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A STUDY OF NUTRIENT DYNAMICS IN THE COASTAL DUNES OF NORTHWESTERN EGYPT.

By

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Key Words: desert dunes, phytomass, phenology, nutrient cycling.

ABSTRACT

Biomass and nutrient cycling are evaluated in sites of *Ammophila arenaria* and *Ononisvaginalis* which are among the most common species growing on the coastal dunes of the western desert of Egypt.

Both species accumulate N to higher levels than Ca, although growing on calcareous soil, and exhibit faster turnover rates. Uptake and accumulation of nutrients in different organs seem to be a function of phenology. The uptake rate is also affected by carbohydrate supply as an energy source for transport. Large quantities of N and K uptaken by *Ammophila* are retained in its perennating organs, while Ca exhibits a similar trend in *Ononis.*

The mineralomass amounts to about 35 kg/ha for the former and about 40kg/ha for the latter species. The high concentration of nutrients in phytomass and necromass of both species compared to that in soil suggest that plants in deserts may represent the main bulk of the available nutrients. While the withdrawal of critical nutrients from dying parts of both species may reflect a conservation strategy for more efficient growth.

INTRODUCTION

The total amount of biomass of terrestrial heterotrophic organisms is less than 0.1 of the earth's total living matter (Rodin and Basilevich 1968). Consequently, the bulk of minerals in living matter is to be found in plants. Meanwhile, compared to the other components in the ecosystem, a large portion of the available supply of the critical elements is locked up at any given time in either living (phytomass) or dead (necromass) plant material and partly decomposed remains.

In arid ecosystems, where nutrient resources are meager, cycling and turnover rates of nutrients become more limiting to net primary production than in other ecosystems; minor changes in recycling rates may result in remarkable changes in organic matter increment (Abdel-Razik 1989). Yet, nutrient cycling in these ecosystems received less attention than in other ecosystems.

This study provides an analysis of nutrient cycling in sites representing two of the most common species dominating the sand dune ecosystem on the coastal belt of the western desert of Egypt.

The study site is located at about 55 km west of Alexandria. The main habitat types are the immature (mobile), the consolidated and the more or less stable dunes. The main features of climate and soil are described by Ayyad (1973). The average rainfall is about 150 mm, and the monthly average temperature ranges between 13.2°C in January and 26.0°C in August. Average values of soil measures are: pH=7.23, TSS=0.46 mmhos/cm, $CaCO_3$=4.82%, and OM=2.17%. Abdel-Razik *et al.* (1984) recorded about 25 species in this area with an average density of 5.07 ind/m^2. Perennial grasses and dwarf shrubs constitute about 60% of the life-form spectrum of the area. *Ammophila arenaria* (L.) Link is the most common species of the first, and *Ononis vaginalis* Vahl is among the most common species of the second growth form.

MATERIAL AND METHODS

A site was selected for each of *Ammophila* and *Ononis* in its typical habitat. A survey was caried out to evaluate average densities of their populations using the quadrat method. Samples of plant material and of soil were collected from random locations in both habitats every month. The phenological changes were also recorded at the time of each sampling. Plant samples were separated into different organs and standing dead material. They were cleaned, dried and weighed. Soil samples were collected at the zone of maximum root distribution. Both plant and soil samples were prepared and analysed for determination of their contents of nutrients (Allen *et al.* 1974).

The monthly averages of nutrient content in different organs were calculated by multiplying their biomass by nutrient concentration. The monthly nutrient uptake was thus estimated based on the differences in their total contents in plant individuals at successive months. The allocation and translocation rates were estimated as the monthly increases and decreases of nutrient contents in the different organs of the plant.

RESULTS

The absolute densities of *Ammophila* and *Ononis* in their typical habitats are estimated as 9.98 and 2.47 ind/m^2 respectively. Their phytomass is calculated from average individual weight and plant density as about 440 and 121 gm/m^2 respectively. The temporal variations in the average organ weights and of the necromass calculated as ratios of the average phytomass is represented in figure 1. It is notable that the allocation of material to reproductive parts of *Ammophila* occurs mainly

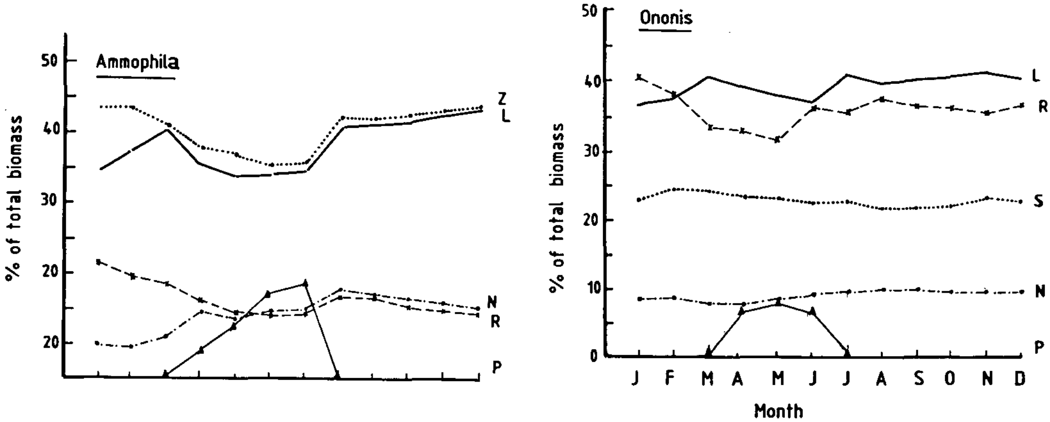

Fig. 1: Temporal variations in the average organs weight and in necromass of *Ammophila* and *Ononis* calculated as ratios of total phytomass. (L = leaves, R = roots, P = reproductive parts, S = stems, Z = rhizomes and N = necromass).

on the expense of its allocation to leaves and rhizomes if compared to *Ononis.* In the latter species allocation of material to reproductive parts affects more the root ratio. The apical dominance of the grass growth form results in higher reproductive effort (up to 18% of total phytomass) if compared to that of the dwarf shrub growth form (less than 8 % of phytomass). On the other hand, the root ratio in the grass growth form (average 16 % of total phytomass) is much less than that in the shrub growth form (average 36% of total phytomass).

The ranges of annual variation in nutrient concentration (mg/g) in the phytomass, necromass and the soil of *Ammophila* and *Ononis* ecosystem are presented in Table 1. The peak concentrations of the macronutrients in the phytomass of *Ammophila,* except for P and K, are lower than those in *Ononis,* with the sequence N>Ca>K>Na>Mg for the second species. This is associated with lower concentrations of the nutrients, except for P and Ca, in the soil underneath *Ammophila* than in the soil underneath *Ononis.* The sequence of concentration in the soil is Ca>N>K>Na. The necromass of the former species is more rich in N, Mg and Ca while that of the latter is rich in N, Ca and K.

Table 1

Annual variation in nutrient concentration in phytomass, necromass and the soil underneath each of *Ammophila arenaria* and *Ononis vaginalis*

Ecosystem component	Concentration (mg/g)					
	N	P	K	Ca	Na	Mg
Ammophila						
Phytomass min.	*13.97*	*0.558*	*5.86*	*6.67*	*0.812*	*0.987*
max.	*17.35*	*0.907*	*7.06*	*16.55*	*0.928*	*0.991*
Necromass min.	*0.99*	*0.371*	*0.12*	*0.55*	*0.033*	*0.074*
max.	*1.43*	*0.653*	*0.28*	*1.12*	*0.082*	*1.396*
Soil min.	*0.23*	*0.019*	*0.15*	*1.98*	*0.067*	*0.048*
max.	*0.40*	*0.048*	*0.23*	*2.81*	*0.106*	*0.058*
Ononis						
Phytomass min.	*24.69*	*0.437*	*2.50*	*15.86*	*0.842*	*0.145*
max.	*28.88*	*0.619*	*3.16*	*26.07*	*2.709*	*1.972*
Necromass min.	*1.48*	*0.030*	*0.12*	*0.76*	*0.041*	*0.085*
max.	*2.71*	*0.062*	*0.25*	*1.90*	*0.079*	*0.152*
Soil Min.	*0.37*	*0.027*	*0.17*	*1.72*	*0.048*	*0.051*
max.	*0.44*	*0.042*	*0.27*	*2.52*	*0.110*	*0.065*

The temporal variations in nutrient concentrations in relation to phenological development of *Ammophila* (figure 2) and of *Ononis* (figure 3) indicate that the perennial grass accumulates higher concentrations of N, K and Mg in its photosynthetically active parts concentrations of N, K and Mg in its non-photosyntheticaly active parts (rhizome and roots), while Ca and Na are more or less shared equally by both parts. The reproductive parts of this growth form have the highest concentrations of P, K and Na. The perennial dwarf shrub, on the other hand, accumulates higher concentrations of N, P and Ca in the photosynthetic active part than in the other parts.

The reproductive activity (flowering through seed shedding) in the first growth form is characterised by peak concentration of N in leaves and roots and of Ca in the rhizome, while the vegetative activity is characterised by peak concentrations of N, K and Na in the rhizome and of P, K, Ca; Mg and Na in the roots. In the second growth form the vegetative activity is characterised by peak concentrations of all nutrients in leaves and of P, K and Mg in the stems.

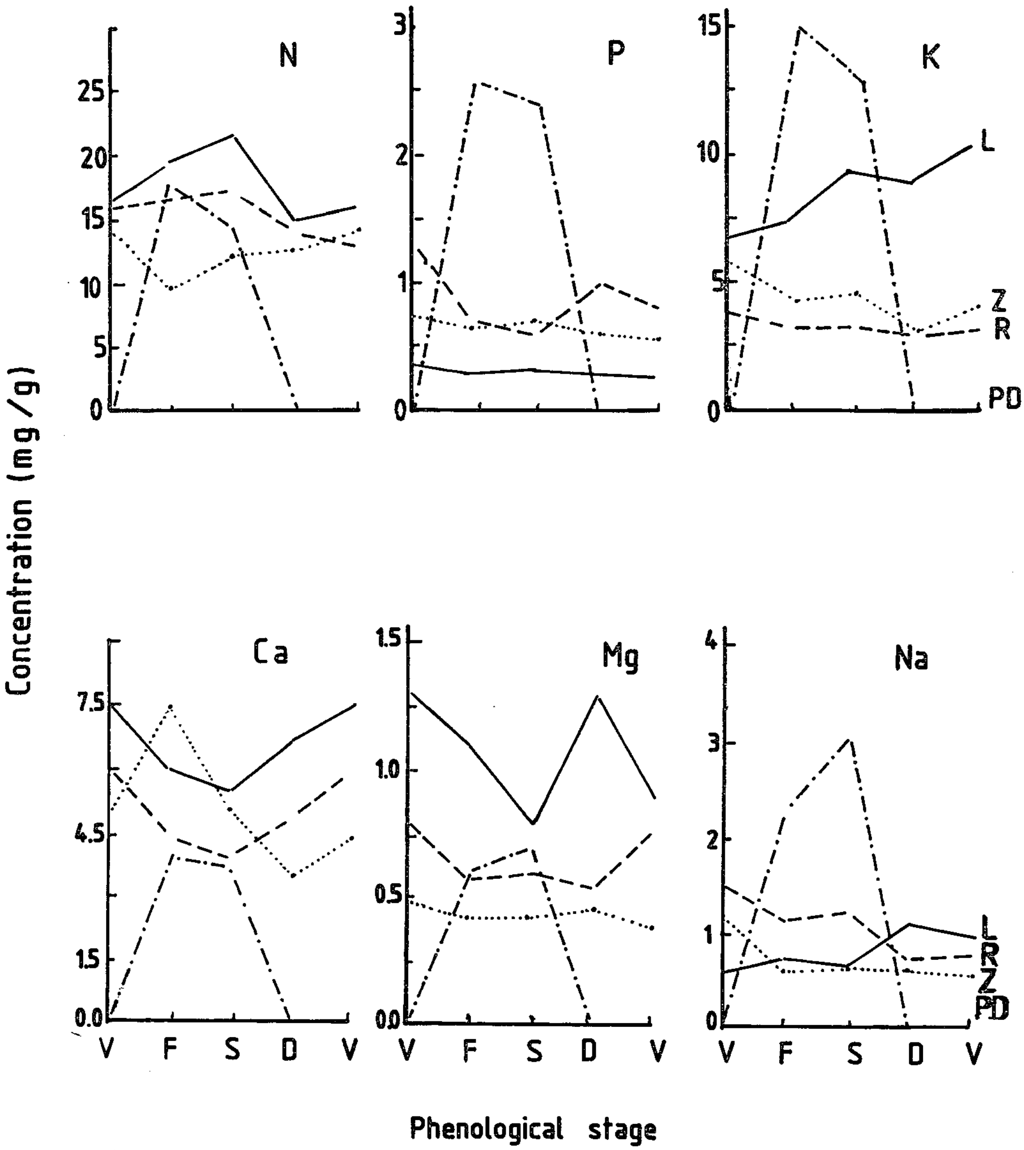

Fig. 2: Variations in nutrient concentration in the different organs of *Ammophila arenaria* in relation to phenological changes (V = vegetative, F = flowering, S = seed shedding and D = dormancy). The organs are: leaves (L), rhizome (Z), roots (R) and reproductive parts (PD.)

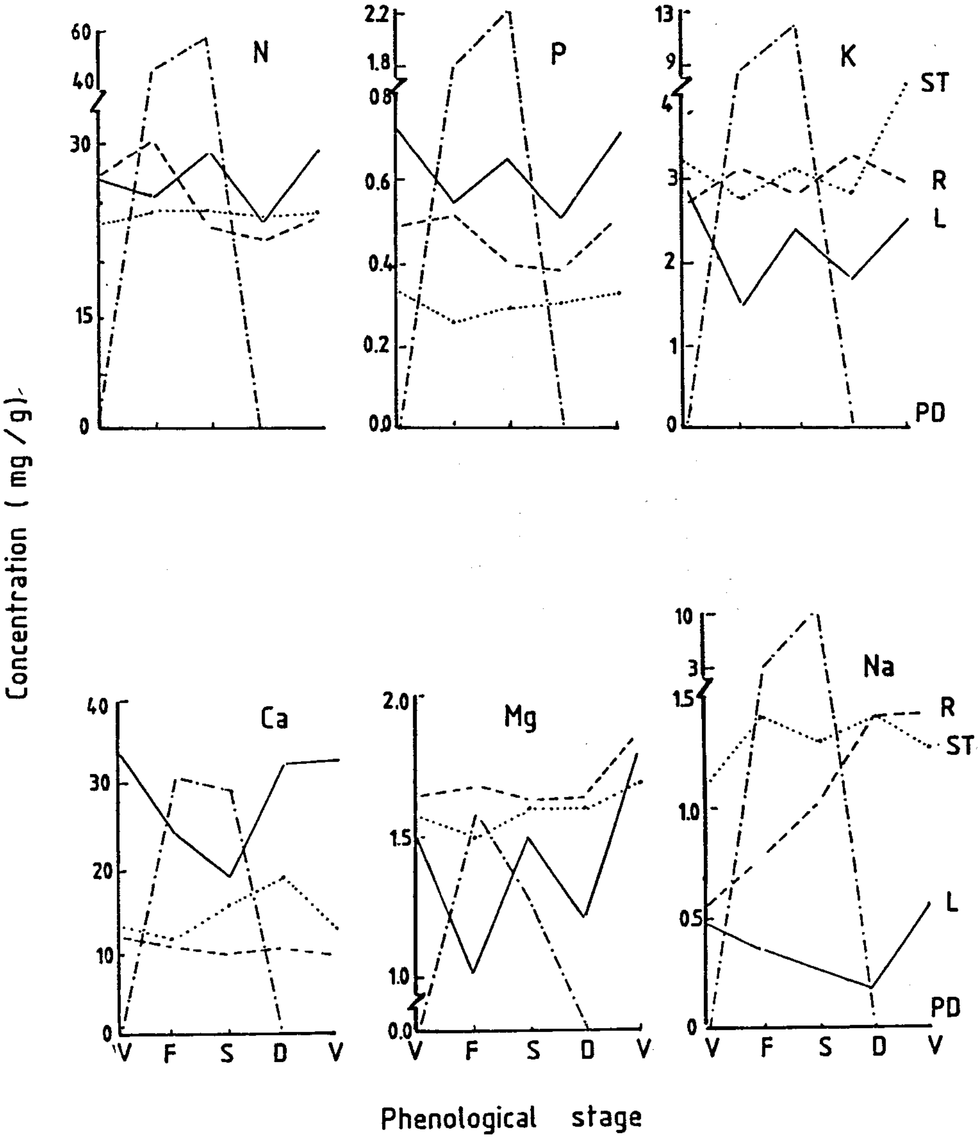

Fig. 3: Variations in nutrient concentration in the different organs of *Ononis vaginalis* in relation to phenological changes (V = vegetative, F = flowering, D = dormancy). The organs are: leaves (L), Stems (ST), roots (R) and reproductive parts (PD.)

The significant associations (r > 0.7) between the concentrations of different nutrients in the system components of both species indicates fewer nutrient associations within each component of *Ammophila* than for *Ononis*.

The monthly total nutrient uptake, calculated as the sum of the differences between the nutrient contents of the plant in successive months is presented in figure 4. The periods of high uptake activity for *Ammophila* are during autumn (about 572

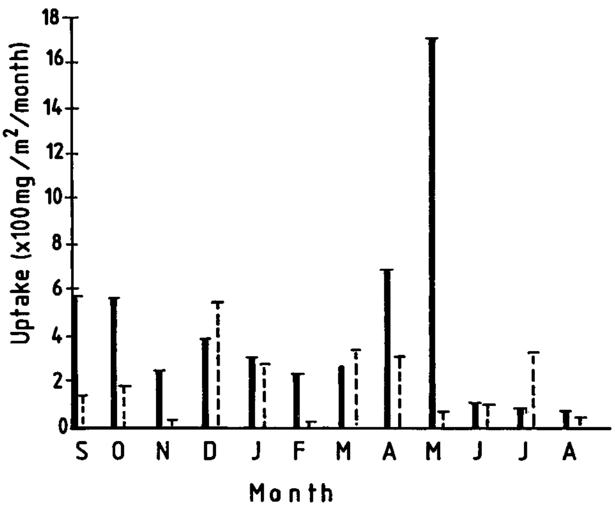

Fig. 4: Monthly average total nutrients uptake by *Ammophila arenaria* (solid bars) and *Ononis vaginalis* (dashed bars) calculated per unit area.

mg/m²/month), and in late spring (about 1710 mg/m²/month). N, K and Ca contribute the major part of total uptake during the first period (345,112 and 110 mg/m²/month respectively) while the second period is mainly due to uptake of N and K (1249 and 409 mg/m²/month respectively).

The monthly total nutrient uptake by *O. vaginalis* exhibits three peaks: the highest is during winter (about 547 mg/m²/month) and is attributed mainly to N and Ca (about 286 and 240 mg/m²/month respectively), the second is during spring (340 mg/m²/month) and is mainly due to te uptake of N (about 275 mg/m²/month), and the third peak is in July (about 330 mg/m²/month) and is attributed to Ca (about 325 mg/m²/month).

The annual total uptake of the different nutrients is in general higher in *Ammophila* than in *Ononis* except for Ca (figure 5). This is more evident for K-uptake which is about 10 fold higher in quantity. It is notable that N,K and Ca constitute the bulk of total nutrient uptaken by *Ammophila* (about 9 %), while N anc Ca are the major constituents of total nutrient uptake by *Ononis* (about 88%).

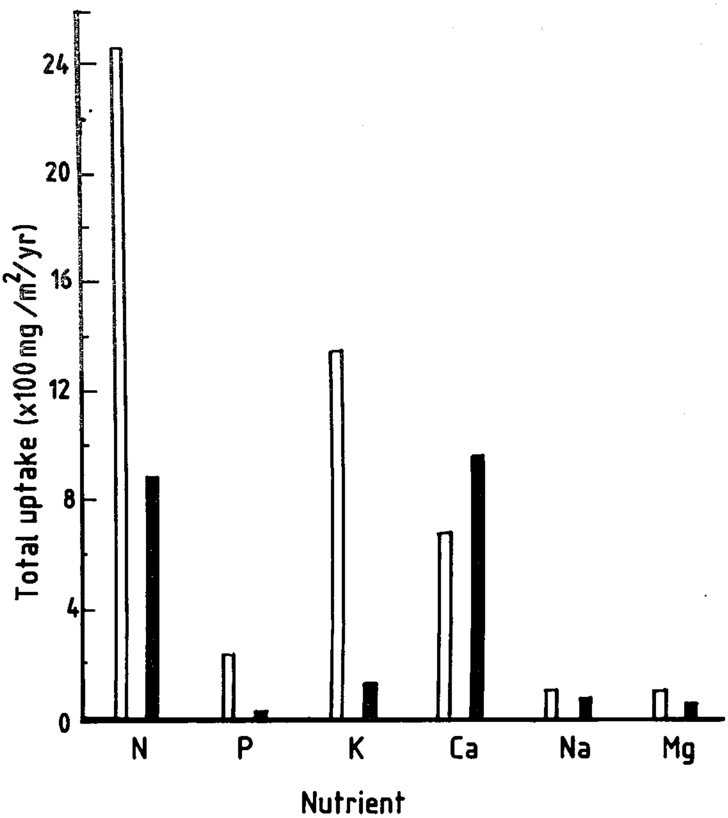

Fig. 5: Annual total uptake of macronutrients by *Ammophila arenaria* (light column) and *Ononis vaginalis* (dark column) calculated per unit area.

Simplified relational diagrams which integrate the available information on *Ammophila* and *Ononis* plant systems are presented in figures 6 and 7. It is clear that the perennating organs of *Ammophila* (rhizome and roots) retain higher quantities of the uptaken N and K compared to other nutrients (about 31.5 and 17.7 % respectively), while a greater quantity of the uptaken Ca is returned to the soil through litterfall (about 52.6 %). On the other hand, the perennating organs of *Ononis* (stems and roots) retained more of uptaken Ca (about 57.8 %), while large proportions of uptaken N and P are returned to the soil (about 32.0 and 23.1% respectively). However, large proportions of the nutrients translocated to leaves and reproductive parts are retranslocated to perennating organs prior to foliage senescence at the end of the season, which is not presented in the figures.

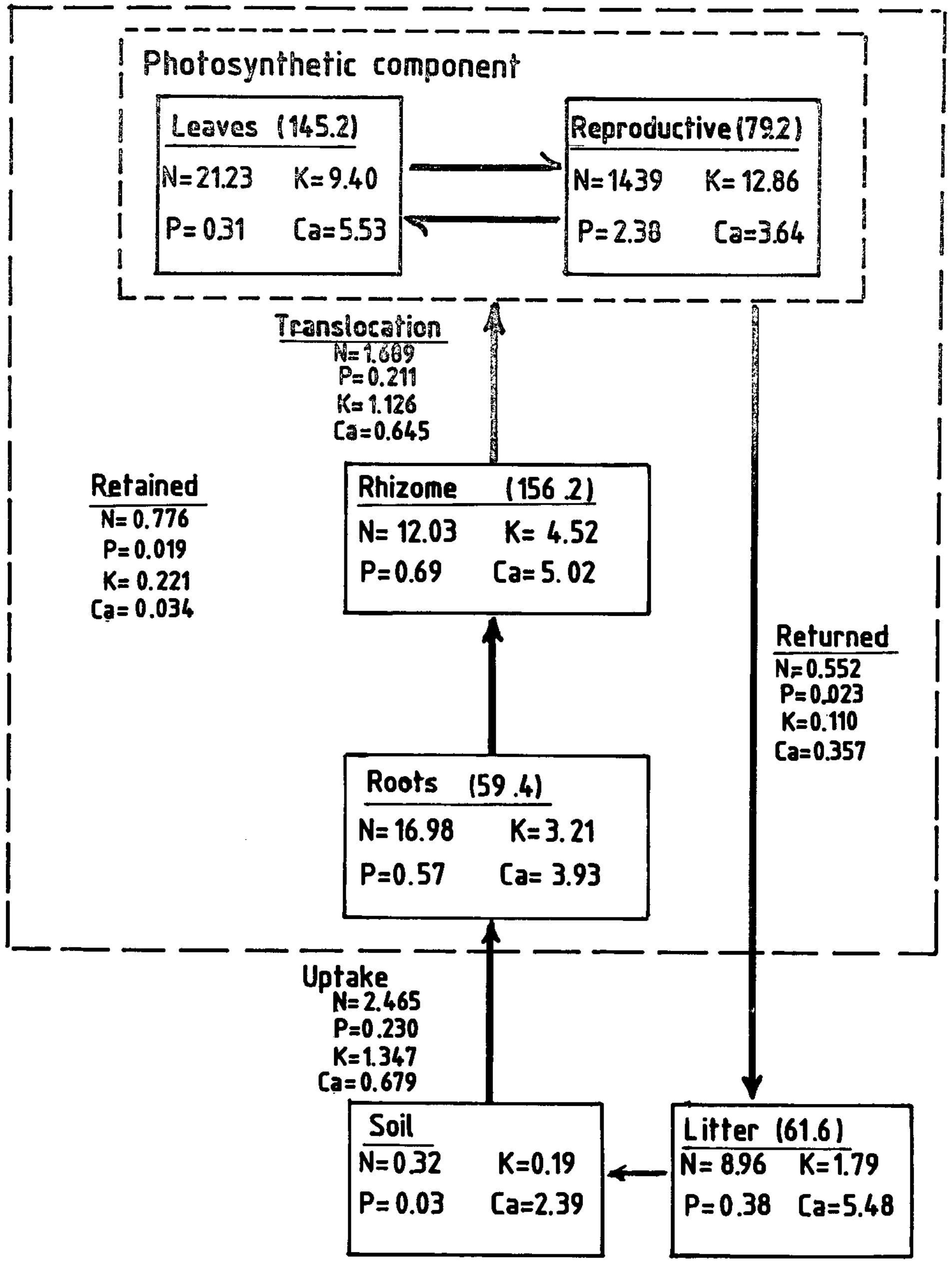

Fig. 6: Simplified relational diagram of *Ammophila arenaria* system at peak plant activity. Organ components and litter include biomass (g/m^2) and nutrient concentrations (mg/g). All processes are calculated in g/m^2.

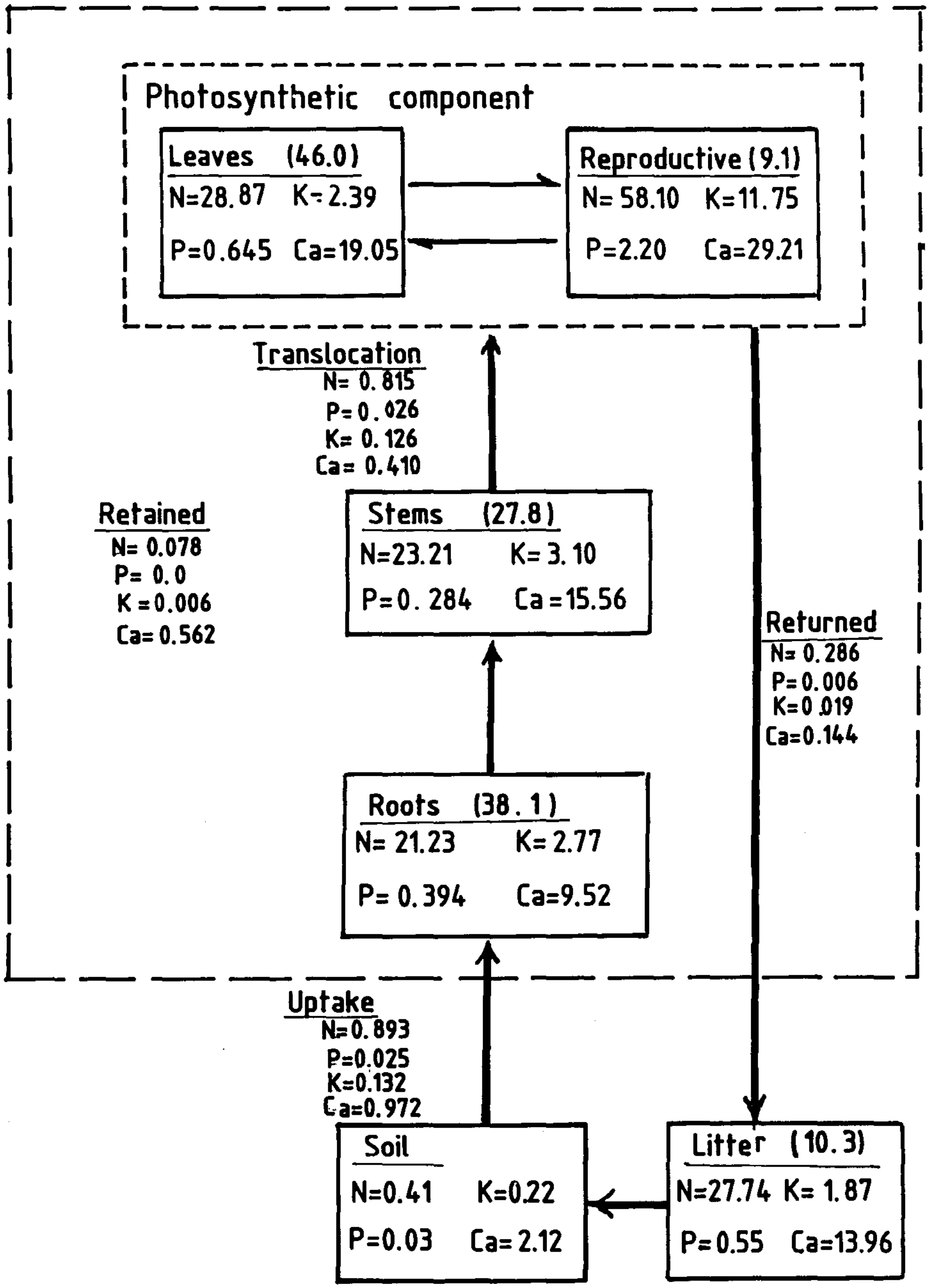

Fig. 7: Simplified relational diagram of *Ononis vaginalis* system at peak plant activity. Organ components and litter include biomass (g/m^2) and nutrient concentrations (mg/g). All processes are calculated in g/m^2.

DISCUSSION

A relatively wide range of variability in the biomass and its nutrient content would be expected for plants in desert ecosystems at various times of the year (e.g. Wallace and Romney 1972, Nilsen 1981, Veresoglou and Fitter 1984). In the present study wide ranges of variation in the contents of P and Ca have been recorded in the biomass of *Ammophila* and *Ononis* where the maxima are at least 1.6 fold the minima for the former, and 1.4 fold for the latter species. The higher concentration of P in the phytomass of *Ammophila* may be attributed to the higher concentration in its soil compared to that under *Ononis*. On the other hand, although Ca comes in the first rank of the soil nutrient concentrations, both plant species accumulate N to higher levels than Ca. The litter of both species is also more rich in N compared to the other nutrients. This may imply faster turnover rates of this critical nutrient.

The temporal variations in the content of most nutrients in plant tissues seem to be a function of phenology (Klemmedson and Smith 1973, Davy and Taylor 1975, Abdel-Razik *et al.* 1985). In the present study, the vegetative activity of *A. arenaria* and *O. veginales* is, in general, associated with notably high concentrations of most nutrients in the shoot, which results in the decrease of their concentrations in the root during this stage. Meanwhile the reproductive activity is associated with an accumulation of nutrients in the reproductive parts at the expense of their concentrations in the other organs.

In fact, it is important not only to identify the causes and sources of variation in nutrient content but also to determine which nutrients are most important in contributing to differences in this content and what relationships exist among elements. The critical nutrients are used more sparingly (in the sense of low concentration) in woody parts than in other active parts of the plant (e.g. Tyler 1971, John 1972, Woodwell *et al.* 1975). In the present study, the concentrations of N, P and K in photosynthetically active parts of *Ononis* are about 1.4, 3.9 and 2.0 fold those in woody parts, while the concentrations of Mg and Fe in the active parts are lower. The same trend also applies to *Ammophila,* except that P-concentrations in the underground parts are twice as high as in the aerial shoots. Willis (1965) indicates that N, P, and K limit the growth of *A. arenaria,* and that their defficiency severely affects the development of dune vegetation.

Groups of nutrient elements are found to be associated (high correlation coefficients between their pair-wise combinations) in different components of the plant system for both species, (e.g. Ca and Mg in leaves of *Ammophila* and P, K and Mg in leaves and stems of *Ononis).* Analysis of variance of the nutrient concentrations in different individuals of both species indicates that variations among organs as well as variations with time, and the interactions between them, are highly significant (P

<.005) for all nutrients except for K in *Ammophila* and P in *Ononis.* Although such relationships may not have immediate importance to plant environment interactions, they appear to be of ultimate significance as they may be a consequence of similarity in physiological functions of nutrient uptake and accumulation (Garten *et al.* 1977).

The retained elements (growth increment) accumulating in the biomass, when measured at any given time constitute the mineral standing crop or "mineralomass" (Duvignead and Denaeyer-Desmet 1970). The mineralomass varies from one ecosystem to the other depending on the vegetation type, the phytomass of the individuals of each species and its density. The following is a comparison between the mineralomass (gm/m^2) of macronutrients in the two plant systems:

	N	P	K	Na	Ca	Mg
A. arenaria	0.320	0.176	1.330	0.210	1.252	0.185
O. vaginalis	1.867	0.050	0.240	0.100	1.630	0.116

The total mineralomass of the macronutrients amounts to about 35.0 kg/ha for the former and 40.0 kg/ha for the latter species.

The restitution (losses) of nutrients may be through translocation, foliage drip and stem flow for senescing organs before they die (Stenlid 1958). The litter of plant species of infertile soils generally returns relatively large amounts of nutrients to the soil (Charley and Cowling 1968, Small 1972, Binet 1981). Therefore, losses of nutrients from phytomass as litter is considered the main source for recharging the soil in desert ecosystems. The high N concentration in the litter of *Ammophila* and *Ononis* in the present study (about 1.4 and 2.7% respectively) would confirm this idea when compared with the average litter content in desert communities (1.5 %) in comparison to that in grasslands and forests (1.2 and 0.6 % respectively, Rodin and Basilevich 1968). On the other hand, the soil solution of the sand dunes under study exhibits low concentrations of P compared to all other macronutrients, while N content is higher. Nevertheless, the nitrogen concentration in the dead organic material is much higher than that in the soil, which proves that the organic pool is the reservoir of N in the soil and suggests that the growth of plants on the dunes is often limited by soil fertility (Willis and Yemm 1961). Thus while the nutrient uptake causes the depletion of the soil, the litterfall and the relatively shortlived roots will produce a mosaic of depleted, recharging, and unexploited soil zones. Coupling this with the high concentrations of nutrients in the phytomass of both plant species in this study, we would assert that plants in deserts may represent the main bulk of the available nutrients. Hence, any uncontrolled disturbance in this component may result in a large dissorder and changes far beyond any expectations.

Two striking features of ion uptake by plants dominate, viz the concentration factor (the ability of plant to accumulate ions several orders of magnitude greater than that in the soil), and the quantitative difference between species and even within a species in the requirement for different nutrients. For example, the peaks of uptake of N and K by *Ammophila* are about 1.25 and 0.41 g/m²/month respectively which results in their accumulation in the phytomass to concentrations of about 17.35 and 7.06 mg/g, while their concentration in the soil is only about 0.4 and 0.23 mg/g respectively. A similar trend is found for *Ononis* but with expected quantitative differences. Generally, the uptake of all nutrients except for Ca is greater for *Ammophila,* where N and K constitute the major part of total annual uptake when compared to *Ononis,* where n and Ca constitute the main bulk of annual uptake. The total annual uptake of macronutrients by these species amounts to about 48.2 and 21.0 kg/ha respectively.

The uptake rate depends on the concentration of ions in the roots which is areflection of ion utilization by the plant. This rate is a function of root sugar level which provides energy for transport even when transport is occurring in the transpiration stream. For example, the uptake rate of N, P and K of *Ammophila* amounts to about 26.6, 1.4 and 11.7 mg/gm root/month respectively in late summer, and decreases to about 24.5, 1.1 and 10.9 mg/gm root/month in winter. This decrease coincides with the decrease recorded for total carbohydrate content in the roots from 9.8 mg/100 gm in late summer to 7.6 mg/100 gm in winter (Barakat 1978). However, the associated increase in the concentration of these nutrients in roots may also reflect lower demands for them by the shoots. A similar trend is found for *Ononis* on comparing the uptake rates of N, P and K during late summer (41.5, 0.9 and 5.3 mg/gm root/month respectively) with those during winter (38.4, 0.8 and 4.6 mg/gm root/month respectively), and relating this to the difference in total carbohydrate content in roots during these periods (9.3 and 3.5 mg/100 gm root respectively).

The translocation of the nutrients uptaken by roots and the subsequent allocation to different organs is a very complex mechanism. It is noticed that, in most cases, these processes are phenology-dependent in both species. The perennating organs (rhizome, stems and roots) conserve material, and perhaps uptake and store critical elements early in the season, which would alleviate competition for nutrients during the peak of vegetative activity. This may explain the high values of uptake of N and K during the early season (autumn). Such a relationship with phenology is confirmed by several studies (e.g. Klemmedson and Smith 1973, Davy and Taylor 1975, El-Ghonemy *etal* 1978). It is also notable that while the highest percentages of uptaken nutrients that are retained in the perennating organs of *Ammophila* are those of N and K (about 31.5 and 17.7 % of total annual uptake), the highest percentage retained in such organs for *Ononis* is that of Ca (about 57.8 %). This is associated with lower percentages when returned to the soil as litter. Therefore, it may be asserted that a physiological component dominates for the first species, while a structural component dominates for the second species as a perennation strategy.

The most mobile nutrients, in the sense of high percentage of translocation compared to that of allocation to different organs of *Ammophila* are N, K and Na. While for *Ononis,* Ca and Mg in leaves, K in stems and N, Na and Fe in roots are the most mobile nutrients. The possibility of causal relationships between translocation and tissue death is of interest. The withdrawal of nutrients from older tissues may precipitate their death (Davy and Taylor 1975). Therefore, such a mechanism may result in a conservation of critical elements allowing the plant to re-use them and lessen the need for additional uptake when the soil is drier. Both species in the present study demonstrate clear examples of this strategy.

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دراسة ديناميكية العناصر الغذائية في النظام البيئي لكثبان الساحل الشمالي الغربي بمصر

محمد سعد الدين عبد الرازق و أحمد شرف الدين عبد الوهاب

تم تقدير الوزن النباتي وتقييم دورات العناصر الرئيسية في النظم البيئية لنبات قصب الرمال Ammophila arenaria ونبات الزيته Ononis vaginalis ، وهما من أكثر الأنواع شيوعاً على الكثبان الساحلية بصحراء مصر الغربية .

إتضح من الدراسة زيادة تراكم النيتروجين إلى مستويات أعلى من نظيرها من الكالسيوم في أنسجة كلا النوعين بالرغم من نموهما فوق تربة كلسية . وتميزت عمليتي إمتصاص العناصر وتراكمها في الأعضاء المختلفة بإرتباطهما بالتباينات الغينولوجية للنباتات . كما تأثرت عملية إمتصاص العناصر بالكمية المتاحة من المواد السكرية في الجذور . وتبين أن كمية كبيرة من النيتروجين والبوتاسيوم الممتصة بنبات قصب الرمال قد أختزنت في أعضاءه المعمرة ، بينما قابل ذلك إختزان جزء كبير من الكالسيوم الممتص بنبات الزيته في أعضاءه المعمرة . وقد قدرت الكمية الكلية من محتوى العناصر بحوالي ٣٥ كجم/ هكتار في النبات الأول وحوالي ٤٠كجم/ هكتار في النبات الثاني .

تبين نتائج الدراسة إرتفاع تركيزات العناصر في الكتلة الحية وفي النثار لكلا النوعين بالمقارنة بتركيزاتها في التربة مما يعضد فكرة إحتواء النباتات الصحراوية على الجزء الأكبر من العناصر المتاحة في نظمها البيئية . كما تمثل عملية إعادة نقل العناصر من الأجزاء المتساقطة قبل موتها إلى الأجزاء المعمرة أحد صور الحفاظ على الموارد لتحسين أداء نمو هذه النباتات .