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Growth Pattern and Nutrient Cycling in a *Trifolium alexandrinum* (Clover) Agroecosystem Under Rotational Grazing in the Mediterranean Desert of Egypt

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ABSTRACT. The productivity and nutrient cycling are evaluated in a clover desert agroecosystem under the conventional rotational grazing. A descriptive model of the state of the system that integrates the collected information is presented.

The annual total production of clover is estimated as 16.65 tonnes per hectare, while that of the associated weeds is about 2.41 tonnes per hectare. The temporal variations in biomass and nutrient content in different system components are promoted by defoliation by grazing animals. Most resources are manipulated by both shoots and roots during the growing season, which allows for a turnover ratio of about 30% of annual production (surplus for long term ecosystem maintenance), and consequently to positive net ecosystem production levels. Therefore, clover with minimum subsidy of irrigation water may be one of the best crops to be raised under arid conditions. It serves a multiple conservation purpose by releasing grazing pressure on natural range lands and fields of the Nile Delta and improving the nutrient status and soil structure of the desert lands.

Clover (*Trifolium alexandrinum*) is an essential crop for pasturalism in Egypt. It contributes a major proportion of feed in the Nile Delta, and provides supplementary feed in the desert. Under desert conditions, this crop may provide an extended production for several defoliation treatments in a rotational grazing regime. The regrowth capability, following defoliation, of this leguminous annual plant coupled with a higher source of nitrogen is considered an important criterion in favour of this type of cultivation to many of the range crops used in the area.

The present study aims at the elucidation of the growth pattern of clover cultivation under rotational grazing by sheep and goats, and the construction of a model representing the nutrient cycling in this agroecosystem.

The site of study is located in the non-saline depression (Abdel-Razik *et al.* 1988a), about 40 km west of Alexandria and 9 km inland from the sea. It lies within a cropping area irrigated by Nile water. The area belongs to the attenuated (of shorter dry period) arid Mediterranean coastal belt province of Egypt on the basis of the ratio between precipitation (average 150 mm/yr) and evapotranspiration (average 2.46-5.93 mm/d), and the average air temperature of the coldest (13.2°C) and the hottest (26.0°C) months (Ayyad *et al.* 1984). The relative humidity ranges between mean minimum of 60% and mean maximum of 72%. The bioclimatic map of UNESCO (1977) designates its climate as arid with mild winters and warm summers.

Methods

Clover was sown in October and harvested in May (220 days long) in the site of the present study with no direct irrigation. Samples of plant material and soil were collected from 10 randomly located plots (1×1m) every 10 days. The plant samples were separated into different organs as well as the standing dead material, and their oven-dry weights (at 105°C) were estimated. The oven-dry weights of associated wild species in the sampled plots were also estimated. The barley individuals intermingled with clover were treated separately, while annual weeds were pooled into one group and the perennial weeds into another group. Soil samples were collected at the zone of maximum root distribution. Composite samples of each plant organ, of the standing dead material and of the soil representing each sampling date were analysed for the determination of their contents of nutrients according to the procedures of Allen *et al.* (1974).

The grazing animals were introduced to the clover field in the same size and frequency traditionally practiced in the area. The nutrient uptake in each time interval was estimated on the basis of the nutrient content in the biomass added during that interval. The translocation and allocation of nutrients were estimated as the increases and decreases in their contents in different organs.

Results

The soil texture of the clover agroecosystem of the present study averages about 35.3, 35.0 and 29.7% of sand, silt and clay respectively. The average organic matter content is about 3.9%. The maximum soil moisture content was attained in February and reached a value of about 28% of the oven-dry weight, mainly due to the exceptionally high rainfall in January during the study period (Table 1), and which is equivalent to 28.6% soil moisture content at the depth of maximum root distribution. The soil moisture content was also high in November and December (25%) which was attributed mainly to subsurface flow of irrigation water from neighbouring irrigated crop fields since the recharge by rainfall was relatively low (Table 1).

The rotational grazing regime led to the recognition of three characteristic growth periods (Fig. 1), one before the first defoliation by grazing animals, one between the first and second defoliation, and one after the second defoliation. Each of these periods was characterized by a specific trend of variation in the values of relative growth rates (g/g/day) in relation to variation in the crop biomass (Fig. 2). The first period was about 110 days long starting in mid October when the seeds were sown, and ended when the animals were introduced into the

Table 1. Variations in the monthly amounts of rainfall during the investigation, and in the measured (rainfall + subsurface flow) and estimated (recharge by rainfall only) soil moisture contents in the clover agroecosystem

				Months			
	Nov.	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**
Rainfall (mm)	7.0	15.0	103.0	52.0	18.0	1.0	0.0
Soil Moisture (%)	25.0	24.8	16.7	28.0	10.6	9.9	8.9
ERM*	1.9	4.2	28.6	14.4	5.0	0.3	0.0

* ERM = [RF/D × BD] × 100
where,
ERM = estimated rain moisture, RF = rainfall/unit area (cm^3), D = maximum root depth (25 cm), BD = average bulk density (1.44 g/cm^3).

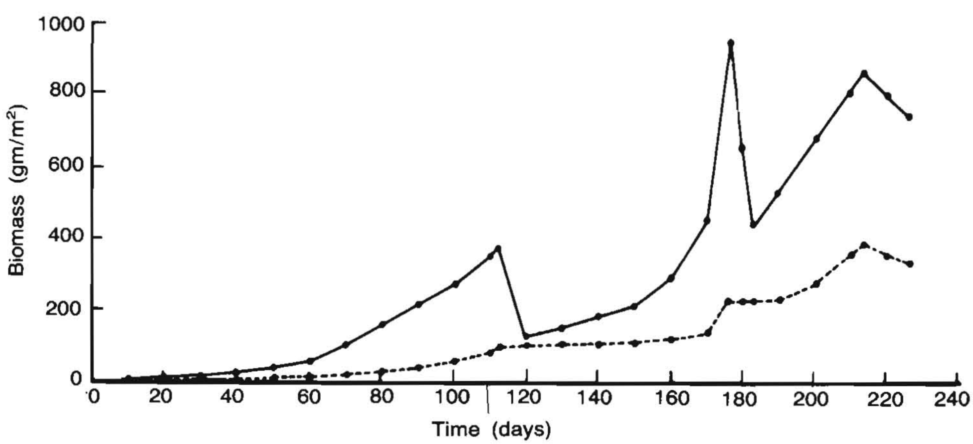

Fig. 1. Temporal variations in the total biomass (solid line) and root biomass (dashed line) of the clover crop. The first and second peaks correspond to the successive defoliation treatments.

Table 2. Variations in nutrient concentration (mg/g) attained in different parts of clover plant during each growth period

Organ		Nutrients					
		N	P	K	Ca	Na	Mg
		First period (weeks 2-18)					
Root	min.	7.67	0.003	10.31	5.00	7.12	0.12
	max.	34.20	0.039	27.52	9.20	26.11	2.00
Shoot	min.	13.20	0.300	13.19	6.99	9.99	2.97
	max.	29.00	0.680	36.19	13.00	23.00	6.32
		Second period (weeks 19-27)					
Root	min.	34.23	0.038	27.41	9.21	26.92	2.03
	max.	38.12	0.059	30.29	15.29	30.11	5.29
Shoot	min.	28.92	0.623	36.00	14.23	23.20	4.01
	max.	39.21	0.849	49.31	23.00	36.66	13.07
		Third period (weeks 28-34)					
Root	min.	38.92	0.043	30.20	16.00	28.20	5.95
	max.	43.00	0.069	36.93	21.00	33.20	10.03
Shoot	min.	38.21	0.850	45.20	20.07	33.11	11.93
	max.	50.19	0.953	57.21	34.21	43.00	22.00
Flowers	min.	6.99	0.032	5.12	0.92	3.12	0.39
	max.	20.19	0.320	13.00	3.00	7.19	2.96
Dying parts		10.13	0.420	12.71	7.12	11.73	0.13

field for the first time (late January). After about three weeks of establishment, the growth proceeded to a maximum biomass (about 374 g/m^2) at the end of that period (Fig. 1). The shoots contributed about 80% of that biomass which was, more or less, shared equally by both leaves and stems. The maximum relative growth rate during this period was 0.09 g/g/day when the biomass was about 50 g/m^2. The first defoliation brought the total biomass down to about 115 g/m^2 of which the ungrazed shoot biomass was about 39 g/m^2.

The second growth period was about 60 days (during spring). After a short stabilization period of about two weeks, the growth was resumed to another maximum biomass (about 943 g/m^2) at the end of that period (Fig. 1). The relative conributions of leaves, stems and roots to this biomass was, more or less, similar to those of the first growth period. This period was characterized by an exponential increase in the relative growth rate up to a maximum of 0.117 g/g/day (Fig. 2) when the biomass was about 435 g/m^2. The second defoliation brought again the total biomass down to about 435 g/m^2 of which the ungrazed shoot

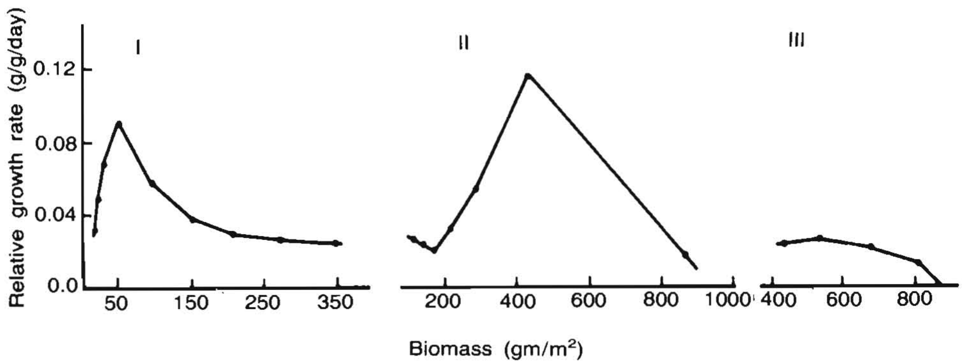

Fig. 2. Relationship between the relative growth rate and the biomass of clover during the first, second and third growth periods (I, II & III respectively).

biomass was about 238 g/m^2.

The last growth period was about 45 days long and was characterized by the initiation of the reproductive activity. The maximum biomass of this period (about 850 g/m^2) was attained after four weeks. The reproductive parts contributed about 17% of this biomass while roots contributed about 38%. The maximum relative growth rate during this period was only 0.026 g/g/day when the biomass was about 535 g/m^2. Towards the end of this period a large proportion of leaves and stems died off at a rate which increased rapidely during the last week, after which the whole plant became standing dead material.

The concentration of different nutrients in clover varied notably from one growth period to the other (Table 2). There was a gradual increase in nutrient concentration coinciding with the elapsed time during each growth period. Therefore, all nutrients exhibited higher concentrations in both shoots and roots after each defoliation treatment. However, there was no abrupt changes in concentration throughout the growing season under defoliation treatments while it was building up in the plant parts. The highest means of nutrient concentration were those of nitrogen in roots and potassium in shoots. The reproductive parts attained much less nutrient concentrations than those attained by other plant parts.

The clover cultivation stimulates the growth of some wild annual and perennial herbs, as well as some barley individuals from seeds mixed with those of clover or which were blown over by the wind from adjacent fields. The total biomass of these plants in the clover field attained a maximum of about 210 g/m^2 at the end of the first growth period. Of this biomass, barley contributed 46 g/m^2, while annual herbs contributed 38 g/m^2. After the first defoliation treatment a large proportion of the annual herbs as well as all the barley plants did not recover. Hence the maximum biomass decreased to about 106 g/m^2 of which 61 g/m^2 was represented by annual herbs. After the second defoliation treatment, only some perennial herbs existed with a few late growing annuals.

Barley had high concentrations of most nutrients compared to those in associated herbs especially in the first growth period except for roots of perennials (Table 3). Also the nutrient levels in the shoots of annuals during this period exceeded their levels in similar parts during the successive growth periods. The nutrient concentrations in the soil did not exhibit much variability throughout the growing season.

The proposed descriptive flow diagram model of the annual production and nutrient status of the clover agroecosystem (Fig. 3) comprises eight compartments three of which are for shoot biomass at different growth periods and one for each of root biomass, herbs biomass, defoliation by grazing, harvesting by man, and soil nutrient content pool. The flows between compartments represent the gain processes of uptake and translocation, and the losses through grazing treatments and death.

Each of the clover biomass compartments includes five measures: initial biomass (Vi), maximum biomass attained during the growth period (V_m), biomass at maximum growth rate (Vx), maximum relative growth rate (Gx), and the length of the growth period (p). Each compartment is also associated with values of maximum concentrations retained of N,P,K and Ca. All biomass units are in g/m^2, those of growth rates are in g/g/day, while nutrient concentrations are in mg/g on dry matter basis.

The uptake and translocation rates are calculated on annual basis ($mg/m^2/$ year), while losses by grazing and death of plant parts are estimated in terms of nutrient contents (g/m^2). The herbs are described in two terms; one representing its maximum biomass, and the other for maximum concentrations (mg/g) of N,P,K and Ca as averages for the total plant.

The growth pattern of each of the biomass compartments can be determined using a generalized Poisson density function relating the relative growth rates to the biomass base development. Different values for shape parameters are assigned to the ascending and descending limbs of the curves to and from the maximum rate for each compartment. Consequently, the biomass will change from the initial value to its maximum value according to the equation:

$$Vt+t^* = Vt\ (1.0 + Gr \times Gx \times t^*)$$

where: Vt and $Vt+t^*$ = biomass at the beginning and at the end of each time step (g/m^2), t* = time step in days,

Gx = maximum relative growth rate (g/g/day), and

Gr = scaling factor for variations in the relative growth rate with variations

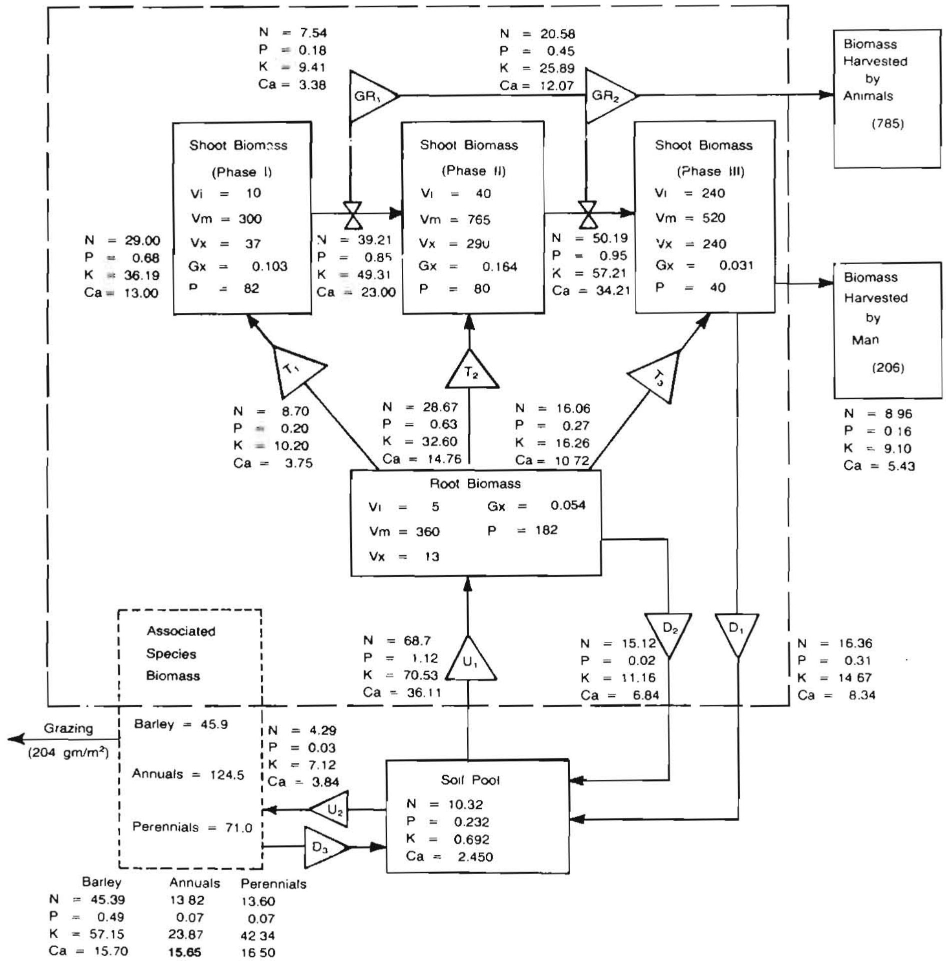

Fig. 3. A proposed descriptive model of the annual flux of N, P, K and Ca in clover agroecosystem.

(U = uptake, and D = death in g/m²/yr; T = translocation and GR = grazing rate in g/m²/growth period).

Each biomass compartment includes initial biomass (Vi), maximum biomass attained (Vm), biomass at maximum growth rate (Vx), maximum relative growth rate (Gx), and the length of the growth period (p). All biomass values are in g/m² while concentration data are in mg/g of shoot biomass.

in biomass base following the generalized Poisson density function:

$$Gr = W^c \times (c/d) \times (1.0 - W^d), \; W = (Vm-Vt)/(Vm-Vx)$$

where:

Vm = maximum biomass (g/m^2),

Vx = biomass at Gx (g/m^2),

c & d = shape parameters of descending and ascending limbs of the curves.

The estimated values of these different variables and parameters for the variation in the total crop biomass are presented in Table 4.

The uptake and translocation processes are determined as functions of biomass development pattern. These functions could be approximated into a piece-wise linear function having two ramps with positive slopes for the first growth period of clover (Fig. 4). During the second growth period, the uptake and translocation rates are, more or less, linearly related to biomass with a positive slope, while for the third growth period they represent a negative exponential growth function with an upper limit on biomass after which the relationship is a linear function with a negative slope.

All other processes in the model could be treated on either biomass or time threshold bases as each process depends to a large extent on the biomass level attained at the time when the process is active.

Discussion

A descriptive model is constructed in the form of a relational diagram that integrates the available information on the state of the clover agroecosystem in the present study, and the relationship between its different components. Accordingly, the main characteristics of the clover cultivation can be summarized in the following items:

1. The annual total production (shoots + roots) of clover in the study site adds to about 16.65 tonnes per hectare as well as 2.41 tonnes per hectare of the barley and herbs. About two thirds of this total production is harvested by grazing animals and by man (11.95 g/m^2). This production is promoted by defoliation through rotational grazing; hence the maximum biomass is more or less duplicated after each grazing application. Therefore, the second defoliation by grazing animals results in the removal of twice as much biomass as that removed during the first defoliation.

2. The concentration of most nutrients buildsup in the plant parts despite grazing. This is more detected in roots especially after the first grazing application. The reproductive parts attain much less concentration levels of most nutrient at the end of season compared to the other plant parts.

Table 3. Variations in nutrient concentration (mg/g) attained in different parts of associated species during each growth period and in the soil of clover cultivation

Organ		Nutrients N	P	K	Ca	Na	Mg
Barley				**First period**			
Root	min.	19.21	0.970	30.98	13.66	15.09	1.94
	max.	22.99	1.350	33.19	21.16	23.91	1.99
Shoot	min.	32.59	0.410	41.16	9.71	19.67	5.12
	max.	49.17	0.450	61.19	14.61	27.19	9.97
Perennials							
Root	min.	12.98	0.032	37.09	10.02	34.09	10.91
	max.	17.98	0.093	60.66	13.71	41.19	14.23
Shoot	min.	9.37	0.029	20.91	13.00	21.04	4.05
	max.	13.96	0.071	29.77	16.96	25.19	7.92
Pooled annuals							
Root	min.	6.34	0.090	18.72	10.27	15.21	1.12
	max.	7.14	0.170	22.17	12.19	19.12	2.04
Shoot	min.	11.21	0.040	27.19	10.16	15.02	4.01
	max.	16.71	0.060	30.19	16.79	18.76	5.96
				Second period			
Perennials							
Root	min.	4.11	0.052	30.20	21.30	14.72	1.02
	max.	8.19	0.076	41.72	27.90	19.89	4.90
Shoot	min.	5.11	0.012	10.19	7.91	6.21	2.01
	max.	7.16	0.021	20.16	11.17	15.72	4.00
Pooled annuals							
Root	min.	4.13	0.070	17.97	13.71	17.76	2.52
	max.	8.12	0.106	28.72	15.62	20.71	3.66
Shoot	min.	2.71	0.007	5.01	1.93	3.72	0.10
	max.	6.21	0.010	11.16	13.12	6.71	2.12
Soil	min.	10.06	0.227	0.52	2.34	0.63	0.69
	max.	10.32	0.232	0.69	2.45	0.82	0.75

3. Relatively small proportion of the annual total uptake of N,P,K and Ca are retained in the roots (15.29, 0.022, 11.47 and 6.88 g/m^2 respectively). The remainder is translocated to the shoots, half of which is translocated during the second growth period.

4. About 30% of the annual total production of clover is returned to the soil, by death of shoots and roots, two thirds of which is contributed by roots. Consequently, the ratios of the total amount of uptaken N,P,K and Ca that returned to the soil is relatively large (46, 30, 37 and 42% respectively).

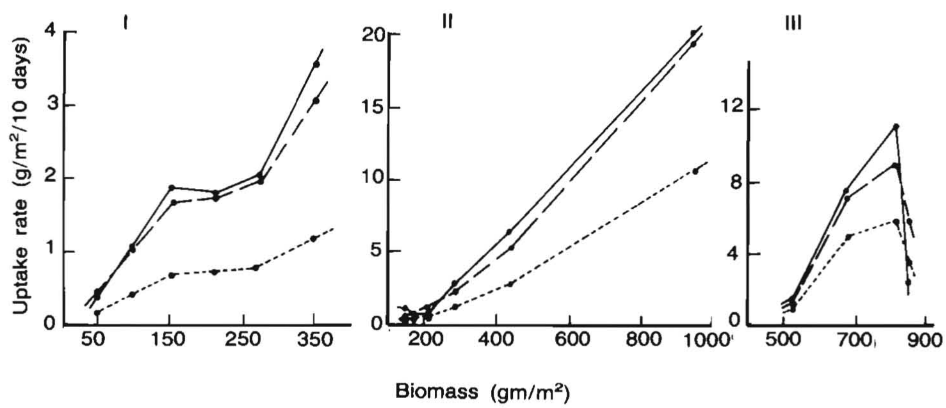

Fig. 4. Relationship between the uptake rate of N (solid), K (dashed), Ca (dotted line) and the biomass of clover during the first, second and third growth periods (I, II & III respectively).

Table 4. Estimated values of variables and parameters for determination of variations in total crop biomass

Variable or Parameter*	Growth Period		
	First	Second	Third
p (days)	82	60	40
Vi (g/m 2)	15	115	435
Vm (g/m^2)	370	945	850
Vx (g/m^2)	50	435	535
Gx (g/g/day)	0.09	0.117	0.026
c	2.0	1.0	0.5
d	15.0	7.5	7.5

* Refer to text for identification.

The previous characteristics of the clover agroecosystem demonstrate that it may be considered of prime importance in alleviating current pressures on areas of intensive agriculture. The site of the present study is located in the immediate vicinity of developed rural and urban zones next to the Nile Delta. It is used as a source of supplementary feed for animals (sheep and goats) grazing rain-fed rangelands in the area (average annual net primary productivity is about 668 kg/ha; Abdel-Razik *et al.* 1988b). This type of supplementary feed was previously provided from cultivations in the more fertile land of the Nile Delta, which decreased the availability of agricultural land for other crops. The estimated production level of clover with the indirect subsidy of water (subsurface flow of irrigation water from cropping desert agroecosystems in the area) is much higher than that of some other crops cultivated in the area even when subsidized with water and nutrients. Barley, for example, produced a biomass of about 1.7 tonnes per hectare associated with about 4.4 tonnes per hectare of weeds (Ayyad *et al.* 1985).

Melillo (1985) stressed the idea that the optimum rate of agricultural production for minimizing ecosystem degradation on a site should allow for sufficient investment of annual net primary production to maintain the sites net ecosystem production (rate of change in the carbon stocks) equal to or greater than zero. This idea is conveniently met in the clover cultivation of the present study, since about one third of the total annual production of the ecosystem is returned to the soil pool in the form of litter from shoots and dead roots retained in the soil. Furthermore, the soil nutrients status of this ecosystem becomes more favourable because of the building up of especially nitrogen in the rhizosphere of this leguminous crop root system. This becomes obvious on comparing for example soil pool nitrogen content under clover cultivation (10.32 mg/g) with that under barley cultivation in the same region (2.56 mg/g for rain-fed and 6.75 mg/g for irrigated fields; Ayyad *et al.* 1986). Therefore, while Greenwood (1982) stated that the average N% in dry matter in different agricultural and horticultural crops falls from about 4% when dry weight is 1×10^3 kg/ha to about 1.1% when it is 20×10^3 kg/ha, the clover maintains an average content of about 4% while its production is rather near the higher level.

The relative growth rate of clover plants starts with high values at the begining of the growing season when a subsidy of harvested water, from irrigated fields, is available. The maximum relative growth rate of 0.09 g/g/day is thus achieved when the biomass is only 50 g/m^2, and declines sharply afterwords which in turn has a limiting effect on the final product of this growth period. During the second growth period (after the first grazing application), the release of the apical dominance of growth and the high soil moisture content, due to high rainfall, as well as the high nutrients stock in roots result in an exponential increase in the relative growth rate with increasing the biomass base. It reaches a maximum of 0.117 g/g/day near the end of this period when the biomass is about 435 g/m^2. This trend enhances the productivity of the plant, hence the biomass reaches its highest levels. Kamidi and Wanjala (1988) postulated that the trend of regrowth rates of fodder crops within each year generally followed the rainfall pattern, therefore harvesting should be based on plant height rather than on a fixed cutting frequency.

The third growth period (after the second grazing application) has upper limits on growth which are most probably controlled by environmental (soil moisture and temperature) and biological (phenological development and age structure) factors. Therefore, the maximum relative growth rate is 0.026 g/g/day only, which is attained at the middle of this period when the biomass base is about 535 g/m^2. The upper limit on growth is followed by an increasing rate of death of different plant parts. During this phase, the reproductive parts are produced and attain much less biomass and nutrient content compared to many other cultivated or wild plants in the region (*e.g.* Abdel-Razik *et al.* 1985, Ayyad *et al.* 1986, Abdel-Razik *et al.* 1988b). Both the uptake and translocation of nutrients in the clover system are piecewise linear functions of biomass change during the first growth period, and are linearly related to biomass during the second period, while they are negatively exponentially related to biomass during the third period with an upper limit on biomass production. These trends may be simply attributed to the remarkable variations in the relative growth rate values.

Although the conversion of natural ecosystems to an agroecosystem causes basic changes (mostly decreases) in resource availability (Melillo 1985), yet subsidized yields of certain crops may considerably exceed the levels of production in mature ecosystems (Cox 1985). Exploitation of ecosystem production and export of harvested material is the main form of disturbance that inevitably reduces net primary production below the regional climax level. Therefore, it may be concluded that clover cultivation in the study area under minimum subsidy of water may be one of the best crops that provide multiple conservation purposes. It substitutes other crops in the more fertile parts of the Nile Dela in producing supplementary feed for grazing animals in a relatively high production level. This level is sustained with a sufficient investment of annual production in ecosystem's maintenance. This leguminous crop also provides an incrment of nitrogen to the soil pool each cultivation. Moreover, the relatively large mass of roots provides a remarkable source of organic matter at the end of the season which increases the soil fertility.

In order to assess the prospects for improvement of crops, it is necessary to gain an insight in the quantitative aspect of plant nutrients and its influence on yield (van Keulen and van Heemst 1982). Consequently, while clover crop under study is considered as a good source of protein (N = 2.9-5.0%) yet it exhibits P−deficency (P = 0.07−0.10%) as may be the result of over exploitation of its resources. Inadequate supply of P, for grazing animals, by natural forage was also discussed by Abdel-Razik *et al.* (1988a). Since P– deficency leads as well to reduced N absorption and hence to lower biomass production (Penning de Vries *et al.* 1980), it may be suggested to apply a P– source fertilizer to improve the quality of this fodder crop.

However, since the data is based on one growing season only, it is emphasized that all conclusions should be regarded as very tentative. Further investigation covering both temporal and spatial scales is recommended.

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نمط النمو ودورة العناصر الغذائية في أحد النظم البيئية لزراعات البرسيم تحت تأثير الرعي المنظم في صحراء الساحل الشمالي بمصر

محمد سعد الدين عبدالرازق

قسم النبات - كلية العلوم - جامعة قطر - الدوحة - ص. ب: ٢٧١٣ - قطر

تم تقدير الإنتاجية الأولية وتقييم دورات العناصر الرئيسة في نظام زراعي للبرسيم بالساحل الشمالي الغربي لمصر تحت تأثير نظام الرعي التقليدي بالمنطقة، وأعد نموذج وصفي لهذا النظام لبلورة النتائج.

قدر الإنتاج الكلي للمحصول بحوالي ١٦,٦٥ طن/ هكتار، إلى جانب حوالي ٢,٤١ طن/ هكتار من الحشائش المصاحبة للزراعة، ولوحظ أن الرعي قد ساهم في زيادة أوزان الأعضاء النباتية ومحتوياتها من العناصر الغذائية، إذ تضاعفت قيمها تقريباً بعد كل دورة رعي، خاصة بعد الدورة الأولى.

قدرت نسبة الكمية المسترجعة إلى النظام البيئي بحوالي ٣٠٪ من الإنتاج السنوي الكلي، وأكثر من ثلث كمية العناصر التي أمتصها المحصول، وقد ساهمت الجذور بأكثر من ثلثي تلك الكمية المسترجعة. وتمثل هذه الكمية فائضاً يساهم في صون النظام البيئي على المدى البعيد، مما يؤدي إلى الحفاظ على مستوى إنتاجية صافية موجبة.

تبين الدراسة أن البرسيم المروي بقدر محدود من الماء هو من أفضل المحاصيل التي يمكن زراعتها بنظم صحراء الساحل الشمالي بمصر. فإلى جانب إنتاجيته المرتفعة بالنسبة للعديد من المحاصيل الأخرى بالمنطقة، فإنه يساعد على

الحد من تأثير الرعي الجائر على المراعي الطبيعية، وعلى رفع مستوى الخصوبة الخواص التركيبية للتربة في الأراضي الصحراوية. كما أنه يساهم في توفير بعض أراضي الدلتا الخصيبة التي تزرع بنباتات الأعلاف لزراعتها بالمحاصيل الغذائية.