

Effect of Moisture Availability on Nitrogen and Phosphorus Uptake by Plants Under Semi-arid Soil Conditions

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INTRODUCTION

The semi-arid and arid rangeland environment is characterised by limited rainfall that is erratic in the distribution within and between seasons and years. Temperatures are high year long, and the potential evapo-transpiration exceeds the annual rainfall resulting in low relative humidity (Cocheme, 1966; Stoddart et al., 1975; Pratt and Gwynne, 1977; Musembi, 1986; Ekaya, 1998). These characteristics, particularly the low moisture content have concert profound effects on both the structural and functional aspects of the ecosystems. For example, the annual growth period may consist of a few to several days or weeks during the expected wet season with subsidiary periods of activity spread over the year. As a result, total annual primary production is often the summation of a limited number of short bursts of growth events randomly distributed in time, and showing high variability. Equally, there are far reaching effects of this climatic behaviour on mineral cycling. The overall effect is that ecosystem structure and function tends to be episodic in nature, and is seldom sustained for long periods of time.

Fertility of rangeland soils especially nitrogen and phosphorus content is a key factor in determining range productivity (Charley, 1977; Whiteman, 1980; Crowder and Chheda, 1982). These two elements are fundamental to plant biochemistry, the main effect of shortage being interference with protein synthesis and hence growth and production / productivity.

Phosphorus is an important element influencing nitrogen fixation. The rate of protein synthesis is low in soils deficient in phosphorus. Phosphorus is also important during the early stages of legume nodulation (Whyte et al., 1959). Total soil phosphorus in rangeland soils is relatively small, usually much lower than for nitrogen. The level of phosphorus in plants depends on the level of available phosphorus in the soil, which is determined by the soil type and soil fertility (Minson,

1990). Further, stage of plant growth is a major factor determining differences in nutrient content of the pasture and levels decrease from the young stage of growth towards maturity.

The aim of this study was to investigate the effect of moisture availability on nitrogen and phosphorus uptake by plants under semi-arid rangeland conditions.

MATERIALS AND METHODS

Study Site: The study area was Kibwezi division, Kenya. This area lies in agro-ecological zone V (Pratt et al., 1966) and at an altitude of about 800 m above sea level. The general area is characterized by low unreliable bimodal rainfall. Short rains are expected between October and January, whereas the long rains are expected between March and May. During the duration of this study, the total rainfall received during the short and long rains was 605.5 mm and 183.3 mm respectively. The mean annual temperature is about 25°C, with a mean annual potential evaporation of 2094 mm (Touber, 1983). The vegetation of the area is the typical *Commiphora/Acacia* deciduous bushland. The area is of marginal agricultural potential and has dispersed human population practicing subsistence mixed farming.

Experimental Design: The study consisted of four treatments, i.e. Bare ground (which also served as a control), grass plot, Legume plot, and grass/legume mixture plot. *Chloris roxburghiana* was used in this experiment based on its dominance in the study area. *Desmodium uncinatum*, being one of the best performing legumes in East Africa (Keya, 1974; Skerman, 1977; Boonman, 1993) and being able to grow at altitudes ranging from sea level to about 2400 m above sea level was used.

Two enclosures measuring 12 m x 6 m were established on different soil types to exclude livestock and/or wildlife herbivory or interference. The soils at the experimental sites were the basement system complex whereby they were developed on gneiss rich in ferromagnesian minerals i.e.

biotite and hornblende–biotite gneiss. Site I was situated on well drained, very deep, dark reddish brown soils with sandy clay loam texture. Site II was situated on well-drained, moderately deep, brown sandy clay soils.

Each enclosure was divided into eight plots measuring 2 m x 2 m arranged in two rows containing four plots each. Each plot was further subdivided into four equal sub-plots measuring 1 m x 1 m. The rows within sites were 1 m apart. Treatment allocation was conducted on a plot basis and consisted of randomly assigning each of the four treatments to one of the four sub-plots within a plot. Half of the plots were watered whereas half remained unwatered. In plots assigned to a watering regime, ten litres of water was applied twice a week to four of the plots. The water was applied in a slow fashion to avoid runoff, and at the same time ensure soaking into the soil.

The experiment was conducted during the short rains season and repeated during the long rains season. Soil samples were collected twice during each of the two seasons. An initial soil sampling was conducted prior to planting of *Chloris roxburghiana* and a second sampling at the seeding stage. Plant material was harvested at the vegetative and seed ripening stages of the grass. Harvested material was weighed and oven dried to constant weight at 80°C. The samples were then analyzed for crude protein (CP) and

phosphorus (P) content. CP was determined using the Micro-Kjeldahl method (A.O.A.C., 1980) whereas P was determined using the methods outlined by Hinga et al. (1980). The data on soil and plant samples were statistically analyzed using a 3 factor split-split plot design to test for treatment differences and significant interactions. Treatment means were separated using Tukey's procedure (Steel and Torrie, 1981).

RESULTS AND DISCUSSION

Table 1 presents the CP content from the various treatment plots. The treatment effects on soil nitrogen were significant ($P < 0.05$) only in watered plots and only during the short rains season. These plots had more total nitrogen than unwatered plots ($P < 0.05$). During the long rains season when there was less rainfall, the effect of watering was significant ($P < 0.05$) with the watered plants having higher CP content except for the grass in mixture and legume treatments.

The uptake of some nutrients, particularly nitrogen as nitrate ions, may depend on water flow through the soil roots (Harper, 1977; Haque and Jutzi, 1984). A shortage of water will then manifest itself as reduced nitrogen uptake, and hence low CP. *Desmodium uncinatum* had less CP content during the long rains season. These plants were more affected in their growth by the less soil moisture than *Chloris roxburghiana*,

Table 1: Crude protein content (%) of *Desmodium uncinatum* and *Chloris roxburghiana* grown in watered and unwatered field plots during two seasons.

Treatment	Vegetative stage				Seeding stage			
	Watered		Unwatered		Watered		Unwatered	
	Site I	Site II	Site I	Site II	Site I	Site II	Site I	Site II
SR Season								
Grass plot	7.33 ^{a1}	8.91 ^{a1}	9.71 ^{a1}	7.08 ^{a1}	6.38 ^{a1}	5.97 ^{a1}	7.74 ^{a1}	6.57 ^{a1}
Legume plot	20.38 ^{d1}	16.81 ^{b2}	15.0 ^{b2}	16.91 ^{b2}	13.08 ^{b3}	11.77 ^{b3}	12.21 ^{b3}	11.07 ^{b3}
GL/grass plot	11.21 ^{b1}	9.99 ^{a1}	7.44 ^{a12}	9.21 ^{a1}	8.21 ^{a1}	9.16 ^{b1}	8.55 ^{a1}	9.47 ^{b1}
GL/legume plot	16.49 ^{c1}	15.64 ^{b1}	15.07 ^{b1}	15.30 ^{b1}	12.00 ^{b2}	12.52 ^{bc2}	12.17 ^{b2}	10.49 ^{b2}
LR Season								
Grass plot	8.67 ^a	8.74 ^a	23.22 ^b	10.22 ^b	8.85 ^a	9.07 ^a	0.00 ^a	9.53 ^b
Legume plot	13.25 ^a	15.63 ^b	0.00 ^a	0.00 ^a	9.80 ^a	11.99 ^a	0.00 ^a	0.00 ^a
GL/grass plot	9.86 ^a	11.34 ^b	11.56 ^b	14.06 ^b	6.66 ^a	9.86 ^a	10.56 ^b	11.60 ^b
GL/legume plot	11.85 ^a	12.75 ^b	0.00 ^a	0.00 ^a	10.50 ^a	13.78 ^a	0.00 ^a	13.22 ^b

Key:

GL/grass= grass component in grass/legume mixture

GL/legume=legume component in grass/legume mixture

Column means with different letter superscripts are significantly different ($P < 0.05$)

Row means with no number superscripts are not significantly different ($P > 0.05$)

which was better adapted to the study area. *Desmodium uncinatum* has a tap root whereas *Chloris roxburghiana* has adventitious roots and therefore in mixtures, competitive interference for soil nutrients and water is minimized due to differences in root depths.

Generally, CP content of the grass and legume decreased as the plants progressed from vegetative stage to the seeding stage. Interactions between growth stage and the treatments were significant ($P < 0.05$) only in short rains season. Watering did not have a significant effect on the CP content of the plants during the short rains season ($P > 0.05$). During the long rains season, with less rainfall, watering had a significant effect. During both seasons, the legume component had higher CP content than the grass component. The watered legume plots had more CP than unwatered plots at both stages of growth. During the long rains, the legumes in the unwatered plots died off due to lack of moisture.

During the short rains, the watered grass and legume plots in site I had higher CP content than those in site II. However, for grass/legume mixture plots, site II had higher CP content. During the long rains, all site II plots had higher CP content than site I plots for both the watered and the unwatered plots.

Table 2 presents the P content from the various treatment plots. The effect of watering was

significant only during the long rains season ($P < 0.05$). This implied enough rainfall for the growth of the plants during the short rains season. The overall mean showed that during the long rains, plants had less P content possibly due to the low amount of available P in the soil. There was a rise in soil P at the end of the short rains and a decrease at the end of the long rains in both watered and unwatered plots.

A change of soil pH was recorded with an increase in site I and a decrease in site II. At the beginning of the experiment, the pH was 7.0 and 7.1 for sites I and II respectively. At the end of second growing season, the pH of site I had become more alkaline with a pH range of 7.0 - 7.7 in unwatered plots. The watered plots were also alkaline with a pH range of 6.9 - 7.9. The unwatered site II plots had a pH ranging from 6.1 - 6.5 and the watered plots had a pH range of 6.4 - 7.0. The pH decreased with depth, the topsoil being more alkaline. White specks of salt were observed on the surface of the watered plots. The possible fixation of soil available phosphorus (due to a change of pH) probably affected the absorption of phosphate ions leading to a decline of P content of the plants during the long rains season.

Under the watering regime, the grass in monoculture had higher P content than when grown in mixture with the legume ($P < 0.05$). Under unwatered conditions, the grass in mixture had

Table 2: Phosphorus content (%) of *Desmodium uncinatum* and *Chloris roxburghiana* grown in watered and unwatered field plots during two seasons.

Treatment	Vegetative stage				Seeding stage			
	Watered		Unwatered		Watered		Unwatered	
	Site I	Site II	Site I	Site II	Site I	Site II	Site I	Site II
SR Season								
Grass plot	0.9 ^a	0.38 ^a	0.32 ^a	0.33 ^b	0.31 ^a	0.28 ^a	0.28 ^a	0.22 ^a
Legume plot	0.37 ^a	0.40 ^a	0.44 ^b	0.40 ^b	0.28 ^a	0.34 ^a	0.33 ^a	0.35 ^b
GL/grass plot	0.36 ^a	0.36 ^a	0.37 ^a	0.30 ^a	0.31 ^a	0.27 ^a	0.32 ^a	0.22 ^a
GL/legume plot	0.37 ^a	0.43 ^a	0.43 ^b	0.40 ^b	0.31 ^a	0.35 ^b	0.36 ^b	0.35 ^b
LR Season								
Grass plot	0.53 ^b	0.19 ^a	0.23 ^b	0.16 ^a	0.26 ^a	0.18 ^a	0.00 ^a	0.14 ^a
Legume plot	0.28 ^a	0.23 ^a	0.00 ^a	0.00 ^a	0.19 ^a	0.21 ^a	0.00 ^a	0.00 ^a
GL/grass plot	0.44 ^b	0.21 ^a	0.44 ^c	0.12 ^a	0.18 ^a	0.22 ^a	0.13 ^a	0.16 ^a
GL/legume plot	0.36 ^a	0.24 ^a	0.00 ^a	0.00 ^a	0.20 ^a	0.16 ^a	0.00 ^a	0.10 ^a

Key:

GL/grass= grass component in grass/legume mixture

GL/legume=legume component in grass/legume mixture

Column means with different letter superscripts are significantly different ($P < 0.05$)

Row means with no number superscripts are not significantly different ($P > 0.05$)

more P than the monoculture grass. This phenomenon was probably because under watered conditions, the legume had a competitive advantage of P uptake at the young growing stage. The mean P content of the grass in pure stand decreased from 0.31% during short rains to 0.21% during the long rains, while that of grass in mixture decreased from 0.31% to 0.24% respectively. The highest decrease was recorded in the legume plants.

There was no significant difference in the P content of the watered plots between sites during the short rains season. The P content ranged from 0.36–0.43. In the unwatered plots, the P contents of the grass and legume plots were significantly different ($P < 0.05$). Site differences were not significant. During long rains season, the site differences only manifested in the plots planted with grass, whether as sole or in intercrops. The P contents were generally lower at seeding stage than at vegetative stage. During short rains season, the site differences only occurred in legume grown in mixture under watering regime and in the sole legume plots under non-watering regime. During long rains season, there was no significant difference between sites. The watered plots in site I had higher P content in plots with grass component than those in site II, whereas the plots with a legume component registered more P content in site II plots than in site I. At seeding stage, the plants had less P content in during both seasons.

The legume in a monoculture and in mixture with the grass did not have a large difference in the P content. The mean P content in the pure legume stand decreased from 0.31% during the short rains to 0.11% during the long rains while that of legume in mixture decreased from 0.38% to 0.13% between the two seasons. The positive response to watering during the long rains season is associated with the nature of long rains in range ecosystems. The long rains tend to be less effective in terms of fuelling range ecosystems, due to the poor distribution within the rain season or even out of season. The effect of this phenomenon is that the plants will receive inadequate rainfall and hence will have slow growth and low annual production (Ekaya, 1998). The plants may then concentrate CP in their shoots than plants having fast growth due to adequate rainfall.

Wijngaarden (1985) stated that vegetation production in semi-arid environments is often controlled by the availability of water. However, availability of nutrients such as nitrogen and phosphorus affect primary production. Research in Tsavo National Park (Wijngaarden, 1985) revealed that at flowering, the CP content of grasses was above 9.38% and P values ranged between 0.09% and 0.20%. The values agree with those from the current study. Power (1967) traced nitrogen applied as fertilizer in irrigated and non-irrigated plots. Under irrigation, over 80% of the nitrogen was recovered from the shoots and roots, whereas only 5–10% was fixed in the soil. Without irrigation, the amount of nitrogen fixed in the soil was equal to, or exceeded that recovered by plant. It was reported that the primary effect of water was to hasten absorption of nitrogen and that nutrients are limiting to primary productivity at high moisture levels whereas water is the limiting factor in dryland ecosystems. In this study, additional moisture increased the P content of both the legume and grass plants. These findings agree with those of Cosper and Thomas (1961) who reported higher P content in fertilized and irrigated prairie vegetation compared to similar but non-irrigated vegetation in Western South Dakota.

The level of CP and P content of *Chloris roxburghina* and *Desmodium uncinatum* plants depended on the level of available N and P in the soil. According to Power (1972), P is readily fixed in the soil and is less susceptible to leaching unlike nitrogen which is subject to leaching by water, and losses to the atmosphere in gaseous form may be as much as 20%. Phosphorus is necessary for nodulation of legumes, hence increasing CP and P content of the plants. Better nodulation of legumes leads to a better uptake of other nutrient elements essential for plant growth and production.

KEY WORDS Moisture. Semi-Arid. Soils. Nitrogen. Phosphorus. Grass. Legume.

ABSTRACT A study was conducted in the semi-arid Kibwezi division of Kenya to investigate the effect of moisture availability on nitrogen and phosphorus uptake by plants. The study consisted of four treatments i.e. control, grass, legume, and grass/legume mixture. These were replicated on two sites with different soils. On each site, two sets of treatment were set up whereby one was

given additional water, whereas one remained unwatered. The experiment was conducted during the short and the long rains. CP and P contents were determined for each of the treatments and seasons.

The CP content of plants generally decreased as they grew from vegetative to seeding stage. Watering had no significant effect ($P < 0.05$) on the CP content of plants during the short rains. During both seasons, the legume component had higher CP content than the grass. The effect of watering on P content was only significant during the long rains. Overall, during the long rains, plants had less P content. There was no significant difference ($P < 0.05$) in the P content of the watered plots between sites during the short rains season. Generally, the level of CP and P of grass and legume depended on the level of available nitrogen and phosphorus in the soil, as well as soil moisture content.

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