

## STRUCTURE, COMPOSITION, PHYTOMASS AND NET PRIMARY PRODUCTIVITY IN A *LASIURUS SCINDICUS* HENR. DOMINATED SEMI-MOIST SITE OF KARACHI, PAKISTAN

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### ABSTRACT

The variation in composition, structure, phytomass and net primary productivity was analyzed in a *Lasiurus scindicus* Henr. dominated community in a semi-moist site of Karachi, Pakistan. Phyto-ecological parameters of vegetation were studied at monthly interval for a year. Fifty Nine species in all were encountered from this site. On the basis of phytomass, *Lasiurus scindicum* was the leading dominant throughout the year except in rainy season when *Cenchrus setigerus* dominated the community. The Maximum density in this site occurred in August when it reached to 588.4 plants.m<sup>-2</sup>. The highest density at this point of time was exhibited by *Tragus roxburghii* (382 plants. m<sup>-2</sup>). The density of *L. scindicus* remained more or less unchanged.

The changes in the aboveground live plant biomass (LB), standing dead (SD), litter (L) and belowground biomass were studied. LB was maximum (694.7 g.m<sup>-2</sup>) in September and minimum (196.5 g.m<sup>-2</sup>) in June- averaging to 341.3 ± 42.9 g.m<sup>-2</sup>. LB proportion of legumes varied from 0.9 to 8.65%. The effects of rainfall remained noticeable for not more than up to 50- 60 days. SD was maximum in December (564.6m<sup>-2</sup>). Litter was maximum in January (249.9g.m<sup>-2</sup>) and minimum in August (115.8m<sup>-2</sup>). Above- ground net primary productivity (ANP), as evaluated by various methods, varied from 674.7 to 947.1g.m<sup>-2</sup>.year<sup>-1</sup> (average = 805.3 ± 50.76g.m<sup>-2</sup>. year<sup>-1</sup>; CV = 13.8%). Belowground net productivity (BNP) was 814.9 g.m<sup>-2</sup>.year<sup>-1</sup>.

Annual efficiency of energy capture by the primary producers was estimated to be 0.68% on the basis of half total solar radiation. Annual energy flow diagram through primary producer compartments is presented.

**Key Words:** *Lasiurus scindicus*, Community structure, phytomass, net primary productivity, energy efficiency

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### INTRODUCTION

A great deal of data on structural and functional characteristics of many plant communities have accumulated from many countries of the world during past few decades (Golley, 1965; Pearson, 1965; Singh, 1968; Sims and Singh, 1971, 1978; Singh and Yadava, 1974; Lieth and Whittaker, 1975; White *et al.*, 1978; Ross *et al.*, 2001; Halin *et al.*, 2002; Huenneke *et al.*, 2002; Osem *et al.*, 2003; 2004). Some data on vegetation and phytomass dynamics of some grass communities of Karachi (Pakistan) have been published by Khan *et al* (1989,1999, 2000, 2001, 2002, 2005a and b) but there remains paucity of such data from Pakistan and most Asian countries. The present paper describes seasonal variation in structure, composition, phytomass and net primary production in a semi-moist site of Karachi, Pakistan, dominated by *Lasiurus scindicus* Henr. (vern: Gorka), a highly palatable, nutritive desert grass.

### DESCRIPTION OF THE AREA

The climate of Karachi is of BWh type and bioclimate as determined by Holdridge's system falls in the category of Tropical bush formation (Qadir *et al.*, 1966). The rainfall is irregular and averages below 200 mm; mostly received in summer. Annual potential evapo-transpiration is c.1750 mm (Zubenok, 1977). Minchen (1907) recognized summer (May-October) and winter (November-April), two climatic extremes. The precipitation during the study period has been far below the average. During study period, it was 86.8 mm in summer (1990) and 24.3 mm in winter (early 1991). The total solar radiation, as calculated from Ahmad *et al.*, (1991) was maximum in the summer months of May and June and substantially lower in winter months. The diffuse radiation remained 20 - 30% of the global radiation. Climatic details are given in Khan *et al.* (2000).

The site under study, situated in the premises of Karachi University campus was subject to water logging due to seepage from a damaged waterline leading to the city of Karachi. It stretched over an area of 200 x 50m. The soil was compact, sandy to sandy loam (sand: 84.6%, silt: 9.3%, clay: 6.1%), non-calcareous (calcium carbonate: 13.3%), basic (pH: 8.4) and marginally non-saline (EC: 3.36 dS.m<sup>-1</sup>), deficient in K (0.46 meq/l) and organically poor (H<sub>2</sub>O<sub>2</sub> oxidizable organic matter - 0.84%). The water table in the area was at c 5-7m depth. The site has been subject to cutting and grazing in the past. To protect it, a fence was erected.

## MATERIALS AND METHODS

The site was regularly visited round the year for vegetation sampling and plant collection. During the last week of each month, 30 quadrats of 1 m<sup>2</sup> were laid at random in the field to sample the vegetation abundance. In case of a sod forming grass a portion of plant possessing an independent shoot and root was considered an individual (Singh and Yadava, 1974). Aboveground biomass was evaluated by harvest method; dividing the field into three more or less equal areas. On each sampling date five quadrats, each measuring 1 m<sup>2</sup>, were randomly laid in each area and each quadrat was divided into 25 x 25 cm subquadrats. From each quadrat two subquadrats were randomly selected and harvested. Thus in all 30 quadrats were sampled on each sampling date. All vegetation was harvested at the ground level (Green, 1959). The litter was gathered after the plot had been cleared. The samples were washed through floatation, dried and weighed.

The harvest for each species was kept in separate paper bag, quadrat wise. The species were further separated into live and dead parts in laboratory. All samples were dried at 80°C and weighed.

For the estimation of below-ground plant material, 25 x 25 x 30 cm monoliths, one from each quadrat, were dug out from the field on each sampling date. The soil samples were soaked in water and biomass was screened using 32-mesh-sieve under a jet of water. It was dried at 80°C and weighed. The belowground biomass was expressed as biomass per 0.3 m<sup>3</sup> monolith of soil i.e., biomass in an area of 1m<sup>2</sup> dug up to a depth of 30 cm.

The importance value index (IVI) for each species was computed by direct summation of relative density and relative frequency following Curtis and McIntosh (1951). The relative abundance pattern among species based on biomass were plotted (Whittaker, 1965).

## OBSERVATION, RESULTS AND DISCUSSION

### Vegetational dynamics:

Fifty nine species were encountered from the site during year long study (Table 1). Among these species, there were eleven grasses, thirteen legumes, two sedges and thirty three other species. The species occurring thrice or less than thrice a year were twenty eight - constituting around 47 % of the total species where as the species occurring ten or more than ten times a year were fourteen (c 24%). *Lasiurus scindicus*, *Cenchrus setigerus*, *Crotolaria burhia*, *Cyperus atkinsonii*, *Dactyloctenium scindicum*, *Ochthocloa compressa*, *Oligochaeta ramosa*, *Panicum antidotale*, *Launaea nudicaulis*, *Polygala erioptera*, *Sida pakistanica*, *Tephrosia strigosa*, *T. subtriflora*, *Rhynchosia schimperii*, *Indigofera linifolia*, *Commelina albescens* etc. were the species, which occurred for most part of the year. There were initially thirteen species contributing to the live biomass which increased to thirty seven in August, after rains. The field became all lush green in August and September. Nearly all species started flowering in September and seeds were mature by November. The mean number of species harboring this semi-moist site through months was relatively high and less variable ( $s = 25.23 \pm 2.12$ , Range: 13 – 37; CV = 30.36%) as compared to a similar but dry site of *Lasiurus* (Khan *et al* (2000) ( $s = 17.85 \pm 2.80$ , Range: 4 –28; CV = 56.55%), which may presumably be attributed to improved moisture availability in the present case.

Initial density of this site, in the month of June, was 28 live plants.m<sup>-2</sup>. The density maxima occurred in August when it reached to 588.4 plants.m<sup>-2</sup>. Around 65% of the density at this point of time was contributed by *T. roxburghii* (381 plants.m<sup>-2</sup>) (Fig. 1). *Tephrosia strigosa* was second highest in density (71.5 plants.m<sup>-2</sup>). The density of *Cenchrus setigerus* and *Blepharis sindica* was almost comparable (c 27 plants/m<sup>2</sup>). The density of *L. scindicus* fluctuated but little. The total plant density related with rainfall (P) as:

$$\text{Density.m}^{-2} = 28.102 + 6.8147 P \text{ (mm)} \pm 48.73$$

$$(t = 10.53)$$

$$r^2 = 0.9097, \text{ Adj. } r^2 = 0.9015; F = 110.8, p < 0.0.001$$

In spite of the presence of relatively larger number of species throughout the year, there was a marked seasonality in species performance, which is the case in monsoon grasslands and desert communities (Babu, 1971; Kumar and Joshi, 1972; Singh and Yadava, 1974; Khan *et al.*, 2000, 2005a). Ephemerals and annuals dominate the vegetation, at least numerically, during monsoon season, complete their life-cycle within minimum possible time and disappear.

**Biomass dynamics:****Aboveground Live biomass (LB):**

The aboveground live biomass varied considerably through different months and among and within various species (**Fig. 2**; Table 2) – averaging to  $341.3 \pm 42.9 \text{ g.m}^{-2}$ . Initially, LB was  $196 \text{ g.m}^{-2}$  (in June) which after summer rains attained maxima in September ( $694.7 \text{ g.m}^{-2}$ ). Then it declined regularly up to a winter month of January ( $222.5 \text{ g.m}^{-2}$ ). After winter rains, LB again increased significantly ( $334.4 \text{ g.m}^{-2}$  in March). *L. scindicum*, *C. setigerus*, *D. scindicum*, *P. antidotale*, *O. compressa* and *S. pakistanica* were the substantial biomass contributors.

**Temporal Variation in Live biomass apportionment among Grasses, Legumes and Other Species:**

LB as well as the per cent proportion of total LB was variable but of higher magnitude for grass component. The LB proportion of legume component was low and fluctuated from 0.90 to 8.65% of the total LB. Number of leguminous species was maximum in August and September. The LB proportion for species other than grasses and legumes remained varied from 6.98 to 22.5% of the total LB (**Fig. 3**) being relatively high in April, May and June.

**Relationship between aboveground LB and soil moisture content and climatic variables:**

LB of this site showed no significant correlation with climatic variables such as T ( $r = 0.2749$ ), RH ( $r = 0.3360$ ), SR ( $r = -0.0006$ ) and SM ( $r = 0.1706$ ). LB related with P ( $r = 0.5564$ ;  $p < 0.048$ ) significantly. P accounted for around 25% of the variation in LB.

$$\text{LB} = 306.50 + 3.965 \text{ P} \pm 134.40$$

$$t = 2.22 \text{ (} p < 0.048 \text{)}$$

$$r^2 = 0.3096; \text{ adj. } r^2 = 0.2468; F = 4.32$$

The increase in magnitude of LB associated with soil moisture content and the time of precipitation (**Fig. 4**) as a time lag phenomenon i.e., the biomass maxima occurred in the month subsequent to that of the precipitation occurrence. It was indicated by correlation analysis (Table 4) that effects of precipitation lasted for short period of time and were not detectable after 50-60 days of rains. In addition to precipitation, relative humidity, temperature and solar radiation, in lag (-1) transformed data, collectively accounted for 77.6% variation in LB. These results are similar to that reported for a dry sandy *Lasiurus* site in the campus of University of Karachi (Khan *et al.*, 2000). Hullet and Tomaneck (1969) also showed a direct relationship of seasonal estimated total forage production with May + June precipitation in a clay upland range site in Western Kansas.

**The relative abundance pattern:**

Relative abundance patterns based on live biomass were essentially linear for the months of June and July showing geometric distribution. For August and September, the curves were essentially sigmoid. This character diminished slowly but not completely until December and January. On rains in February curves again became more or less sigmoid. The sigmoid character in curves gradually reduced for months onwards. (**Fig. 5**). The linear curves signified the fact that the most successful species preempted a fraction say 'k' of the available resources, next a fraction 'k' of the remainder and so on (May, 1975). This appears to be related to species poor and stressful situations indicating monopolization of the resource largely by a few species (Whittaker, 1975). The sigmoid type of curves which signify log-Normal distribution, on the other hand, is a characteristic of communities with more competitive species. None of the species usurps a especially large portion of niche space and there is large "middle class" species utilizing similar portion of niche space. The high diversity situations (larger number of species in a area) of vegetation are associated with this feature (Yodzis, 1978).

**Growth patterns of species:**

The change in growth of species was expressed following Singh (1968) as follows:

$$\log \text{ ratio} = \log_{10} \times \text{Dry Wt.m}^{-2} \text{ at a later date} / \text{Dry Wt.m}^{-2} \text{ in the initial date.}$$

It was indicated that *C. setigerus* had two peaks of growth, smaller winter peak and larger summer peak associated with magnitude of rains *pro rata*. Plants such as *Dactyloctenium scindicum*, *Cyperus atkinsonii* and *Leptothrium senegalense* showed one peak of growth during summer. *Sida pakistanica* showed fluctuating trend. *Launaea nudicaulis* in this site increased its weight more or less consistently except some decline in November (**Fig. 6**).

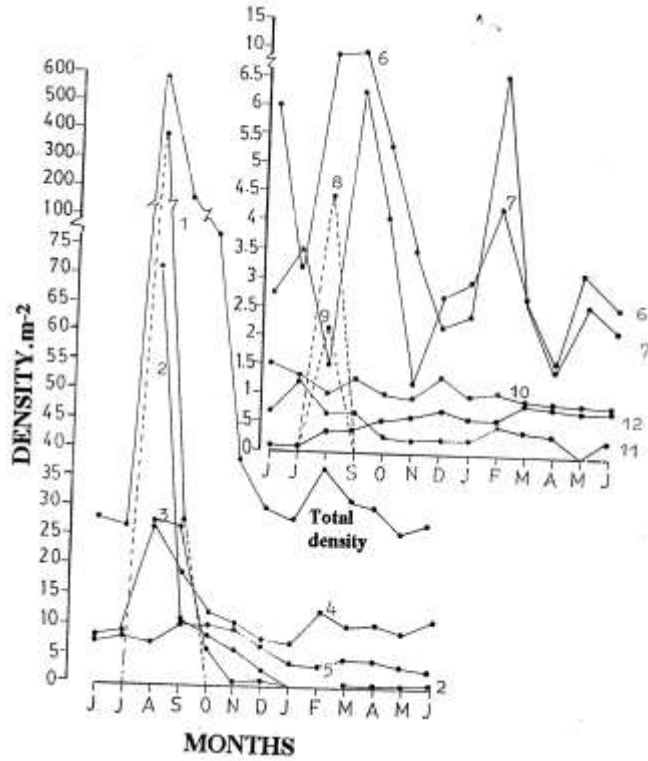


Fig.1. Changes in density of some species recorded in a semi-moist site of *L. scindicus*. Key to the species: 1.*T. raxburghii*, 2. *T. strigosa*, 3. *B. sindica*, 4. *C.setigerus*, 5. *S.pakistanica*, 6. *D.scindicum*, 7. *C.atkinsonii*, 8. *D.muricata*, 9. *I.cordifolia*, 10. *L.scindicus*, 11. *L.senegalensis*, 12.*L.nudicaulis*.

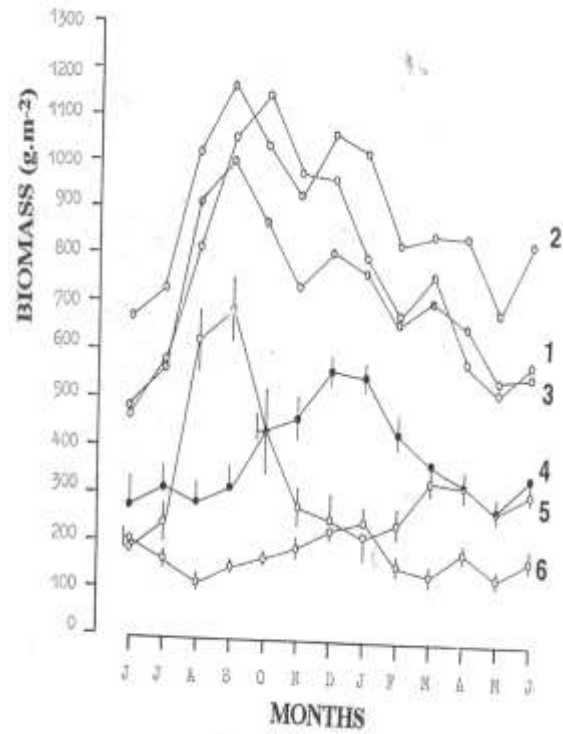


Fig.2. Variation in biomass components, 1. Belowground biomass, 2. Aboveground standing crop (litter+dead+live biomass), 3.Total aboveground biomass (live = dead), 4. Aboveground standing dead, 5. Aboveground live biomass, 6. Litter. The belowground biomass expressed in g per 0.3m<sup>2</sup> monolith.

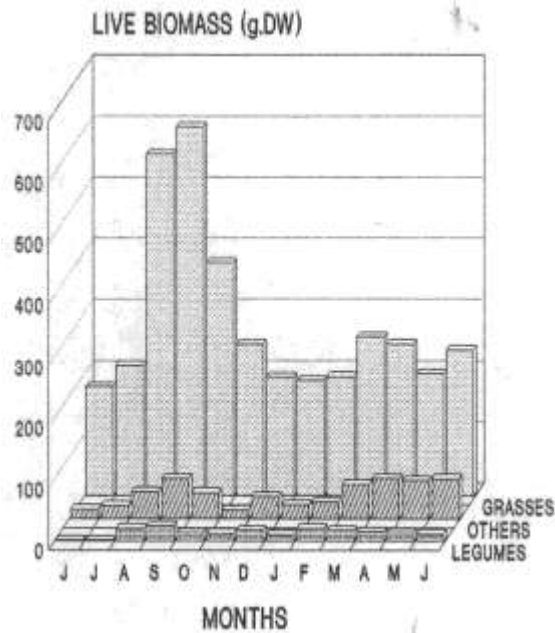


Fig. 3. Live biomass apportionment in grasses, legumes and other Species occurring in semi-moist site dominated by *Lasiurus Scindicus*.

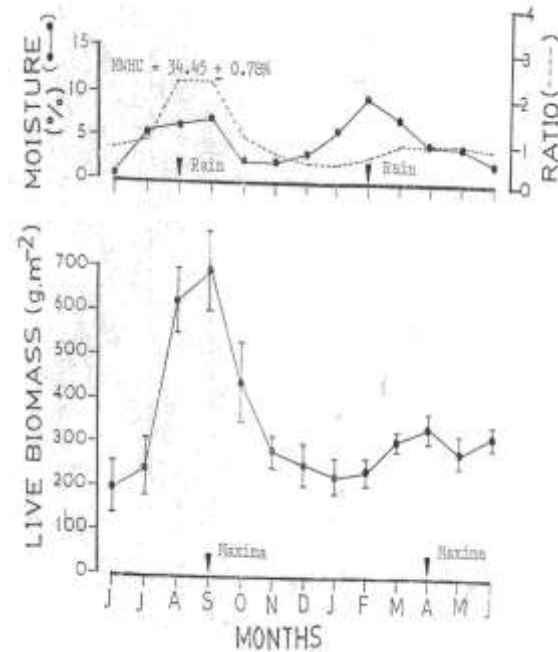


Fig. 4. Relationship between soil moisture content and live standing biomass in a semi-moist site of Karachi. The dotted line represents Live / dead biomass ratio.

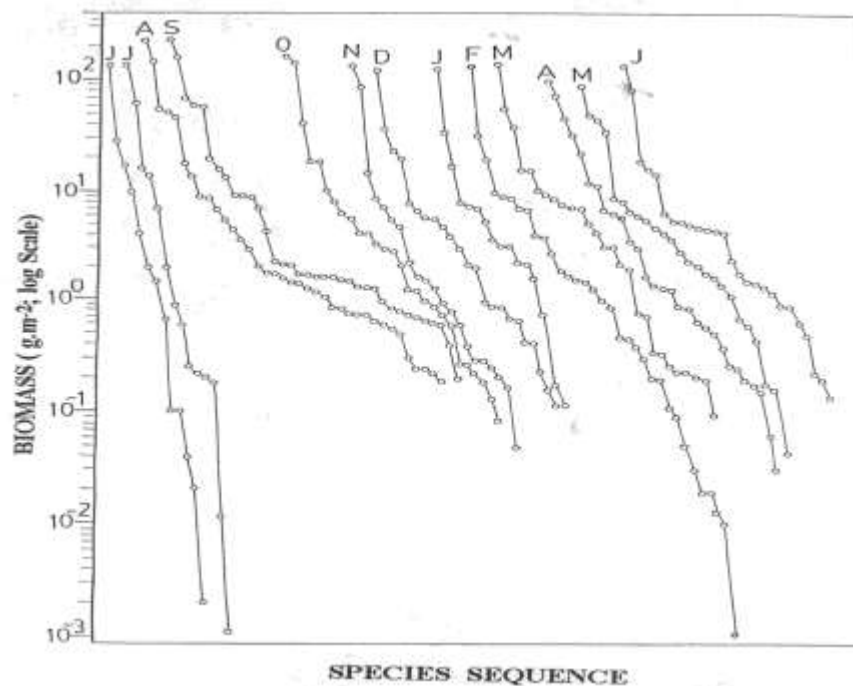


Fig. 5. Relative abundance curves for a semi-moist site of *Lasiurus* drawn on a semi-log plot on the basis of live biomass of the species occurring during June 90 – June 91.

#### Standing dead biomass, litter and Total above ground biomass:

The standing dead biomass of the species entering the site and cumulative biomass components are given in Table 4 and Fig. 2, respectively. The standing dead biomass varied greatly with different months and reached to be maximum in December. Litter was maximum value in January (249.9 g.m<sup>-2</sup>) and minimum in August (115.8 g.m<sup>-2</sup>). The total standing crop (live + dead + litter) was maximum in September (1163.7 g.m<sup>-2</sup>) and minimum in June (672.4g.m<sup>-2</sup>). These trends were more or less similar to that reported for dry *Lasiurus-Cenchrus* community of Karachi (Khan *et al.*, 2000). The proportion of dead biomass associated with *L. scindicum* remained generally around 50% of its total biomass, throughout the year (Fig. 7). *C. setigerus* and *D. scindicum* exhibited low dead biomass proportion (< 25%) during monsoon period. In other months more than 75% of their biomass was dead. Species such as *T. roxburghii*, *I. cordifolia*, *I. Linifolia*, *I. sessiliflora* (very short lived species) and *S. pakistanica* during their course of occurrence exhibited very low biomass in the standing dead compartment. *L. nudicaulis* exhibited low proportion of dead biomass also.

#### Belowground biomass:

The below ground biomass remained fluctuating round the year and was maximum for the month of October (1150 ± 205 g.m<sup>-2</sup>) (Fig. 2). It was consistently larger in magnitude (1.32 to 3.60 times; mean = 2.42 ± 0.21) as compared to the live aboveground biomass. Most of the grasses in arid region are bunch forming in habit which are known to have high root/shoot ratio (Odum, 19712). Seischab *et al.* (1985) while studying above- and belowground standing crop partitioning of biomass in *Eleocharis rostellata* have reported belowground biomass varying from 1.60 to 12.95 times of the aboveground biomass depending upon the habitat. High amounts of belowground biomass in the site in hand may also be attributed to its past grazing history.

#### Above ground net primary productivity (ANP):

ANP estimated by four different ways viz. i) difference method, ii) method of summation of peak values of individuals species, iii) positive increase sum method and iv) sum of positive changes in biomass plus mortality method (Khan *et al.*, 2000) appeared to be 805.9, 674.7, 947.1 and 793.6 g.m<sup>-2</sup>.year<sup>-1</sup> (mean = 805.3 ± 55.8 g.m<sup>-2</sup>.year<sup>-1</sup>; CV=13.8%). Therefore, production rate, on annual basis, varied from 1.85 to 2.6g.m<sup>-2</sup>.day<sup>-1</sup> (mean = 2.2 ± 0.156g.m<sup>-2</sup>.day<sup>-1</sup>) which is substantially larger than that of a similar community abounding a dry habitat (*L. scindicus* and *C. setigerus* community with mean production rate of 1.00 to 1.61g.m<sup>-2</sup>.day<sup>-1</sup> (mean = 1.23 g.m<sup>-2</sup>.day<sup>-1</sup>) (Khan *et*

al., 2000). The variation around 13.8% in ANP estimates by various methods is, obviously, natural and is in agreement with Singh and Yadava (1974) who reported c 30% variation in their estimate of ANP with these methods in a tropical grassland of Kurukshetra, India. Jukola-Sulonen (1983) while studying hay field in central Finland also reported considerable variation among the productivity estimates when measured by different methods. A variation of 23% in ANP estimates for a dry site dominated by *Lasiurus scindicus* and *Cenchrus setigerus* (Khan et al., 2000) and 36.5% in *Dichanthium annulatum* dominated coastal community of Karachi (Khan et al., 2005) have been reported when evaluated by these methods. For further discussion, estimate obtained by method (iv) has, however, been used because this method lends itself well for further apportionment of production in different seasons (Singh and Yadava (1974).

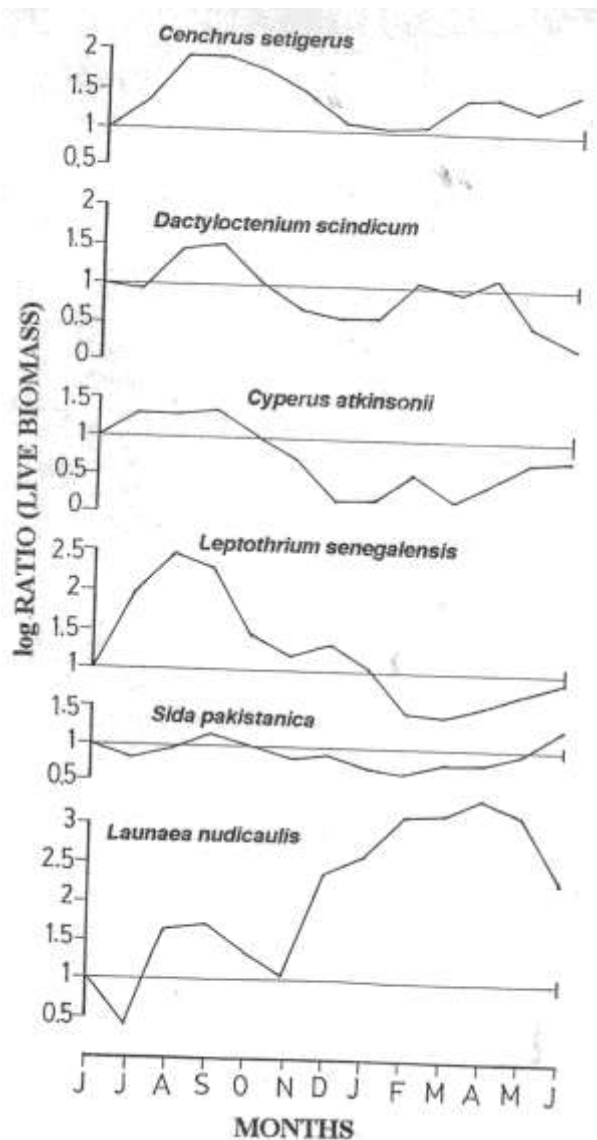


Fig.6. Changes in standing live biomass of some species.

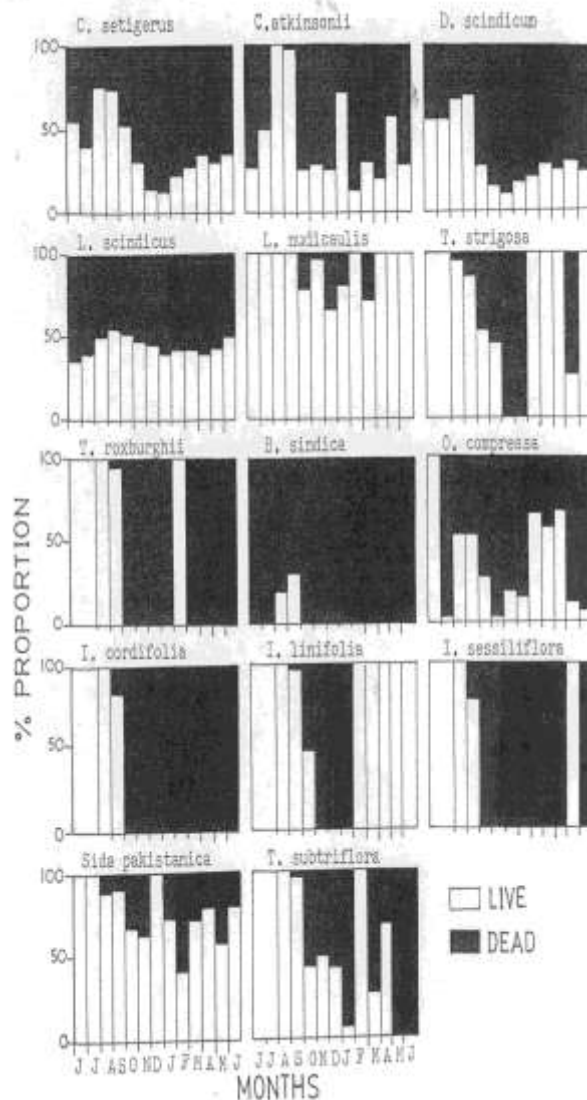


Fig.7. Live and dead biomass proportions of some species occurring in semi-moist site dominated by *Lasiurus scindicus*.

Our estimate of ANP (mean:  $805.3 \pm 55.8 \text{ g.m}^{-2}.\text{year}^{-1}$ ) for this site is comparably higher than the estimates reported for other arid lands grass communities. Mohammad (1989) have reported the estimated yield of 3–4 t / Ha ( $300\text{--}400 \text{ g.m}^{-2}$ ) from *Lasiurus scindicus* seeded areas of Rakh Choti Dalana in D.G. Khan rangelands under rainfall well below 200 mm. ANP for a similar local community dominated by *L. scindicus* and *C. setigerus* abounding to a dry habitat is reported to be  $448 \text{ g.m}^{-2}.\text{year}^{-1}$  (Khan et al., 2000). Khan et al. (2001) have reported ANP for an old community of *D. annulatum* (composed of 32 species in August after rainfall) for a growth period of 92 days in

Karachi University Campus to be  $372.4 \pm 8.9 \text{ g.m}^{-2}$ . The productivity of deserts and semi-deserts is reported to vary between 10 to  $250 \text{ g.m}^{-2}\text{.year}^{-1}$  (Whittaker and Likens, 1975). ANP for nine grass community types of American desert (Sims and Singh, 1971) varied from  $107 \text{ g.m}^{-2}$  for ungrazed shortgrass prairie at Pentex, Texas to  $512 \text{ g.m}^{-2}$  for the grazed tallgrass at Osage, Oklahoma. Our estimate for this semi-moist site is substantially higher than that of an unburned prairie ( $462 \text{ g.m}^{-2}\text{.year}^{-1}$ ) of Texas, USA, composed of several grasses (Harcombe *et al* 1993). It is, however, comparable to the production of *Sporobolus virginicus* salt marsh in Australia amounting as large as  $852 \text{ g.m}^{-2}\text{.year}^{-1}$  (Clark and Jacoby, 1994) which may presumably be attributed to improved moisture regime of the community in hand. Naturally, in arid environment, more available water means more generation of biomass. In a recent study, Osem *et al.* (2004) have reported similar results - productivity in semi-arid ecosystems of Goral hills near Beer Sheva in the N. Negev of Israel to be typically within semi-arid range of  $10\text{-}200 \text{ g.m}^{-2}$  in south and North facing slopes, hill tops and Wadi shoulders but considerably high (up to  $700 \text{ g.m}^{-2}$ ) in Wadi with improved hydric resource and abounding species of relatively larger size.

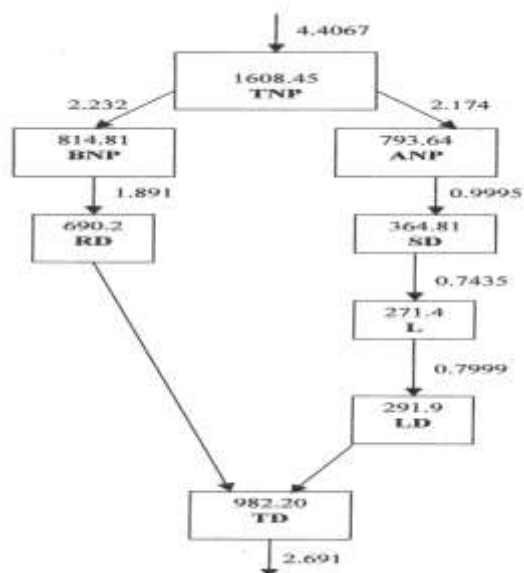


Fig.8. Net primary productivity and accumulation and disappearance Rates in a semi-moist site of *Lasiurus*. Components:  $\text{gm}^{-2}$ , accumulation and disappearance rates:  $\text{gm}^{-2}\text{.day}^{-1}$

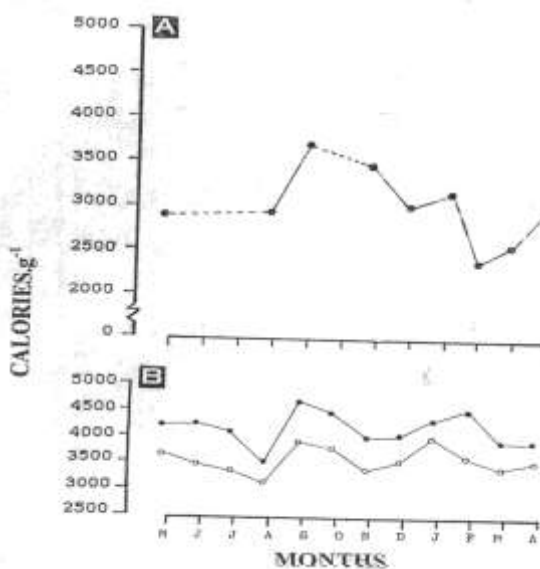


Fig.9. Variation in calorific value of litter (A) and below-ground biomass (B) of *Lasiurus scindicus* site. Open circle: D.wt. basis; closed circle: on ash – free basis.

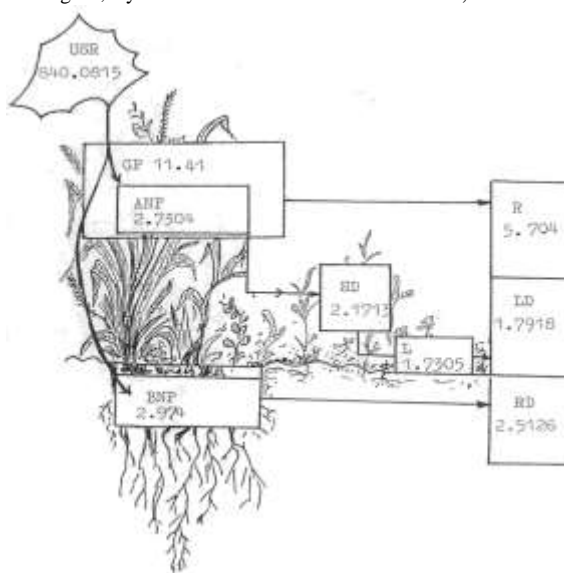


Fig.10. Annual energy flow through primary producer compartments. All values in  $\text{Kcal.m}^{-2}$  ( $\times 1000$ ).

### Below ground and Total net primary productivity (BNP & TNP):

BNP, as estimated by summation of the significant positive peaks in the belowground biomass on successive sampling dates, amounted to  $814.9 \text{ g.m}^{-2} \text{ year}^{-1}$ — comparable to ANP. The TNP of the site was estimated to be  $1608.5 \text{ g.m}^{-2}$ , which was considerably larger than that of similar local grass community under dry condition (TNP =  $1210 \text{ g.m}^{-2} \text{ year}^{-1}$ ; Khan *et al.*, 2000). TNP of *D. annulatum* from India, as cited by Murphy (1975), varied from 650-1420  $\text{g.m}^{-2}$  under 725 mm rains, which is comparable to our estimate under a precipitation regime of merely 110 mm. The magnitude of TNP of the site in hand was even higher than that of a coastal grass community dominated by *D. annulatum* composed of very few species only. The high productivity of the community in hand may presumably be due to elevated moisture availability and larger number of species harboring this community. The productivity of a community is known to be a function of number of factors such as periodicity of rainfall, rate of evapotranspiration, topography, soil texture, temperature, permeability, fertility, number and nature of species entering the composition of a community and their characteristics, grazing pressure or protection, etc. (cf. Murphy, 1975; Steen, 1980; Ludwig, 1986; Milkunas and Laurantroth, 1993; Khan *et al.*, 2000, 2005; Halin *et al.*, 2002; Osem *et al.*, 2003).

ANP, BNP and TNP as well as their production rates were higher in summer growing season than winter (Table 5). The turn over rates of belowground biomass, as calculated by the method of Dahlman and Kucera (1965), showed larger turn-over of biomass after summer rains (major precipitation peak) than in the winter; obviously due to high temperature and rapid microbial activity in summer (Table 6). In spite of the fact that turn over was higher in summer, the overall turn over was 70.9%. The turn over values ranging from 0.19 to 0.68 have been reported for nine grass communities by Sims and Singh (1971). The turn-over as high as 0.97 has been reported for *Panicum* community by Singh and Yadava (1974).

### Net accumulation and disappearance rates:

To depict primary production, accumulation rates and disappearance rates, a block diagram was constructed (Fig. 8). The value on the arrow represents the rate of accumulation and disappearance on a per day basis. SD, L, LD, and TD were calculated following Singh and Yadava (1974). The transfer from live to standing dead compartment was calculated by summation method of positive changes in standing crop of dead material on successive sampling dates where as transfer of standing dead to litter compartment was calculated by negative changes in the standing crop of the dead material summed on successive dates. The litter disappearance was estimated as:

$$LD = (\text{initial amount of litter} + \text{litter production}) - (\text{amount of litter at the end}).$$

The disappearance of the belowground biomass was represented by summation of negative changes in the belowground biomass on successive dates. TD is the sum total of RD + LD. From this block diagram some sort of balance sheet for dry matter may be prepared (Table 8). It may be observed that an amount of  $309.4 \text{ g.m}^{-2}$  remains unaccounted for in the balance sheet. To account for this amount following assumptions were made:

1. that only source of transfer from ANP is through SD and SD may be calculated as:

$SD = (\text{Initial amount of biomass}) + \text{ANP} - (\text{Biomass at the end})$ . This will transfer the unaccounted-for biomass to SD compartment.

2. The value in the L compartment may now be calculated in a different manner in order to balance for SD:

$$L = (\text{Initial Standing Dead} + \text{SD}) - (\text{Standing dead at the end})$$

3. The litter disappearance then will be:

$$LD = (\text{Initial litter} + L) - (\text{Litter at the end})$$

Computation with these assumptions would ultimately transfer unaccounted for biomass to TD through SD, L and LD. There are evidences that some direct transfer of live biomass to the litter compartment may take place (Golley, 1965). Wastage of green herbage may take place due to grass-hopper activity and other insects and small mammals (Currie and Goodwin, 1966). Couple of rabbits were once spotted in this community. Some other random reasons like removal of biomass by nest-forming birds, due to respiration by plants in dry periods when they can not photosynthesize, translocation of photosynthate to help plant survive the unfavourable season, removal of biomass during gales, etc. could also be important in this respect (Struik, 1965, Singh and Yadava, 1974; Khan *et al.*, 2000). The greater estimates for SD, L and LD calculated in accordance with the above-given assumptions amounted to 674.2, 580.8 and 601.4  $\text{g.m}^{-2}$ , respectively.



Table 1. Mean live biomass (g.m<sup>-2</sup>) and the occurrence of species encountered during yearlong sampling of *Lasiurus scindicus* dominated semi-moist site.

| Species  | Mean live Biomass (g.m <sup>-2</sup> ) | Occurrence (No. of months out of 13) |
|--|--|--------------------------------------|
| <i>Abutilon fruticosum</i> Guill.                          | 1.33 ± 0.04                            | 2                                    |
| <i>Achyranthes aspera</i> L.                               | 0.02                                   | 1                                    |
| <i>Aerua javanica</i> (Burm.f.) Juss.                      | 8.04 ± 2.25                            | 7                                    |
| <i>Amaranthes viridis</i> L.                               | 0.12 ± 0.09                            | 2                                    |
| <i>Anagalis arvensis</i> L.                                | 0.86                                   | 1                                    |
| <i>Aristida adscensionis</i> L.                            | 0.36 ± 0.17                            | 3                                    |
| <i>Blepharis sindica</i> T. And.                           | 3.00 ± 1.75                            | 5                                    |
| <i>Boerhavia verticillata</i> Poir                         | 1.10 ± 0.29                            | 10                                   |
| <i>Cassia holosericea</i> Fresen                           | 6.16 ± 0.41                            | 5                                    |
| <i>C. italica</i> (Mill.) F.W. Andr.                       | 4.08 ± 1.05                            | 6                                    |
| <i>Cenchrus pennisetiformis</i> Hochst. & Steud ex. Steud. | 6.39 ± 2.52                            | 9                                    |
| <i>C. setigerus</i> Vahl                                   | 89.81 ± 19.97                          | 13                                   |
| <i>Chloris barbata</i> SW.                                 | 0.21                                   | 1                                    |
| <i>Citrullus colocynthis</i> (L.) Schard.                  | 0.04                                   | 1                                    |
| <i>Commelina albescens</i> Hasskari                        | 0.56 ± 0.22                            | 8                                    |
| <i>Convolvulus rhyniospermus</i> Hochst. ex Choisy         | 0.61 ± 0.34                            | 2                                    |
| <i>C. prostratus</i> Sieb ex Spreng                        | 1.39 ± 0.60                            | 8                                    |
| <i>C. sindica</i> Stocks                                   | 0.54 ± 0.05                            | 2                                    |
| <i>Corchorus depressus</i> (L.) Stocks                     | 15.34 ± 8.66                           | 3                                    |
| <i>C. tridens</i> L.                                       | 0.59                                   | 1                                    |
| <i>Crotalaria burhia</i> Ham ex. Bth.                      | 3.43 ± 0.80                            | 12                                   |
| <i>Ctenolepis cerasiformis</i> (Stocks) Hooker. f.         | 0.76                                   | 1                                    |
| <i>Cucumis prophetarum</i> L.                              | 10.16 ± 7.40                           | 4                                    |
| <i>Cyamopsis tetragonoloba</i> (L.) Taub.                  | 0.55                                   | 1                                    |
| <i>Cyperus atkinsonii</i> Clarke                           | 4.80 ± 1.53                            | 13                                   |
| <i>C. bulbosus</i> Vahl                                    | 0.37 ± 0.36                            | 3                                    |
| <i>Dactyloctenium scindicum</i> Boiss.                     | 18.74 ± 4.56                           | 13                                   |
| <i>Digera muricata</i> (L.) Mart.                          | 0.90 ± 0.45                            | 3                                    |
| <i>Euphorbia dracunculoides</i> Lam.                       | 0.76 ± 0.05                            | 2                                    |
| <i>E. prostrata</i> Ait.                                   | 0.05                                   | 1                                    |
| <i>Erigeron canadensis</i> Willd.                          | 6.17 ± 3.98                            | 4                                    |
| <i>Fagonia indica</i> Burm.f.                              | 0.31 ± 0.16                            | 3                                    |
| <i>Heliotropium ramossissimum</i> Sieb                     | 1.09                                   | 1                                    |
| <i>Hibiscus aristavalis</i> Garcke                         | 0.58 ± 0.15                            | 5                                    |
| <i>Indigofera cordifolia</i> Heyne ex Roth                 | 1.48 ± 0.10                            | 2                                    |
| <i>I. limifolia</i> (Linn.f.) Retz.                        | 0.94 ± 0.47                            | 9                                    |
| <i>I. sessiliflora</i> DC.                                 | 0.67 ± 0.03                            | 3                                    |
| <i>I. hochstetterii</i> Baker                              | 0.48 ± 0.32                            | 4                                    |
| <i>Lasiurus scindicus</i> Henr.                            | 130.65 ± 5.21                          | 13                                   |
| <i>Launaea nudicaulis</i> (L.) Hk. f.                      | 2.95 ± 1.13                            | 12                                   |
| <i>Leptothrium senegalensis</i> (Kunth) W.D. Clayton       | 0.68 ± 0.25                            | 12                                   |
| <i>Lycium edgeworthii</i> Dunal                            | 3.88 ± 0.86                            | 8                                    |
| <i>Medicago polymorpha</i> L.                              | 0.01                                   | 1                                    |
| <i>Mollugo cerviana</i> L. seringe                         | 0.92 ± 0.28                            | 4                                    |
| <i>Ochthocloa compressa</i> (Forssk.) Hilu                 | 17.11 ± 7.59                           | 10                                   |
| <i>Oligochaeta ramosa</i> (Roxb.) Wagenitz.                | 1.95 ± 0.43                            | 10                                   |
| <i>Panicum antidotale</i> Retz                             | 32.48 ± 5.31                           | 11                                   |
| <i>Peristrophe bicalyculata</i> (Retz.) Nees               | 1.75                                   | 1                                    |
| <i>Polygala erioptera</i> DC.                              | 0.57 ± 0.14                            | 11                                   |
| <i>Polypogon monspeliensis</i> (L.) Desf.                  | 2.69                                   | 1                                    |
| <i>Portulaca</i> sp.                                       | 0.10 ± 0.09                            | 2                                    |
| <i>Rhynchosia minima</i> (L.) DC.                          | 1.99 ± 0.02                            | 2                                    |
| <i>R. schimperii</i> Hochst ex Boiss.                      | 5.86 ± 1.22                            | 8                                    |
| <i>Sericostema pauciflorum</i> Stocks ex Wightii           | 2.41 ± 0.55                            | 12                                   |
| <i>Sida pakistanica</i> S. Abedin                          | 8.49 ± 0.91                            | 13                                   |
| <i>Tephrosia strigosa</i> (Delz.) Sant. & Maheshw          | 3.33 ± 1.42                            | 8                                    |
| <i>T. subtriflora</i> Baker                                | 1.78 ± 0.29                            | 9                                    |
| <i>Tragus roxburghii</i> Panigrahi                         | 0.77 ± 0.44                            | 3                                    |
| <i>Tribulus terrestris</i> L.                              | 0.39 ± 0.35                            | 2                                    |

Table 2. Standing live biomass (g.m<sup>-2</sup>) of species occurring in a semi-moist site dominated by *L. scindicus*.

| Species                   | MONTHS |       |        |        |        |        |        |        |        |        |        |        |        |
|---------------------------|--------|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|                           | J      | J     | A      | S      | O      | N      | D      | J      | F      | M      | A      | M      | J      |
| <i>A. fruticosum</i>      | -      | -     | -      | -      | -      | -      | -      | -      | -      | -      | 1.29   | 1.37   | -      |
| <i>A. aspera</i>          | -      | -     | -      | -      | -      | -      | -      | -      | 0.019  | -      | -      | -      | -      |
| <i>A. javanica</i>        | -      | -     | -      | 8.96   | 8.12   | -      | 19.28  | 7.69   | 1.48   | 9.12   | 1.60   | -      | -      |
| <i>A. virtidis</i>        | -      | -     | 0.2154 | -      | -      | -      | -      | -      | 0.019  | -      | -      | -      | -      |
| <i>A. arvensis</i>        | -      | -     | -      | -      | -      | -      | -      | -      | 0.860  | -      | -      | -      | -      |
| <i>A. adscensionis</i>    | -      | -     | 0.246  | 0.692  | 0.129  | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>B. sindica</i>         | -      | -     | 4.431  | 9.251  | 0.868  | 0.280  | 0.160  | -      | -      | -      | -      | -      | -      |
| <i>B. verticillata</i>    | -      | 0.182 | 1.163  | 2.168  | 2.868  | -      | 0.688  | 0.118  | 1.208  | 0.340  | 0.566  | -      | 1.707  |
| <i>C. holosericea</i>     | -      | -     | 5.385  | 6.983  | 5.685  | 5.440  | -      | 7.298  | -      | -      | -      | -      | -      |
| <i>C. italica</i>         | -      | -     | -      | -      | 1.250  | -      | 5.600  | -      | 3.945  | 4.225  | -      | 8.043  | 1.440  |
| <i>C. pennisetiformis</i> | 0.10   | 0.230 | 17.969 | 19.88  | -      | -      | -      | -      | 1.681  | 7.529  | 2.954  | 6.027  | 1.120  |
| <i>C. setigerus</i>       | 28.16  | 62.40 | 226.65 | 235.14 | 152.85 | 88.752 | 36.752 | 34.182 | 31.339 | 56.189 | 73.151 | 48.333 | 83.589 |
| <i>C. barbata</i>         | -      | -     | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | 0.213  |
| <i>C. colocynthis</i>     | -      | -     | -      | -      | -      | -      | -      | -      | -      | -      | -      | 0.043  | -      |
| <i>C. albescens</i>       | -      | 0.011 | 1.723  | 1.264  | -      | -      | -      | -      | 0.449  | 0.230  | 0.150  | 0.160  | 0.475  |
| <i>C. rhyniospermus</i>   | -      | -     | -      | 0.950  | 0.261  | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>C. prostratus</i>      | -      | 0.001 | -      | 0.765  | 0.709  | -      | 0.880  | -      | 1.526  | -      | 0.172  | 1.744  | 5.392  |
| <i>C. scindicus</i>       | -      | -     | 0.492  | 0.592  | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>C. depressus</i>       | -      | -     | -      | -      | -      | -      | 0.416  | -      | -      | -      | -      | -      | -      |
| <i>C. tridens</i>         | -      | -     | 0.594  | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>C. burhia</i>          | 1.96   | 1.93  | 1.42   | 1.660  | 2.82   | 0.920  | 5.584  | 3.168  | 6.781  | 10.210 | 3.446  | -      | 1.280  |
| <i>C. cerasiformis</i>    | -      | -     | -      | -      | -      | 0.760  | -      | -      | -      | -      | -      | -      | -      |
| <i>C. prophetorum</i>     | 0.020  | -     | -      | -      | -      | -      | -      | -      | -      | -      | 32.148 | 3.573  | 4.912  |
| <i>C. tetragonoloba</i>   | -      | -     | 0.354  | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>C. atkinsonii</i>      | 4.00   | 13.89 | 13.631 | 15.261 | 4.129  | 2.192  | 0.864  | 0.725  | 1.828  | 0.778  | 0.880  | 2.011  | 2.229  |
| <i>C. bulbosus</i>        | -      | -     | 0.739  | -      | -      | -      | -      | -      | 0.001  | -      | -      | -      | -      |
| <i>D. scindicum</i>       | 16.96  | 15.63 | 47.573 | 57.98  | 18.592 | 8.648  | 6.584  | 6.825  | 19.44  | 15.292 | 22.154 | 6.500  | 1.435  |
| <i>D. muricata</i>        | -      | -     | 1.233  | 1.464  | -      | -      | -      | -      | 0.010  | -      | -      | -      | -      |
| <i>E. dracunculoides</i>  | -      | -     | 0.708  | 0.802  | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>E. prostrata</i>       | -      | -     | -      | -      | -      | -      | -      | -      | 0.049  | -      | -      | -      | -      |
| <i>E. Canadensis</i>      | -      | -     | -      | -      | -      | -      | -      | -      | -      | 3.120  | 1.268  | 2.240  | 18.064 |
| <i>F. indfica</i>         | 0.10   | -     | -      | 0.621  | 0.215  | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>H. aristavalis</i>     | -      | -     | 0.800  | -      | -      | -      | -      | -      | 0.195  | 0.232  | 0.831  | -      | 0.843  |
| <i>I. cordifolia</i>      | -      | -     | 1.377  | 1.577  | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>I. limifolia</i>       | -      | 0.252 | 0.389  | 0.186  | 0.240  | -      | -      | -      | 0.462  | 0.333  | 0.492  | 1.573  | 4.560  |
| <i>I. sessiliflora</i>    | -      | -     | 0.622  | 0.718  | -      | -      | -      | -      | -      | -      | -      | 0.667  | -      |
| <i>I. hochstetterii</i>   | -      | 0.218 | -      | 1.44   | -      | -      | -      | -      | -      | 0.098  | 0.185  | -      | -      |
| <i>H. ramossissimum</i>   | -      | -     | -      | -      | -      | -      | -      | -      | -      | -      | -      | 1.093  | -      |
| <i>L. scindicum</i>       | 133.44 | 135.4 | 149.48 | 159.68 | 141.25 | 135.99 | 123.02 | 127.88 | 130.45 | 141.11 | 98.37  | 90.02  | 132.47 |
| <i>L. nudicaulis</i>      | 0.04   | -     | 0.185  | 0.199  | 0.082  | 0.048  | 0.968  | 1.598  | 6.931  | 7.215  | 11.815 | 5.381  | 0.896  |
| <i>L. senegalensis</i>    | -      | 0.87  | 2.831  | 2.096  | 0.268  | 0.160  | 0.232  | 0.112  | 0.031  | 0.210  | 0.370  | 0.4270 | 0.608  |
| <i>L. edgeworthii</i>     | -      | -     | 3.508  | 4.188  | 4.012  | -      | -      | 3.120  | 8.623  | 2.120  | 0.246  | -      | 5.267  |
| <i>M. polymorpha</i>      | -      | -     | -      | -      | -      | -      | -      | -      | 0.012  | -      | -      | -      | -      |
| <i>M. cerviana</i>        | -      | -     | 1.046  | 1.254  | -      | 1.264  | -      | -      | 0.101  | -      | -      | -      | -      |
| <i>O. compressa</i>       | -      | -     | 53.11  | 69.25  | 18.68  | -      | 4.72   | 3.52   | 0.30   | 5.00   | 5.85   | 4.65   | 6.02   |
| <i>O. ramosa</i>          | -      | -     | 1.56   | 2.01   | 0.36   | 3.84   | 2.18   | 0.997  | 1.998  | 1.354  | 0.58   | 4.37   | -      |
| <i>P. antidotale</i>      | -      | -     | 54.22  | 58.12  | 40.12  | 14.40  | 22.85  | 15.53  | 8.86   | 38.05  | 45.35  | 44.73  | 14.06  |
| <i>P. bicalyculata</i>    | -      | -     | 1.754  | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>P. eripotera</i>       | 0.64   | 0.58  | 0.25   | 0.62   | 1.21   | 1.60   | 0.42   | -      | 0.20   | 0.26   | 0.26   | -      | 0.19   |
| <i>P. monspeleensis</i>   | -      | -     | -      | -      | -      | -      | -      | -      | 2.69   | -      | -      | -      | -      |
| <i>Portulaca</i> sp.      | 0.002  | -     | -      | -      | -      | 0.20   | -      | -      | -      | -      | -      | -      | -      |
| <i>R. minima</i>          | -      | -     | 1.97   | 2.02   | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>R. schimperii</i>      | -      | -     | -      | -      | 3.30   | 4.76   | 2.07   | -      | 9.62   | 8.93   | 11.02  | 2.81   | 4.34   |
| <i>S. pauciflorum</i>     | 1.44   | 0.21  | 1.34   | 1.62   | 0.99   | 0.56   | 1.96   | 2.16   | -      | 3.12   | 6.80   | 4.16   | 4.32   |
| <i>S. pakistanica</i>     | 9.68   | 6.84  | 8.80   | 13.69  | 9.90   | 7.12   | 7.56   | 5.29   | 3.74   | 7.01   | 6.25   | 8.69   | 15.79  |
| <i>T. strigosa</i>        | -      | -     | 8.68   | 9.13   | 6.29   | 1.51   | 0.66   | -      | -      | -      | 0.063  | 0.16   | 0.13   |
| <i>T. subtriflora</i>     | -      | -     | 0.83   | 1.13   | 0.57   | 0.28   | 2.96   | 0.17   | 0.31   | 0.20   | 0.62   | -      | -      |
| <i>T. roxburghii</i>      | -      | -     | 6.65   | 1.59   | -      | -      | -      | -      | 0.09   | -      | -      | -      | -      |
| <i>T. terrestris</i>      | -      | -     | 0.76   | -      | -      | -      | -      | -      | -      | -      | 0.031  | -      | -      |

Table 3. Standing dead biomass ( $\text{g.m}^{-2}$ ) of species occurring in a semi-moist site dominated by *L. scindicus*.

| Species                    | MONTHS |        |        |        |        |        |        |        |        |        |        |        |        |
|----------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|                            | J      | J      | A      | S      | O      | N      | D      | J      | F      | M      | A      | M      | J      |
| <i>A. adscensionis</i>     | -      | -      | -      | 0.128  | 0.714  | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>A. javanica</i>         | -      | -      | -      | -      | -      | -      | -      | -      | -      | 0.414  | -      | -      | -      |
| <i>B. sindica</i>          | 0.08   | 5.673  | 19.39  | 22.02  | 30.13  | 36.20  | 20.26  | 26.86  | 12.95  | 11.26  | 8.23   | 15.56  | 19.23  |
| <i>B. verticillata</i>     | -      | -      | -      | -      | -      | 0.92   | 4.00   | 4.10   | 2.96   | 5.98   | 9.14   | -      | 0.149  |
| <i>C. italica</i>          | -      | -      | -      | -      | -      | -      | -      | -      | -      | 0.150  | -      | 0.406  | -      |
| <i>C. pennisetiformis</i>  | -      | -      | 7.39   | -      | -      | -      | -      | -      | 1.20   | 2.10   | 4.12   | 7.94   | 0.320  |
| <i>C. setigerus</i>        | 22.04  | 94.33  | 68.40  | 80.14  | 142.0  | 193.85 | 241.53 | 238.24 | 139.26 | 141.25 | 103.96 | 93.141 | 119.86 |
| <i>C. albescens</i>        | -      | -      | -      | -      | 1.50   | -      | -      | -      | 0.010  | -      | -      | -      | -      |
| <i>C. rhyniospermus</i>    | -      | -      | -      | 0.60   | 0.20   | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>C. prostrates</i>       | -      | -      | -      | 0.025  | 1.00   | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>C. scindicus</i>        | -      | -      | -      | -      | 0.60   | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>C. depressus</i>        | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | 1.06   | -      |
| <i>C. burhia</i>           | -      | -      | -      | -      | -      | -      | -      | 0.24   | 0.42   | 1.00   | -      | -      | 8.03   |
| <i>C. atkisonii</i>        | 1.44   | 12.91  | -      | 0.02   | 12.90  | 4.86   | 1.44   | 0.26   | 14.71  | 1.17   | 2.55   | 1.36   | 7.22   |
| <i>D. scindicum</i>        | 12.36  | 11.64  | 24.49  | 26.22  | 48.29  | 44.82  | 62.21  | 32.99  | 73.71  | 23.24  | 37.66  | 9.17   | 2.98   |
| <i>D. muricata</i>         | -      | -      | -      | 1.50   | -      | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>E. drancunculooides</i> | -      | -      | -      | -      | 0.80   | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>F. indica</i>           | -      | -      | -      | -      | 0.40   | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>H. ramossissimum</i>    | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | 1.55   | -      |
| <i>I. cordifolia</i>       | -      | -      | -      | 0.29   | 1.90   | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>I. hochstetterii</i>    | -      | -      | -      | 0.17   | 1.70   | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>I. linifolia</i>        | -      | -      | -      | 0.006  | 0.20   | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>I. sessiliflora</i>     | -      | -      | -      | 0.20   | 0.91   | -      | -      | -      | -      | -      | -      | -      | -      |
| <i>L. scindicum</i>        | 237.08 | 187.67 | 119.40 | 128.16 | 127.99 | 143.25 | 178.22 | 201.86 | 159.75 | 166.21 | 138.12 | 101.89 | 105.78 |
| <i>L. nudicaulis</i>       | -      | -      | -      | -      | 0.023  | -      | -      | 0.48   | 0.41   | -      | 3.22   | -      | -      |
| <i>L. senegalensis</i>     | -      | 1.75   | -      | 0.97   | 3.013  | -      | 2.32   | 1.70   | 0.26   | 1.40   | 2.61   | 2.67   | 0.69   |
| <i>L. edgeworthii</i>      | -      | -      | -      | -      | -      | -      | -      | -      | 0.83   | 0.89   | 1.79   | -      | 0.43   |
| <i>M. cerviana</i>         | -      | -      | -      | -      | 1.00   | 3.02   | -      | -      | -      | -      | -      | -      | -      |
| <i>O. compressa</i>        | -      | -      | 45.35  | 55.17  | 49.58  | 22.08  | 19.20  | 16.98  | -      | 3.21   | 1.92   | 27.91  | 73.30  |
| <i>P. antidotale</i>       | -      | -      | -      | -      | 2.86   | 5.86   | 9.36   | 22.68  | 18.29  | 11.11  | 14.79  | 9.13   | 7.92   |
| <i>P. abyssinica</i>       | -      | -      | -      | -      | -      | -      | -      | -      | -      | -      | 0.123  | -      | -      |
| <i>R. schimperii</i>       | -      | -      | -      | -      | 0.07   | -      | -      | -      | -      | 0.70   | 2.31   | -      | -      |
| <i>S. pauciflorum</i>      | -      | -      | -      | -      | 0.20   | -      | -      | 0.096  | 0.001  | 0.22   | -      | 1.07   | 1.06   |
| <i>S. pakistanica</i>      | -      | -      | 1.081  | 1.27   | 5.28   | 4.44   | -      | 1.999  | 5.194  | 0.62   | 1.06   | 6.57   | 2.66   |
| <i>T. strigosa</i>         | -      | -      | -      | 0.28   | 0.98   | 1.27   | 9.32   | -      | 1.11   | 0.10   | 0.23   | 0.37   | -      |
| <i>T. subtriflora</i>      | 0.52   | -      | -      | 0.02   | 0.81   | 0.28   | 0.18   | 2.11   | -      | 0.17   | 0.26   | -      | 0.91   |
| <i>T. roxburghii</i>       | -      | -      | -      | -      | 1.61   | 0.64   | 1.29   | -      | -      | -      | -      | -      | -      |
| <i>T. terrestris</i>       | -      | -      | -      | 0.64   | -      | -      | -      | -      | -      | 0.22   | -      | -      | -      |

**System Transfer Function (Tfr):**

To reflect the orientation of the community function, Tfr were calculated on the whole year basis using the values of various compartments in the block diagram (Fig. 8) and also the values of the greater estimates. It is the quantity by which the system blocks multiplies the input block to generate output (Golley, 1965). Tfr data indicated that some 50.7% of TNP was directed towards belowground productivity (Table 8). On greater estimate basis 84.8% of the ANP was transferred to SD compartment. It implies that some live biomass was removed by small herbivores such as insects and mammals like rabbits. On normal estimate basis this transfer function was 46.0%. It is, however, obvious from the field observation that great amount of biomass underwent death and decomposition. Nearly 61% (80.3% on greater estimate basis) of TNP is lost through death and decomposition. LD/L ratio of 1.0 signifies the greater decomposition activity in this site due to higher moisture regime. White *et al.* (1978) have also reported higher decomposition rates in salt marsh of Louisiana where *Spartina alterniflora* decomposed rapidly with 100% removal in seven months. Moisture availability coupled with high temperature is known to enhance decomposition due to rapid microbial activity.

**Efficiency of Energy Capture (EEC):**

To investigate EEC, calorific values of live and dead standing biomass of important species of the community and that of composite samples of litter and belowground biomass were determined by adiabatic bomb calorimeter by forming compact pallets oven-dried powdered material and re-drying the pallets at 80°C. The pallets were burnt in

bomb under 30 atm. O<sub>2</sub> pressure using platinum wire. Ash contents were determined by combustion in muffle furnace.

Table 4. Linear correlation and regression analysis of aboveground live biomass (LB) with Soil Moisture Content and climatic variables \* (lag transformed data).

| Parameters X / Y | r <sup>2</sup> | Adj. r <sup>2</sup> | a       | b    | t    | F    | p    |
|------------------|----------------|---------------------|---------|------|------|------|------|
| LB / RH (-1)     | 0.2983         | 0.2224              | -337.20 | 9.54 | 2.06 | 4.25 | 0.06 |
| LB / P (-1)      | 0.4749         | 0.4224              | 308.27  | 4.75 | 3.00 | 9.05 | 0.06 |
| LB / T (-1)      | 0.1438         | -                   | -       | -    | -    | -    | -    |
| LB / SR (-1)     | 0.0002         | -                   | -       | -    | -    | -    | -    |
| LB / SM (-1)     | 0.0509         | -                   | -       | -    | -    | -    | -    |

*Lag (-1) Transformation:*

**LB vs. T (-1), P (-1) SR (-1), SM (-1)**

$$LB = -59.677 + 37.367T (-1) + 2.956 P (-1) - 37.92 SR (-1) + 31.21 SM (-1) \pm 73.46$$

$$\begin{array}{cccc} t = 3.98 & t = 2.64 & t = 2.56 & t = 3.30 \\ p < 0.005 & p < 0.033 & p < 0.037 & p < 0.045 \end{array}$$

$$r^2 = 0.8576, \text{Adj. } r^2 = 0.7762, F = 10.54, p < 0.001$$

*Lag (-2) Transformation:*

$$LB = -92.006 + 18.173 T (-2) \pm 141.30$$

$$\begin{array}{c} t = 1.89 \\ p < 0.09 \end{array}$$

$$r^2 = 0.2836, \text{Adj. } r^2 = 0.2040, F = 3.56, p < 0.09$$

\*, RH, Relative Humidity (8:00 AM); P, Precipitation (mm); SM, Soil Moisture (%); SR, Solar Radiation (MJ.m<sup>-2</sup>.day<sup>-1</sup>); T, Mean Monthly Temperature (°C).

Table 5 . Seasonal apportionment of above- and belowground production and production rates.

| Season *                      | Net Production (g.m <sup>-2</sup> ) | Rate of Production (g.m <sup>-2</sup> .day <sup>-1</sup> ) | Rainfall (mm) |
|-------------------------------|-------------------------------------|--|---------------|
| <b>Aboveground Production</b> |                                     |  |               |
| Summer                        | 681.8                               | 3.71   | 86.80         |
| Winter                        | 111.9                               | 0.62   | 26.30         |
| Annual                        | 793.7                               | 2.17   | 113.10        |
| <b>Belowground Production</b> |                                     |  |               |
| Summer                        | 685.7                               | 3.73   | 86.80         |
| Winter                        | 128.9                               | 0.71   | 26.30         |
| Annual                        | 814.6                               | 2.23   | 113.10        |
| <b>Total Production</b>       |                                     |  |               |
| Summer                        | 1367.5                              | 7.43   | 86.80         |
| Winter                        | 240.8                               | 1.33   | 26.30         |
| Annual                        | 1608.3                              | 4.41   | 113.10        |

\*, Minchen (1907)

Table 6. Maximum belowground biomass and turnover rates.

| Season * | Max. Belowground Biomass (g.m <sup>-2</sup> ) | BNP (g.m <sup>-2</sup> .year <sup>-1</sup> ) | Turnover |
|----------|---|--|----------|
| Summer   | 1150.0  | 685.7  | 0.596    |
| Winter   | 762.2   | 128.9  | 0.169    |
| Annual   | 1150.0  | 814.9  | 0.709    |

\*, Minchen (1907)

Table 7. Annual balance sheet of dry matter.

| Components               | Biomass | Components            | Biomass |
|--------------------------|---------|-----------------------|---------|
| <b>ANP</b>               |         | <b>SD</b>             |         |
| Initial Biomass          | 196.6   | Initial Biomass       | 275.4   |
| ANP                      | 793.6   | SD Production         | 364.8   |
| Input into the system    | 990.2   | Input into the System | 640.3   |
| Transfer to SD           | 364.8   | Transfer to litter    | 271.4   |
| SD at the End            | 316.0   | SD at the end         | 368.9   |
| Output                   | 680.8   | Output                | 640.3   |
| Unaccounted for          | 309.4   | Unaccounted for       | 0       |
| <b>BNP</b>               |         | <b>LITTER</b>         |         |
| Initial Biomass          | 464.8   | Initial               | 200.4   |
| BNP                      | 814.9   | Litter Production     | 271.4   |
| Input into the system    | 1279.7  | Input into the system | 471.8   |
| Disappearance of Biomass | 690.2   | Litter at the end     | 291.9   |
| Biomass at the End       | 88.4    | Litter Disappearance  | 179.8   |
| Output                   | 1278.4  | Output                | 471.8   |
| Unaccounted for          | 1.3     | Unaccounted for       | 0       |

Table 8 . System transfers functions.

| Components | Tfr (Annual) | Tfr (Annual) * |
|------------|--------------|----------------|
| TNP-ANP    | 0.4934       |                |
| TNP-BNP    | 0.5066       |                |
| ANP-SD     | 0.4597       | 0.8485         |
| SD-L       | 0.7439       | 0.8614         |
| ANP-LD     | 0.3420       | 0.7318         |
| L-LD       | 1.0755       | 1.0356         |
| BNP-RD     | 0.8471       |                |
| TNP-TD     | 0.6106       | 0.8030         |

\*, Based on greater estimates of SD, L, LD, and TD.

The calorific values of live and dead biomass, on ash free and dry weight basis, of several perennial and annual species entering composition of this community have already been reported elsewhere (Khan *et al.*, 2000). The calorific values for samples of litter and belowground biomass are given in Fig. 9. The calorific values for litter on dry wt. basis varied considerably from 2400 cal.g<sup>-1</sup> in February to 3803 cal.g<sup>-1</sup> in September- after rainy season growth. The lower calorific value of litter in August appears to be the result of the weathering. The calorific values of belowground biomass on dry wt. basis ranged from 3200 cal.g<sup>-1</sup> in August to slightly less than or equal to 4000 cal.g<sup>-1</sup> in month of September and January. Calorific values on ash free basis were higher than that on dry weight basis.

Mean calorific values representative to different producer compartments were calculated as a function of calorific values of live and dead components of important species entering the community composition and the litter and belowground biomass collected during the observation period. Such values for aboveground live, standing dead,

litter and belowground biomass were  $3440.4 \pm 96.2$ ,  $3220.7 \pm 106.4$ ,  $2979.7 \pm 156$  and  $3650.3 \pm 84.6$  cal.g<sup>-1</sup>, respectively.

Efficiency is the ratio of output (calories in vegetation) to input (radiant energy) (Botkin and Malone, 1968). When it is based on total radiation, it is referred to as "relative efficiency" and when it is based on photosynthetically efficient radiation (0.4 - 0.7  $\mu$ m), it is called "absolute efficiency". For calculation of energy capture efficiency, Botkin and Malone (1968) have opined that the actual amount of light intercepted by the canopy should be considered. Since, data on interception and albedo is not available, 50% of total incident solar radiation is termed here as usable incident solar radiation following the practice of Singh and Yadava (1974). This amount is roughly equivalent to the solar radiation available to plants for photosynthesis (Daubenmire, 1959; Singh and Misra, 1968; Yokum, 1961; Sims and Singh, 1971, 1978).

In present studies, efficiency is determined on the basis of calorific values of ash-containing matter of species-samples as suggested by Murphy (1975). Based on the usable solar radiation, EEC in ANP, BNP and TNP of this site amounted to 0.325, 0.354 and 0.679%, respectively. EEC values for ANP, BNP, and TNP for a similar *L. scindicus* community under dry conditions have been reported to be as low as 0.15, 0.32 and 0.47%, respectively (Khan *et al.*, 2000). In grasslands situated in different parts of the world the value of EEC of 0.1 to 5.1% have been reported (Golley, 1960, 1965, 1968; Botkin and Malone, 1968; Sims and Singh, 1971, 1978; French, 1979; Coupland, 1979). The perennial grasses of Japan were reported to have ANP-EEC 0.51% based on photosynthetically available radiation for growing season and 0.35% on annual basis. For desert community of Arizona ANP-EEC was much low around 0.06% only and for alpine tundra (xeric) community around 0.2% (Jordon, 1971). Misra and Misra (1989) have reported efficiency value of 0.81% for perennial *Aristida setacea* dominated community receiving as high rainfall as 1200mm and situated in Brahampur on the coastal belt of Bay of Bengal. Data on EEC for grass dominated communities of Pakistan is not available for comparison. However, Chughtai *et al.* (1978) have presented EEC estimate for a cultivated legume (*Phaseolus acontifolius*) from Peshawar to be 0.26 and 0.56 % on the basis of total solar incident and photosynthetically available radiation, respectively.

#### Annual Energy Flow (AEF):

An estimate of AEF through the primary producer compartments is depicted in Figure 10. The new symbols used in the diagram are usable solar radiation = USR, gross primary production = GP and respiration = R. The values of GP and R are hypothetical being based on the assumption that generally 50% of the gross primary productivity is realized as net primary production and 50% is dissipated via respiration (Odum, 1971). For SD, L, and LD compartments, their greater estimates are used to construct AEF diagram. Some 52.2% of the energy fixed in TNP moved towards belowground production and 47.9% stayed aboveground. The energy that dissipated through root and litter disappearance constituted 76%. Nearly 24% of the total energy fixed in TNP remained surplus in this site.

The greater energy allocation in BNP appears related with the effects of grazing to which this site has been exposed over past years. (Pearson, 1965; Smith, 1980). The net surplus of 24% of total energy fixed in this community indicates its tendency to move towards a scrub forest type (cf. Golley, 1972). Under conditions of disturbance such sites are being rapidly colonized by *Prosopis juliflora*, an aggressive exotic species, which at several places has indeed changed the physiognomy of the landscape (Khan and Ahmad, 1992). In arid regions this process is obviously very slow.

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#### REFERENCES

- Ahmad, F., S.M. Aqil Burney and S.A. Hussain (1991). Monthly average daily global and diffuse solar radiation and its correlation with hours of bright sunshine of Karachi, Pakistan. *Renewl. Energy*, 1: 115-118.
- Ambasht, R.S. (1984). *A Text Book of Plant Ecology*. Upadhayay Press. India.
- Babu, V.R. (1971). Population dynamics of herbaceous communities of Pilani (Rajasthan). *Jap. J. Ecol.*, 21: 87 - 95.
- Botkin, D.B. and C.R. Malone (1968). Efficiency of net primary production based on light intercepted during the growing season. *Ecology*, 49: 438 -444.

- Chughtai, S.M., Q. Ali and S. Islam (1978). Net primary productivity and efficiency of *Phaseolus acontifolius* Jacq. (Moth bean) in the cultivated fields (NWFP), *Pakistan. J. Agric. Res.*, 2 : 225 - 240.
- Clark, P.J. and C.A. Jacoby (1994). Biomass and aboveground productivity of salt marsh in south-eastern Australia. *Aust. J. Marine and Freshwater Res.* 45:1521 - 1528.
- Coupland, R.T. (Ed.). 1979. *Grassland Ecosystems of the World: analysis of grasslands and their uses*. IBP 18. 401 p. Cambridge Univ. Press.
- Currie, P.O. and D.L. Goodwin (1966). Consumption of forage by black tailed jack rabbits on a salt desert range of Utah. *J. Wild Life Manage*, 30: 304 - 311.
- Curtis, J.T. and R.P. McIntosh (1951). An upland forest continuum in the prairie forest border region of Wisconsin. *Ecology*, 32: 476-496.
- Dahlman, R.C. and C.L. Kucera (1965). Root productivity and turn-over in native prairie. *Ecology*, 46: 84 - 89.
- Daubenmire, R.F. (1959). *Plants and Environment*. J.C. Wiley & Co. N.Y. 422 pp.
- French, N.R. (ed.) (1979). *Perspectives in Grassland Ecology. Results and applications of the US/IBP grassland biome study*. N.Y., Springer - Verlag, 204 pp.
- Golley, F.B. (1960). Energy dynamics of a food chain of an old field community. *Ecol. Monogr.*, 30: 187 - 206
- Golley, F.B. (1965). Structure and function of a old field broom-sedge community. *Ecol. Monogr.*, 35: 113 -137.
- Golley, F.B. (1968). Secondary productivity in terrestrial ecosystems. *Am. Zool.*, 8: 53-59.
- Golley, F.B. (1972). Summary. p. 407 -413. In: *Papers from symposium of tropical ecology with emphasis on organic productivity* (P.M. Golley & F.B. Golley (ed.). Inst. ecol., Univ. Georgia, Athens.
- Green, G.O. (1959). The measurement of herbage production. p 62 - 68. In: *The Measurement of Grassland Productivity*. (J.D. Irvins, ed.). Butterworths, London.
- Halin, Z., Z. Tongui, Zhao Xue Yong Chi Jianyuan (2002). Changes in soil environment and their effect on crop productivity in desertification processes in sandy cropland. In: *Proceedings of ICAR5/GCTE-5EN Joint Confr. Int. Cent. Arid and semi-Arid lands Studies* (Lee, J.A. and T.M. Zobeckeds). Texas Tech. Univ. Lubbock USA, Publ. 02-2. pp. 362.
- Harcombe, P.A., G.N. Cameron and E.G. Glumac (1993). Above-ground net primary productivity in adjacent grassland and woodland on the coastal prairie of Texas, USA. *J. Vegetation Science*, 4: 521 - 530.
- Hullet, G.K. and G.W. Tomanek (1969). Forage production on a clay upland range site in western Kansas. *J. Range Manage*, 22: 270 - 276.
- Huenneke, L.F, J.P. Anderson, M. Rommenga and W.H. Schlesinger (2002). desertification alters pattern of aboveground net primary production in Chihuahuan ecosystems. *Global Change Biology*, 8: 247 – 264.
- Jordan, C. F. (1971). Productivity of a tropical forest and its relation to a world pattern of energy storage. *J. Ecol.* 59: 127 - 142.
- Jukola-Sulonen, E.L. (1983). Vegetation succession of abandoned Hay fields in central Finland: A quantitative approach. Communications *Instituti Forestalis Fenniae* No. 112, Helsinki: pp. 85.
- Khan, D. and R. Ahmad (1992). Floristics, life-form, leaf-size and halo-physiotypic spectra of coastal flora of Pakistan. Proc. National conf. On “Problems And Resources Of Makran Coast And Plan Of Action For Its Development”. Quetta, Sept. 1991. PCST. Islamabad.
- Khan, D., R. Ahmad and S. Ismail (1989). Structure, composition and above ground standing biomass of some grazable grass dominated communities of Pakistan coast. *Pak. J. Bot.*, 21: 88-106.
- Khan, D., M.M. Alam and M. Faheemuddin (1999). Structure, composition and aboveground standing phytomass of some grass dominated communities of Karachi: Summer Aspect. *Hamdard Medicus*, 42: 19 - 52.
- Khan, D., M Faheemuddin, S.S. Shaukat and M.M. Alam (2000). Seasonal variation in structure, composition, phytomass and net primary productivity in a *Lasiurus scindicus* Henr. and *Cenchrus setigerus* Vahl. dominated dry sandy desert site of Karachi. *Pak. J. Bot.*, 32: 171 - 210.
- Khan, D., M Faheemuddin and M.M. Alam (2001). Temporal variation in structure and phytomass of an old grass community of *Dichanthium annulatum* (Forsk.) Stapf. *Hamdard Medicus*, 44: 85 - 95.
- Khan, D., M. Faheemuddin and M.M. Alam (2002). Aspect variation of vegetation and phytomass in five grass dominated communities of Karachi. *Hamdard Medicus*, 45: 105-117. 2002.
- Khan, D., M.M. Alam, S. S. Shaukat and M. Faheemuddin (2005). Seasonal variation in structure, composition, phytomass and net primary productivity in a *Dichanthium annulatum* (Forssk.) Stapf. dominated coastal non-saline site of Karachi, Pakistan. *Int. J. Biol. Biotech.*, 2: 329 – 350.
- Khan, D. and S.S. Shauakt. (2005). Aboveground standing phytomass of some grass-dominated communities of Karachi: Winter Aspect. *Int. J. Biol. Biotech.*, 2: 85 – 92.

- Kumar, A. and M.C. Joshi (1972). The effects of grazing on structure and productivity of the vegetation near Pilani, Rajasthan, India. *J. Ecol.*, 60: 665 - 674.
- Lieth, H. and R.H. Whittaker (1975). *Primary Productivity of Biosphere*. Springer - Verlag. N.Y.
- Ludwig, J.A. (1986). Primary production variability in desert ecosystems. In: *Pattern and Processes in Desert Ecosystems* (ed. W.G. Whitford). Pp 5-17. Univ. New Mexico press, Albuquerque, N. Mexico.
- Malone, C.R. (1968). Determination of peak standing crop biomass of herbaceous shoots by the harvest method. *Am. Midl. Nat.*, 79: 429 - 435.
- May, R.M. (1975). Pattern of species abundance and diversity. In: *Ecology And Evolution Of Communities* (Cody, M.L. and J.M. Diamond eds.). Cambridge, Mass, Belknap Press. 81-120.
- Milkunas, D.G. and W.K. Laurenroth (1993). Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecol. Monogr.*, 63: 327 - 366.
- Minchen, C.F. (1907). *Lasbella, Baluchistan*. District Gazeteer Series vol. 8: Allahabad.
- Misra, M.K. and B.N. Misra (1989). Energy structure and dynamics in an Indian grassland. *Folia Goebot. & Phytotaxon.*, 24:25-35.
- Mohammad, N. (1989). *Rangeland Management in Pakistan*. Int. Centre for Integrated Mountain development (ICIMOD). Kathmandu, Nepal. xiv + 193 pp.
- Murphy, P.G. (1975). Net primary productivity in tropical terrestrial ecosystems. In: *Primary Productivity of Biosphere* (Lieth, H. and R.H. Whittaker, eds.). Springer - Verlag. N.Y.
- Odum, P. (1971). *Fundamentals of Ecology*. W.B. Sanders Co.
- Osem, Y., A. Perevolotsky and J. Kigel (2003). Grazing effect on diversity of annual communities in a semi-arid rangeland: interactions with small scale spatial and temporal variation in primary productivity. *J. Ecol.*, 90: 936 - 946.
- Osem, Y., A. Perevolotsky and J. Kigel (2004). Site productivity and plant size explain the response of annual species to grazing exclusion in a Mediterranean semi-arid rangeland. *J. Ecol.*, 92: 297 - 309.
- Pearson, L.C. (1965). Primary production in grazed and ungrazed desert communities of eastern Idaho. *Ecology*, 46: 278 - 285.
- Qadir, S.A., S.Z. Qureshi and M.A. Ahmad (1966). A phytosociological survey of Karachi University Campus. *Vegetatio*, 23: 339-362.
- Ross, M.s., P.L. Ruiz, G.J. Talesnicki and J.F. Meeder (2001). Estimating above-ground biomass and production in mangrove communities of Biscayne National Park Florida (U.S.A.). *Wetlands Ecology And Management*, 9 : 27 -37.
- Seischab, F.K., J.M. Bernard and K. Fiala (1985). Above- and belowground standing crop partitioning of biomass in *Eleocharis rostellata* Torr. in the Byron-Bergen Swamp Genesee, New York. *Am. Midl. Natur.*, 114: 70-76.
- Simpson, E.H. (1949). Measurement of diversity. *Nature* (London) 163: 688.
- Sims, P.L. and J.S. Singh (1971). Herbage dynamics and net primary production in certain ungrazed and grazed grasslands in North America. p. 59 - 124. In: *Preliminary Analysis of Structure and Function in Grasslands* (N.R. French ed). Range Sci. Ser. No. 10, Colorado State Univ. Fort Collins.
- Sims, P.L. and J.S. Singh (1978). Structure and function of ten Western North American grasslands. III. Net primary production, turn over and efficiencies of energy capture and water use. *J. Ecol.*, 66: 573 - 597.
- Singh, J.S. 1968. Net aboveground community productivity in the grasslands at Varanasi. p. 631 - 654. In: *Proc. Symposium on Recent Advances in Tropical Ecology* (R. Misra and B. Gopal, eds.). ISTE, Varanasi.
- Singh, J.S. and P.S. Yadava (1973). Caloric values of plant and insect species of a tropical grassland. *Oikos*, 24: 186 - 194.
- Singh, J.S. and P. S. Yadava (1974). Seasonal variation in composition, plant biomass and net primary productivity of a tropical grassland at Kurukshetra, India. *Ecological Monograph*, 44: 351-376.
- Singh, J.S. and R. Misra (1968). Efficiency of energy capture by the grassland vegetation at Varanasi. *Current Sci.*, 77 : 636 - 637.
- Smith, R.L. (1980). *Ecology and Field Biology*. Harper and Row Publ. NY, 835 pp.
- Steen, E. (1980). Dynamics and production of semi-natural grassland vegetation in Fennoscandia in relation to grazing management. *Acta Phytogeogr. Suec.*, 68: 153 - 156.
- Struik, G.J. (1965). Growth patterns of some native annual and perennial herb in southern Wisconsin. *Ecology*, 46: 401 - 420.
- Struik, G.J. and J.R. Bray (1970). Root-shoot ratio of native forest herbs and *Zea mays* at different soil moisture levels. *Ecology*, 50: 927 - 929.
- Whittaker, R.H. (1965). Dominance and diversity in land plant communities. *Science* (NY), 147: 250-260.



- Whittaker, R.H. and G.E. Likens (1975). The biosphere and man.(p. 305-328) In: *Primary Productivity in The Biosphere* (H. Lieth and R.H. Whittaker, eds.). Springer-Verlag.
- White, D.A.,T.E. Weiss and J.M.Trapani (1978). Productivity and decomposition of the dominant salt marsh plants in Louisiana. *Ecology*, 59: 751 -759.
- Yokum, C.S., L.H. Allen and E.R. Lemon (1964). Photosynthesis under field conditions VI. Solar radiation balance and photosynthetic efficiency. *Agron. J.*, 56: 249 - 253.
- Zubenok, L.I. (1977). Annual potential evapo-transpiration Map Sheet No. 18 In: *Atlas of World Water balance*. (M.I. Budyko, ed.). UNESCO Press, Paris.

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