions between plant species.

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