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# SEASONAL VARIATION IN STRUCTURE, COMPOSITION, PHYTOMASS AND NET PRIMARY PRODUCTIVITY IN A *DICHANTHIUM ANNULATUM* (FORSSK.) STAPF. DOMINATED COASTAL NON-SALINE SITE OF KARACHI, PAKISTAN

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## ABSTRACT

The variation in composition, structure, phytomass and net primary productivity was analyzed in a *Dichanthium annulatum* (Forssk.) Stapf. dominated coastal community of Karachi, Pakistan. Phyto-ecological parameters of vegetation were studied at monthly interval for a year. Only 10 species were encountered from the site. *D. annulatum* was the leading dominant throughout the year in association with *Indigofera oblongifolia* and *Cyperus rotundus*. The density of *Dichanthium* remained more or less unchanged throughout the year except slight increase in September. Other species such as *Cyperus rotundus* and *Alysicarpus scariosus* showed density peak in September. The relative abundance pattern of species was geometric throughout the year.
The changes in the aboveground live plant biomass (LB), standing dead (SD), litter (L) and belowground biomass were studied. LB was maximum (422.4 $g^{-2}$) in October and March (399.2 $g^{-2}$). LB related positively with rainfall and soil moisture content. The effects of rainfall were better represented in the month subsequent to its occurrence and remained noticeable for not more than up to 50- 60 days. SD was maximum in November (358.4 $g^{-2}$). Litter was minimum in September (50.6 $g^{-2}$) and maximum in May (159.7 $g^{-2}$). The below- ground biomass was larger than the aboveground biomass. Above- ground net primary productivity (ANP) as evaluated by various methods varied from 310 to 704 $g^{-2}.year^{-1}$ (average = 496.1 ± 90.63 $g^{-2}.year^{-1}$; CV = 36.5%). Belowground net produc- tivity (BNP) was 754 $g^{-2}.year\ g^{-1}$. Annual efficiency of energy capture by the primary producers was estimated to be 0.53% on the basis of half total solar radiation. Annual energy flow diagram through primary producer compartments is presented.

**Key-words:** Seasonal variation, phytomass, *Dicanthium*, Karachi

## INTRODUCTION

A great deal of data on structural and functional characteristics of many plant community types 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.* (1999, 2000, 2001, 2002) 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 coastal site of Karachi dominated by *Dichanthium annulatum (*Forssk.*)* Stapf.

## 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. 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, a depression in coastal vicinity of Paradise Point, Karachi, stretched over an area of 250 x 50m. It caught run-off water from Northern raised area; likely flooded after rains. The soil was compact, alluvial silt loam (sand: 35.6%, silt: 55.6%, clay: 8.8%), slightly calcareous (calcium carbonate: 21.4%), basic (pH: 8.9) and non-saline (EC: 0.45 $dS.m^{-1}$ and deficient in K (0.18 meq/l) but organically rich due to decomposition of litter and algal mass. Algae such as *Nostoc, Oscillatoria* and *Ophio- cytrium* were identified from the top layer of soil after summer rains. The water table in the area was at c 5m 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 $m^2$ were laid at random in the field to sample the vegetation abundance. Any portion of sod forming grass (*Sporobolus helvolus*) possessing an independent shoot and root was considered as 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 admeasuring 1 $m^2$, 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 80ºC 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 as Singh and Yadava (1974) noted that 93% of the root material in a *Dichanthium annulatum* community is concentrated in the top 30 cm soil layer. The soil samples were soaked in water and biomass was screened using 32-mesh-sieve under a jet of water. It was dried at 80ºC and weighed. The belowground biomass was expressed as biomass per 0.3 $m^{-3}$ monolith of soil i.e., biomass in 1$m^2$ 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).

## RESULTS AND DISCUSSION

### Vegetational dynamics:

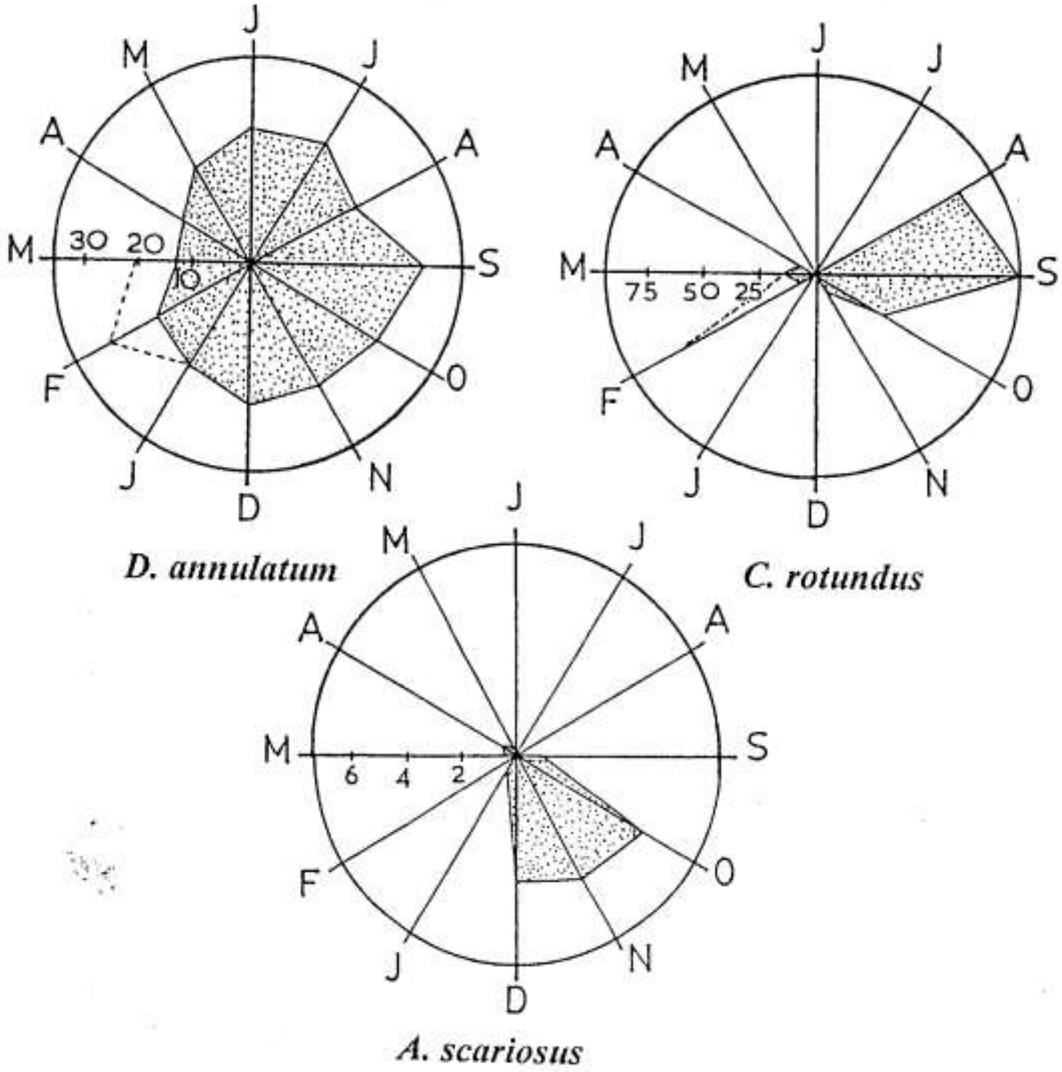
Only ten species were encountered from the site during the sampling period (Table 1). There were three grass, six legume and one sedge species. There were initially only two species contributing to the live biomass- *Dichanthium annulatum* and *Indigofera oblongifolia*. Annuals like *Alysicarpus monilifer* and *Tephrosia subtriflora* (annual/binniel) appeared after summer rains in August when *C. rotundus, Alysicarpus scariosus, I. oblongifolia* and *D. annulatum* germinated and renewed their growth. The field became lush green in September. Nearly all species started flowering in September and seeds were mature by November. *T. subtriflora* disappeared by now. *D. annulatum* again flowered in February. Similarly, *C. rotundus* flowered in March and then September. Its seeds matured in October and its aerial parts died in November. *I. oblongifolia* showed flowering nearly throughout the year.

The density of *D. annulatum* remained more or less constant around the year with only slight increase in September (Fig.**1**). *C. rotundus* and *A. scariosus* showed density peak in September and second smaller peak in March and April, respectively. The total plant density related with rainfall (P) as:

$$\text{Density/m}^2 = 37.53+0.795P \text{ lag } (-1) \pm 25.81 \qquad (t=2.32)$$

$$r^2 = 0.3582, \; F = 5.39, \; p < 0.043$$

The equation indicated a time lag phenomenon between rainfall and density i.e., the effects of rain appearing on density in the subsequent month. The marked seasonality in species distribution, their phenology and performance is common in monsoon grasslands and desert communities (Babu, 1971; Kumar and Joshi, 1972; Singh and Yadava, 1974; Khan *et al.*, 2000). Ephemerals and annuals dominate the vegetation, at least numerically, during monsoon season, complete their life-cycle within minimum possible time and disappear.



*D. annulatum*

*C. rotundus*

*A. scariosus*

Fig.1. Variation in density of some species occurring in *Dichantium annulatum* community during round the year study (1990-91). The broken line indicates the densities in 1991.

### 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). After summer rains LB attained maxima in October (422.4 $g^{-2}$) (Fig. **3**) then it declined regularly up to January (94.8 $g^{2}$). It again increased in February due to the advent of winter rains in early February. During November to January bulk of the biomass was transferred to standing dead compartment.

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

LB as well as the per cent proportion of total LB was of higher magnitude for grass component from August to October and then again in March. The LB proportion of legume component, largely contributed by *I. oblongifolia*, was maximum in rainless June (65.6%) and July (63.2%) and minimum during August to October when grass component was at its peak. The LB component of *C. rotundus* occupied maximum proportion in September (7%) and minimum in November (0.33%; Table 3).

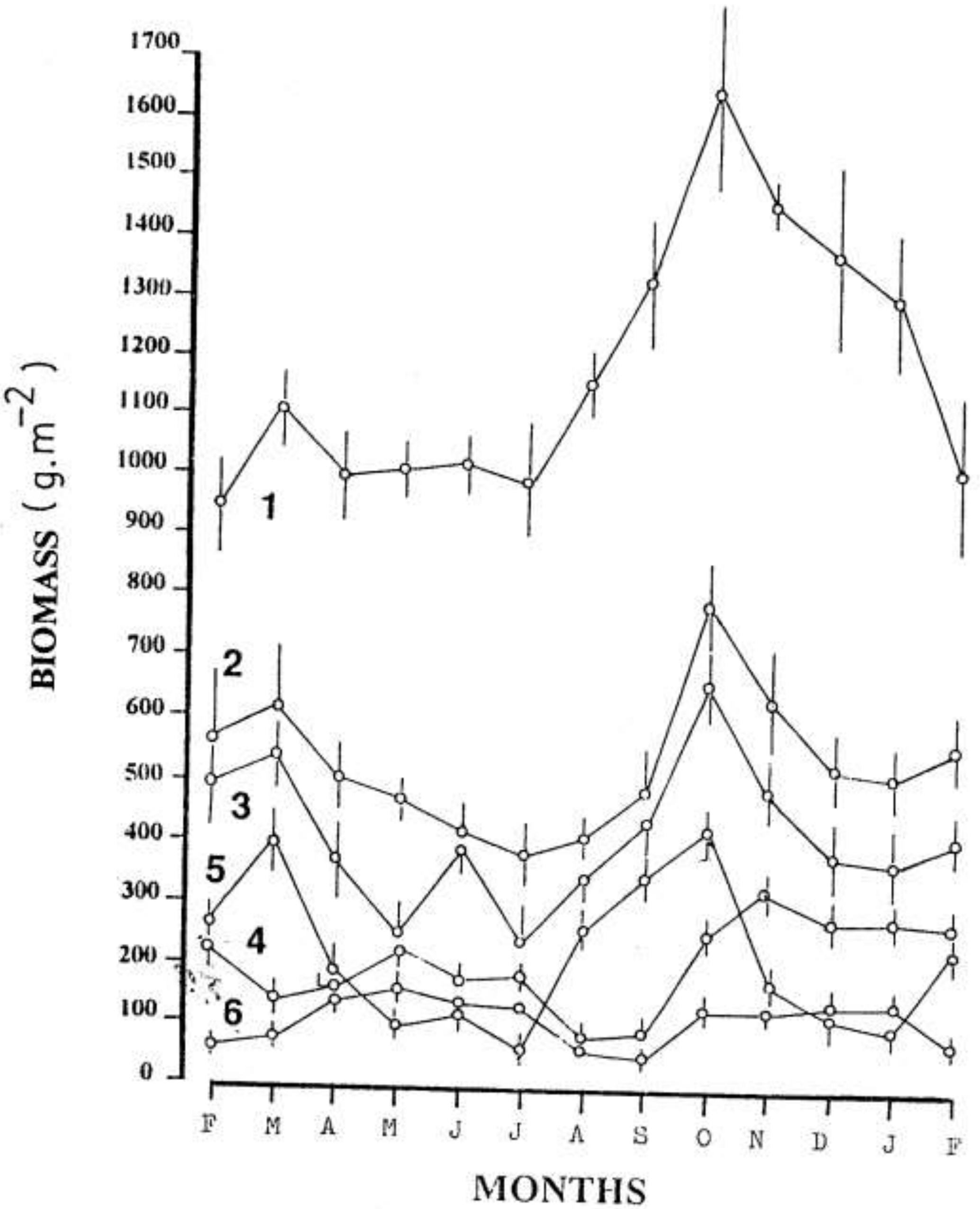


Fig.2. variation in biomass components of *D. annulatum* community, 1. Belowground biomass,;2. Above ground standing crop (litter + live biomass + dead); 3. Total aboveground biomass (live + dead); 4. Aboveground dead biomass; 5. Aboveground live biomass; 6. Litter; The below ground biomass express in g per 0.3 m$^3$ monolith.

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

The magnitude of LB associated with soil moisture content and the time of precipitation as well (Fig.**3**), however, a time lag phenomenon was apparent 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 up to nearly two months of its occurrence and were not detectable for the third month of the rain. In addition to precipitation and relative humidity, temperature and solar radiation also appeared to be the effective factors in determining the magnitude of the live biomass. Within the given pattern and the magnitude of the rain, its effects appear to remain up to 60-70 days only. These results are similar to that reported for a dry sandy *Lasiurus* site of University of Karachi campus (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.

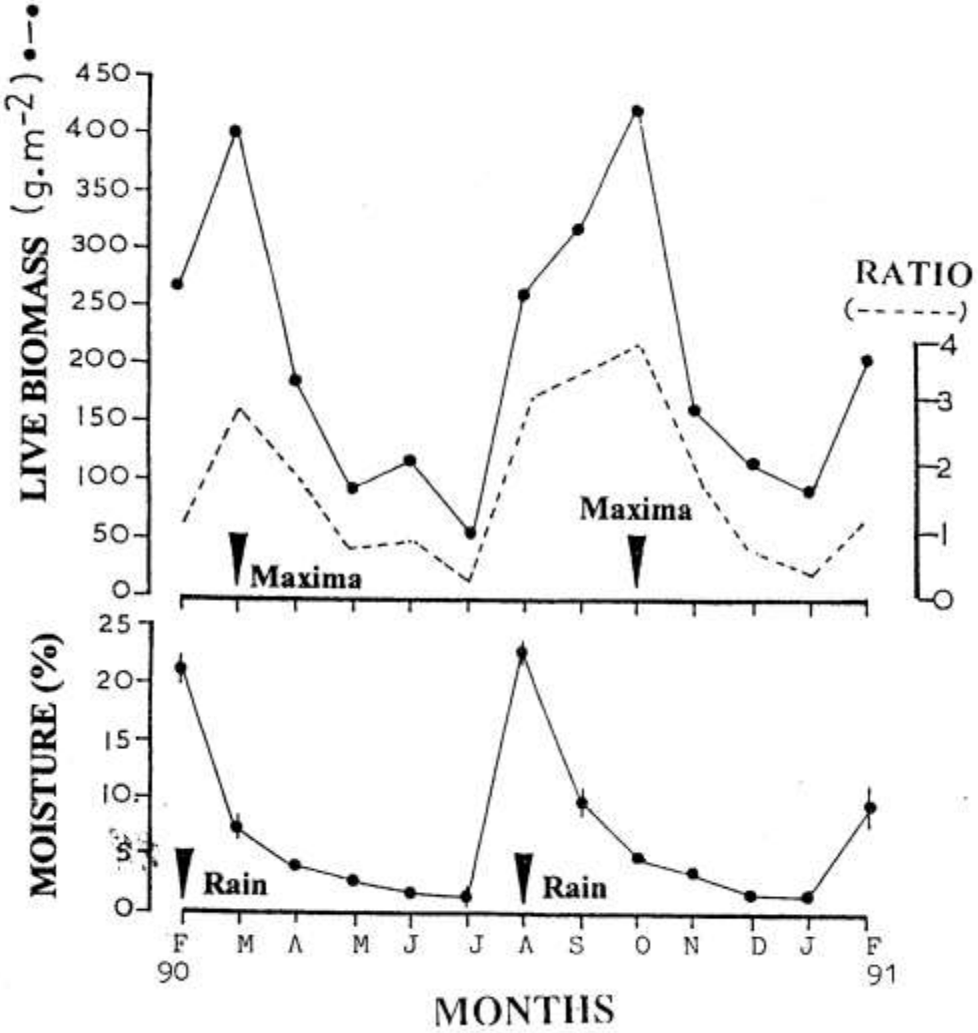


Fig.3. Relationship between soil moisture content at 15-20 cm depth and standing live biomass of *D. annulatum* community, Hawkes Bay, Karachi. Dotted line reprents live / dead biomass ratio.

**The relative abundance pattern:**

Relative abundance patterns based on live biomass were essentially linear throughout the year and no marked seasonal effects were visible on relative pattern of distribution, which remained characteristically geometric (**Fig. 4a & b**) i.e., the most successful species preempted a fraction ‘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 situation in this habitat and monopolization of the resource largely by *Dichanthium* in association with *Indigofera oblongifolia* almost all around the year. There appears paucity of species potentially competitive in this non-saline habitat of fine-textured silty compact soil, which is occasionally flooded after rains. The site being densely populated offers but limited chances of establishment to the new arrivals. The association of *I. oblongidfolia* with *D. annulatum* has also been observed in our early studies (Khan *et al* 1989; 1999). This association is important as both the species are good fodder plants. They should be evaluated for their binary cultivation at a density allowing their mixed growth (Khan *et al.,* 2001).

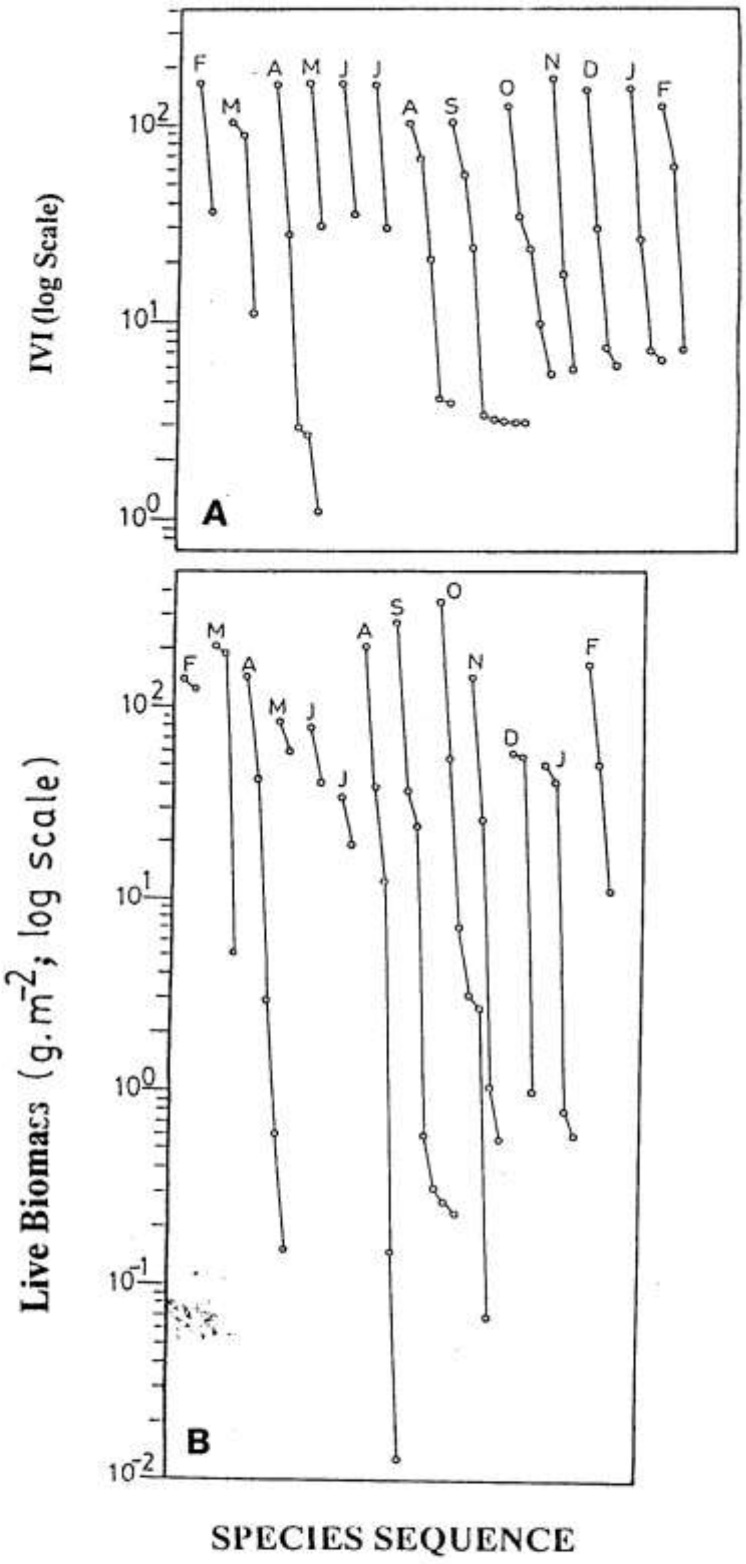


Fig.4. Relative abundance for *D. annulatum* community as varying around the year. A) bassed on IVI and B) based on biomass (g.m2) of the constituent speciesd.

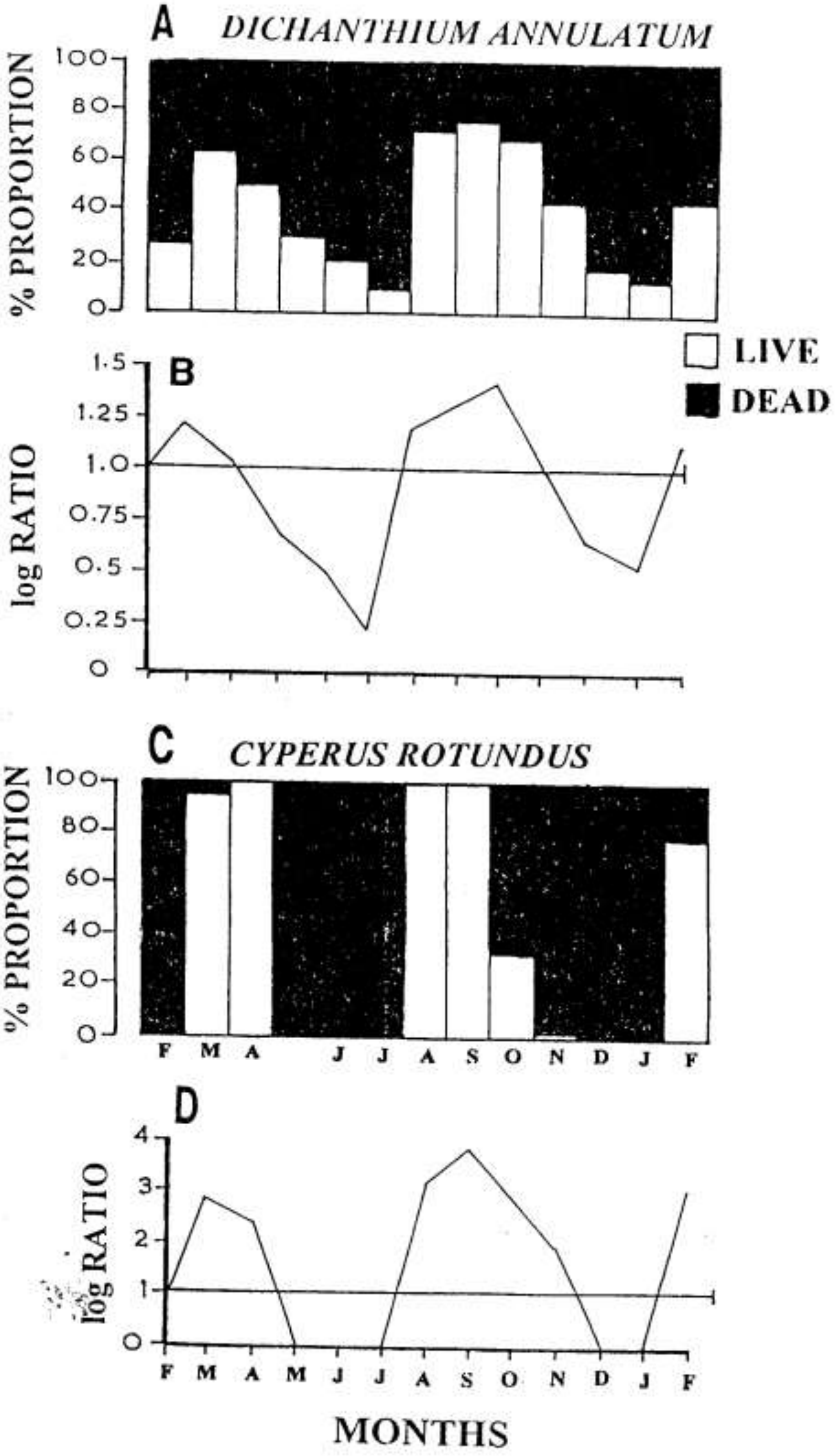


Fig.5. The proportion of live and dead biomass (A & C) and chamges in live biomass (B & C) of *D. annulatum* and *C rotundus* respectively.

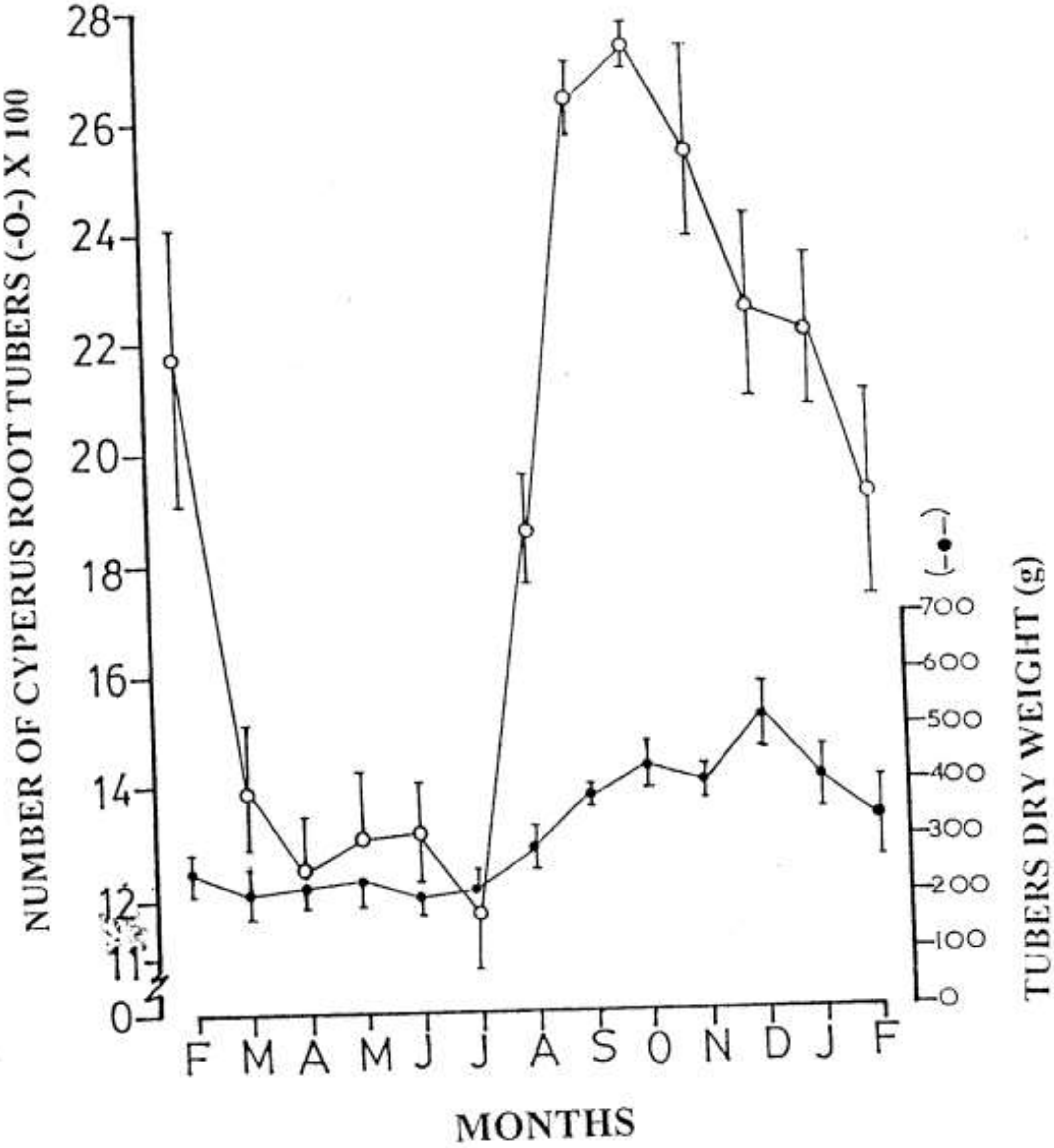


Fig.6. Variation in number and dry weight of root tubers of *C. rotundus* per 0.3 m3 soil monolith i.e., an area of 1 sq.m. dug up to a depth of 30 cm in *D. annulatum* community of Hawkes Bay, Karachi.

**Growth patterns of species:**

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

*log ratio = log10 x D. Wt.m*$^{-2}$ *at a later date / D. Wt.m*$^{-2}$ *in the initial date.*

It was indicated that *D. annulatum* had two peaks of growth, smaller winter peak and larger summer peak associated with magnitude of rains *pro rata*. The major activity of its growth started in August and it considerably increased its weight in October (**Fig.5**). Its minimum biomass was recorded in hot summer month of June. *C. rotundus* also showed two peaks of growth distinctly. Most of the aboveground parts of the plant, died in October and it was absolutely dead in November. The proportion of standing dead biomass of *D. annulatum* was generally substantially high except for the months of March, April and August to October.

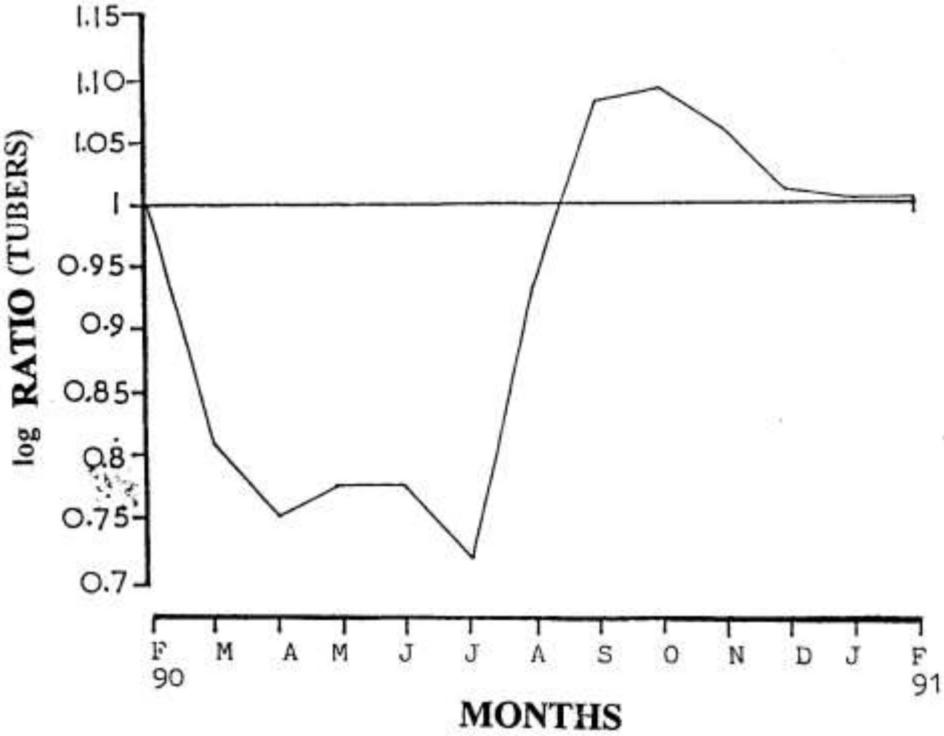


Fig.7. Changes in *C. rotundus* root tubers throughout the year, expressed as log ratio.

**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 5 and Fig. **2**, respectively. The standing dead biomass varied greatly with different months and reached to be maximum in winter when LB entered the dead compartment due to drought (January; 275.8 g.m$^{-2}$). Litter increased from March to July, then decreased in August and September and again increased from September to January (maximum value :147.6 g$^{-2}$). Obviously, it underwent decay and decomposition after rains. The total standing biomass (live + dead + litter) was maximum in October (788.3 g$^{-2}$). These trends were more or less similar to that reported for *Lasiurus-Cenchrus* community of Karachi (Khan *et al.,* 2000).

**Belowground biomass:**

The below ground biomass remained fluctuating round the year and was maximum for the month of October (1654.5 ± 215.3 g$^{-2}$) (Fig. **2**). It was consistently and considerably larger in magnitude (2.53 to 18.1 times; mean = 7.65 ± 1.3) as compared to the live aboveground biomass. *D. annulatum* is a bunch forming grass which are known to have higher root/shoot ratio (Odum, 1971). 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 our site may also be attributed to the fact that *C. rotundus*, an emergent hydrophytic species (Ambasht, 1984), has inherent tendency to allocate greater biomass to underground parts. It reproduced root tubers in great number during July to October (Fig. **6, 7**). On dry wt. basis, root tubers occupied quite substantial proportion (20 – 37.8%) of the total belowground biomass. After summer rains it produced tubers in large number to substantially increase its underground biotic potential. After sparse winter rains the number of tubers, however, declined. Presumably, they were consumed in producing the short-lived aerial parts of the plant.

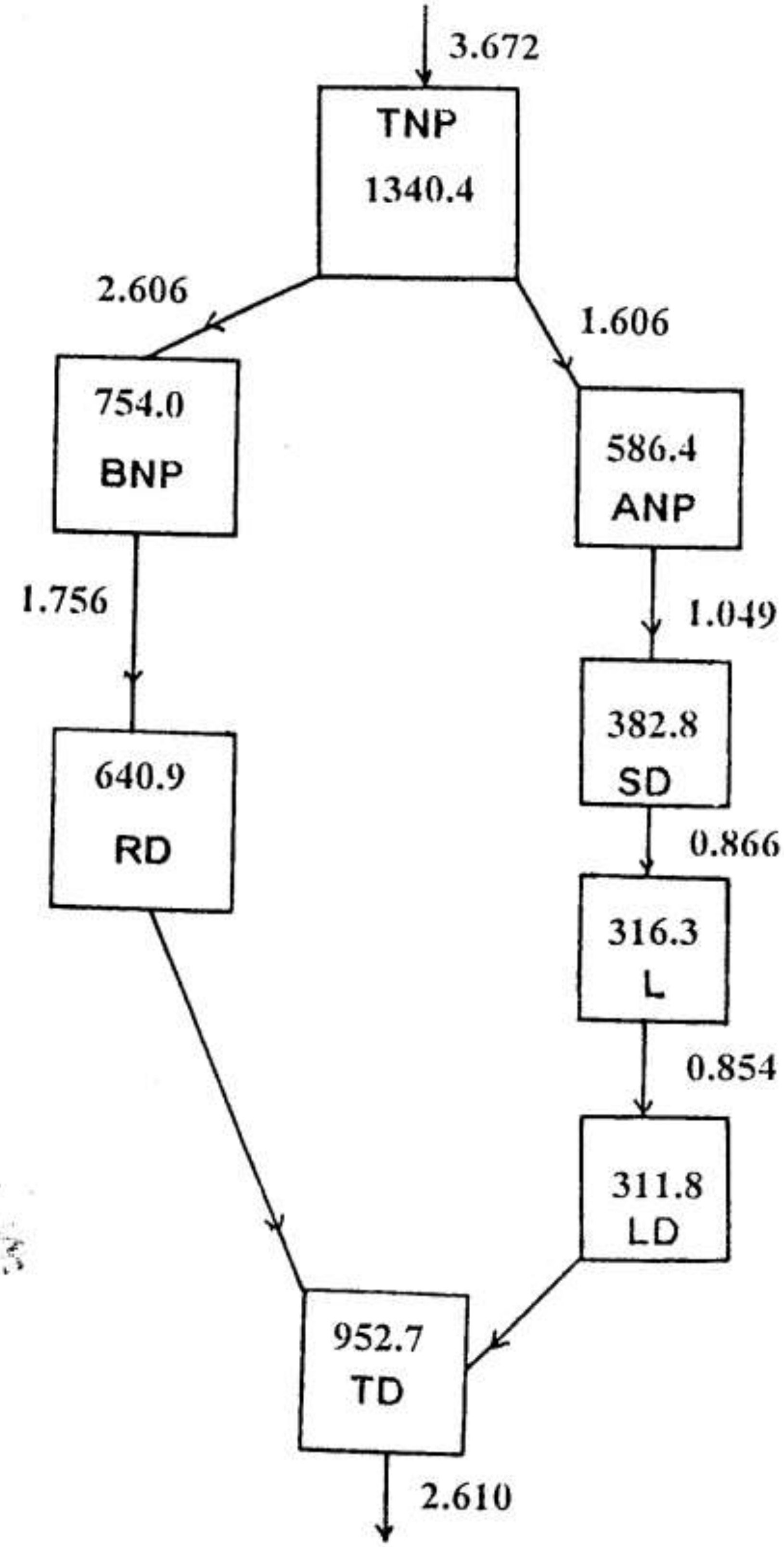


Fig. 8. Net primary production, accumulation rates and disappearance rates during the whole year growth in *D. annulatum* dominated community at Hawkes Bay, Karachi.

**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 383.9, 310.1, 703.9 and 586.4 $g^{-2}$ (mean = 496.1 ± 90.6 $g^{-2}$, CV=36.5%). Therefore, rate of production, on annual basis, varied from 0.85 to 1.9 $g^{-2}$ (mean = 1.36 ± 0.25). The variation around 36% in ANP estimation by various methods is, obviously, natural and 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. Khan *et al* (2000) have also reported around 23% variation in their ANP estimate of a dry site of Karachi when evaluated by these methods. However, for further discussion in present study, estimate obtained by method (iv) has been used because this method lends itself well for further partitioning the production in different season (Singh and Yadava (1974).

Table 1. Mean and range of IVI and live biomass of species encountered during yearlong studies.

| **Species** | **--------- IVI ---------** | | | **---Live Biomass-------** | | | **Occurrence** |
|---|---|---|---|---|---|---|---|
| | **Min** | **Max** | **Mean** | **Min** | **Max.** | **Mean** | (Out of 13) |
| *Alysicarpos monilifer* (L.) DC. | 3.41 | 3.41 | 3.41 | 0.64 | 0.64 | 0.64 | 1 |
| *A.. scariosus* Grah.ex Thwaites | 2.66 | 35.07 | 12.27 | 0.24 | 2.76 | 1.08 | 6 |
| *Cyamopsis tetragonoloba* (L.) Taubert | 3.32 | 4.12 | 3.73 | 0.15 | 0.28 | 0.22 | 1 |
| *Cyperus rotundus* L. | 2.99 | 128.88 | 87.94 | 0.58 | 24.17 | 9.30 | 7 |
| *Dichanthium annulatum* (Forssk.) Stapf. | 55.55 | 176.42 | 132.61 | 19.91 | 352.76 | 141.79 | 13 |
| *Indigofera oblongifolia* Forssk. | 5.98 | 37.18 | 24.05 | 26.06 | 190.24 | 64.31 | 13 |
| *Prosopis juliflora* (Swartz.) DC. | 1.22 | 6.61 | 4.34 | 0.15 | 0.61 | 0.38 | 4 |
| *Sporobolus helvolus* Dur. | 9.82 | 9.82 | 9.82 | 3.20 | 3.20 | 3.20 | 1 |
| *Tephrosia subtriflora* Baker | 5.61 | 5.61 | 5.61 | 0.07 | 0.07 | 0.07 | 1 |
| *Tragus roxburghii* Panigrahi | 3.32 | 4.23 | 3.28 | 0.01 | 0.32 | 0.17 | 2 |

Table 2. Values of live standing biomass ($g.m^{-2}$) of various species in different months in the *Dichanthium annulatum* dominated site at Hawkes Bay, Karachi.

| | **Species*** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Months** | Am | As | Ct | Da | Cr | Io | Pj | Sh | Tr | Ts |
| February | - | - | - | 128.38 | - | 136.00 | - | - | - | - |
| March | - | - | - | 203.10 | 5.88 | 190.24 | - | - | - | - |
| April | - | 0.61 | - | 140.50 | 2.79 | 42.68 | 0.15 | - | - | - |
| May | - | - | - | 58.68 | - | 36.08 | - | - | - | - |
| June | - | - | - | 41.29 | - | 78.68 | - | - | - | - |
| July | - | - | - | 19.91 | - | 34.14 | - | - | - | - |
| August | - | - | 0.15 | 205.81 | 12.68 | 39.68 | - | - | 0.013 | - |
| September | 0.64 | 0.24 | 0.28 | 279.56 | 24.16 | 37.68 | - | - | 0.320 | - |
| October | - | 2.76 | - | 352.76 | 7. 86 | 55.72 | - | 3.20 | - | 0.072 |
| November | - | 1.06 | - | 144.94 | 0.58 | 26.06 | - | - | - | - |
| December | - | 1.00 | - | 58.90 | - | 56.80 | - | - | - | - |
| January | - | 0.80 | - | 42.70 | - | 50.70 | 0.61 | - | - | - |
| February | - | - | - | 168.65 | 11.15 | 51.62 | - | - | - | - |

*, Am, *Alysicarpus monilifer*; As, *Alysicarpus scariosus*; Ct, *Cyamopsis tetragonoloba*; Da, *Dichanthium annulatum*; Cr, *Cyperus rotundus*; Io, *Indigofera oblongifolia*; Pj, *Prosopis juliflora*; Sh, *Sporobolus helvolus*; Tr, *Tragus roxburghii*; Ts, *Tephrosia subtriflora*.

Table 3. Apportionment of live biomass into grasses, legumes and others species.

| | **Components** | | |
|---|---|---|---|
| **Months** | **Grasses** | **Legumes** | **Others** |
| February | 128.38* | 136.00 | - |
| | 48.55** | 51.44 | - |
| | 1*** | 1 | - |
| March | 203.10 | 190.24 | 5.88 |
| | 50.87 | 47.65 | 1.47 |
| | 1 | 1 | 1 |
| April | 140.50 | 43.29 | 2.79 |
| | 75.24 | 23.18 | 1.49 |
| | 1 | 1 | 1 |
| May | 58.68 | 36.08 | - |
| | 51.93 | 38.07 | - |
| | 1 | 1 | - |
| June | 41.29 | 78.68 | - |
| | 34.47 | 65.58 | - |
| | 1 | 1 | - |
| July | 19.91 | 34.14 | - |
| | 36.84 | 63.16 | - |
| | 1 | 1 | - |
| August | 205.82 | 39.83 | 12.68 |
| | 79.67 | 15.41 | 4.90 |
| | 2 | 2 | 1 |
| September | 279.87 | 38.84 | 24.16 |
| | 81.62 | 11.32 | 7.04 |
| | 2 | 4 | 1 |
| October | 355.96 | 58.55 | 7.86 |
| | 84.27 | 13.86 | 1.86 |
| | 2 | 3 | 1 |
| November | 144.93 | 27.12 | 0.58 |
| | 83.94 | 15.71 | 0.33 |
| | 1 | 2 | 1 |
| December | 58.95 | 57.80 | - |
| | 50.49 | 49.50 | - |
| | 1 | 2 | - |
| January | 42.68 | 52.09 | - |
| | 45.03 | 54.96 | - |
| | 1 | 3 | - |
| February | 168.65 | 51.62 | 11.15 |
| | 72.89 | 22.32 | 4.82 |
| | 1 | 1 | 1 |

*, Live biomass (g.m$^{-2}$), **, Per cent Proportion, ***, Number of species.

Our estimate of ANP (496 ± 90.6 g$^{-2}$.year$^{-1}$) for this site is comparable to estimates reported for other arid lands. Khan *et al* (2001) have reported ANPP 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 ± 8.9 g$^{-2}$. The productivity of deserts and semi-deserts is reported to vary between 10 to 250 g$^{-2}$.year$^{-1}$ (Whittaker and Likens, 1975). ANP for nine grass community types of American desert (Sims and Singh, 1971) varied from 107 g$^{-2}$ for ungrazed shortgrass prairie at Pentex, Texas to 512 g$^{-2}$ for the grazed tallgrass at Osage, Oklahoma. Clark and Jacoby (1994) have reported the production of *Sporobolus virginicus* salt marsh in Australia amounting as large as 852 g$^{-2}$.year$^{-1}$. Our estimate is comparable to ANP of a local dry site of *Lasiurus scindicus* (448 g$^{-2}$.year$^{-1}$) (Khan *et al.*, 2000) and an unburned prairie ( 462 g$^{-2}$.year$^{-1}$) of Texas, USA, composed of several grasses and sedges but lower than that of unburned site of this prairie (Harcombe *et al.*, 1993). In a recent study, Osem *et al.* (2004) have reported 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 10-200 g$^{-2}$ in south and North facing slopes, hill tops and Wadi shoulders but considerably high (up to 700 $g^{-2}$) in Wadi with improved hydric resource and abounding species of relatively larger size.

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

| Parameters X / Y | $r^2$ | Adj. $r^2$ | a | b | t | F | p |
|---|---|---|---|---|---|---|---|
| LB / RH (-1) | 0.2151 | 0.1366 | -492.5 | 9.56 | 1.66 | 2.74 | 0.12 |
| LB / P (-1) | 0.2765 | 0.2040 | 180.40 | 2.88 | 1.96 | 3.83 | 0.09 |
| LB / SM (-1) | 0.4786 | 0.4260 | 130.40 | 11.67 | 3.03 | 9.18 | 0.013 |

*Lag (-1) Transformation:*

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

$$LB = -667.7 - 10.25\mathbf{T}(-1) + 22.1\,\mathbf{RH}(-1) - 3.04\,\mathbf{P}(-1) - 26.6\,\mathbf{SR}(-1) + 9.73\,\mathbf{SM}(-1) \pm 77.6$$

$t = 0.70$ $t = 2.43$ $t = 1.28$ $t = 1.29$ $t = 2.56$

$r^2 = 0.7888$, Adj. $r^2 = 0.6122$, $p < 0.001$

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*Log (-2) Transformation:*

$$LB = 157.93 + 3.2174\,\mathbf{P}(-2) \pm 89.85$$

$T = 2.69$

$r^2 = 0.4452$, Adj. $r^2 = 0.3835$, $F = 7.22$, $p < 0.025$

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*Log (-3) Transformation:*

$$LB = -4.02 - 11.39\,\mathbf{T}(-3) + 12.66\,\mathbf{RH}(-3) + 3.74\,\mathbf{P}(-3) - 14.92\,\mathbf{SR}(-3) - 24.29\,\mathbf{SM}(-3) \pm 130.1$$

$r^2 = 0.4826$, Adj. $r^2 = -0.0161$, $F = 0.75$ (NS)

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*, RH, Relative Hunmidity (8:00 AM); P, Precipitation (mm); SM, Soil Moisture (%); SR, Solar Radiation ($MJ.m^{-2}.day^{-1}$); T, Mean Monthly Temperature ($^{o}C$).

Table 5. Values of standing dead biomass ($g.m^{-2}$) of various species in different months in the *Dichanthium annulatum* dominated site at Hawkes Bay, Karachi.

| | **Species*** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Months** | Am | As | Ct | Da | Cr | Io | Pj | Sh | Tr | Ts |
| February | - | - | - | 21.22 | 0.32 | 3.32 | - | - | - | - |
| March | - | - | - | 119.24 | 0.15 | 18.85 | - | - | - | - |
| April | - | - | - | 178.90 | 0.18 | 6.22 | - | - | - | - |
| May | - | - | - | 204.66 | 4.20 | 8.59 | - | - | - | - |
| June | - | - | - | 162.15 | 5.10 | 4.22 | - | - | - | - |
| July | - | - | - | 176.12 | 8.58 | - | - | - | - | - |
| August | - | - | - | 78.95 | - | 76.80 | - | - | 0.003 | - |
| September | - | - | - | 91.20 | - | 2.34 | - | - | 0.120 | - |
| October | 0.001 | - | - | 159.16 | 39.51 | 43.44 | - | 3.50 | - | - |
| November | - | - | 0.003 | 193.16 | 51.26 | 113.94 | - | - | - | 0.16 |
| December | - | - | - | 253.33 | 18.80 | - | - | - | - | - |
| January | - | - | 0.20 | 259.58 | 16.05 | - | - | - | - | - |
| February | - | - | - | 211.86 | 2.86 | 4.85 | - | - | - | - |

*, Am, *Alysicarpus monilifer*; As, *Alysicarpus scariosus*; Ct, *Cyamopsis tetragonoloba*; Da, *Dichanthium annulatum*; Cr, *Cyperus rotundus*; Io, *Indigofera oblongifolia*; Pj, *Prosopis juliflora*; Sh, *Sporobolus helvolus*; Tr, *Tragus roxburghii*; Ts, *Tephrosia subtriflora*.

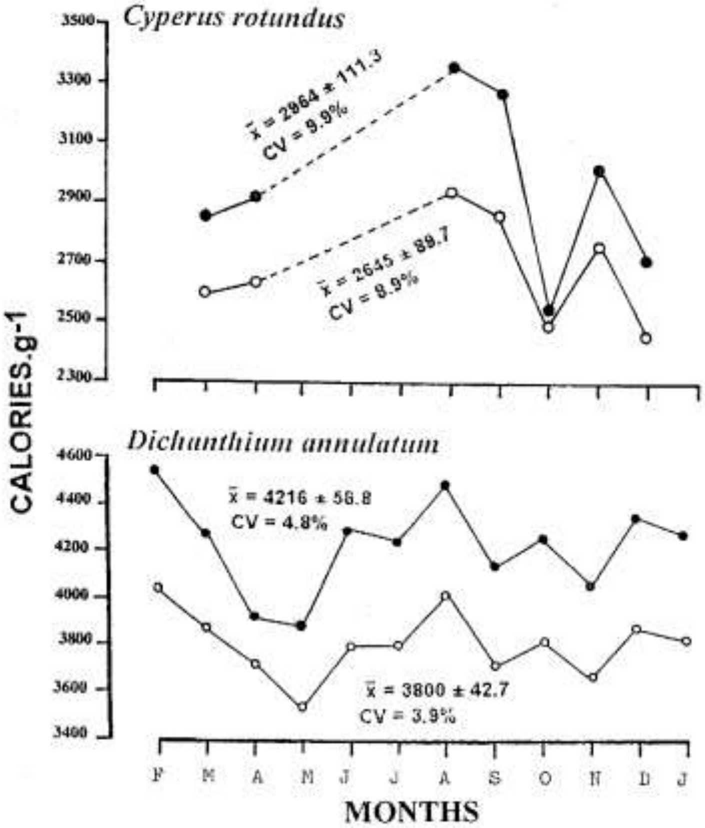

Fig.9. Variation in caloricfic values of live above ground biomass of *C. rotundus* and *D. annulatum*. Hallow circle = dry wt basis; solid circle = ash free basis.

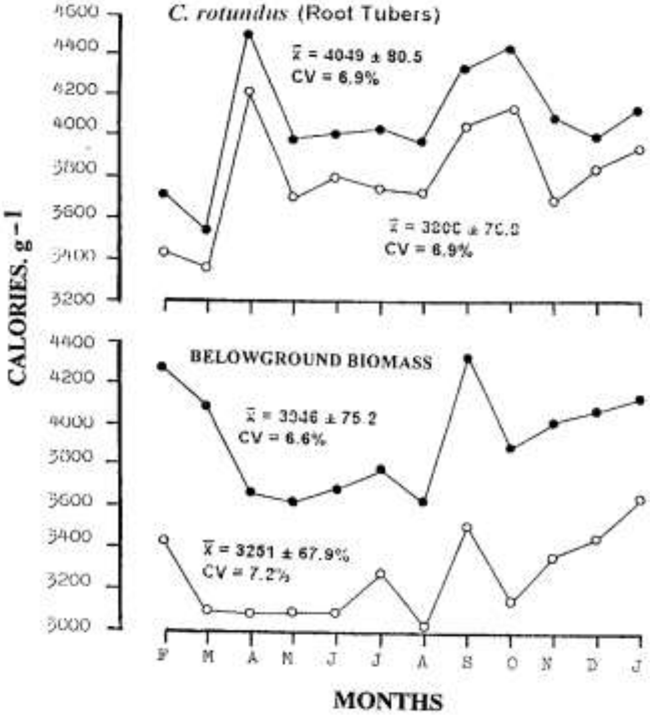

Fig.10. Variation in caloricfic values of root tubers of *C. rotundus* and *D. annulatum*. Hallow circle = dry wt basis; solid circle = ash free basis.

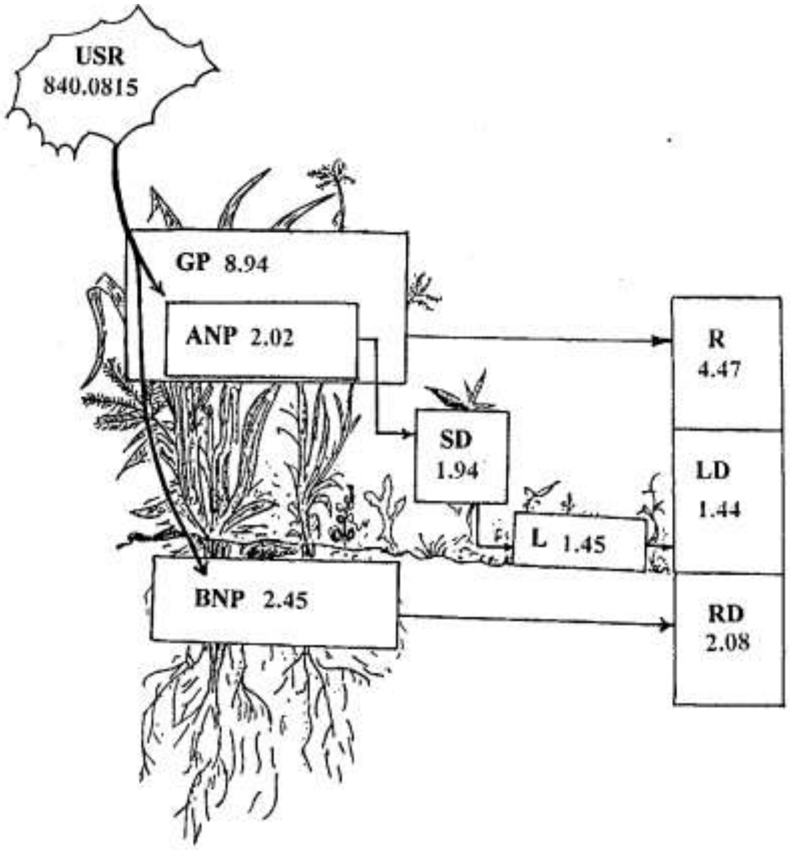

Fig.11. Annual energy flow through primary produce compartments in *D. annulatumn* community. All values in Kcal.$m^{-2}$ (x1000).

Table 6. Seasonal apportionment of above- and belowground production and production rates.

| Season * | Net Production ($g^{-2}$) | Rate of Production $g^{-2.}day^{-1}$) | Rainfall (mm) |
|---|---|---|---|
| **Aboveground Production** | | | |
| Summer | 449.9 | 2.445 | 86.80 |
| Winter | 136.5 | 0.754 | 24.30 |
| Annual | 586.4 | 1.607 | 111.10 |
| **Belowground Production** | | | |
| Summer | 689.3 | 3.743 | 86.80 |
| Winter | 64.7 | 0.358 | 24.30 |
| Annual | 754.0 | 2.085 | 111.10 |
| **Total Production** | | | |
| Summer | 1138.30 | 6.186 | 86.80 |
| Winter | 201.24 | 1.112 | 24.30 |
| Annual | 1340.43 | 3.672 | 111.10 |

*, Minchen (1907)

Table 7. Maximum belowground biomass and turnover rates.

| Season * | Max. Belowground Biomass ($g^{-2}$) | BNP ($g^{-2}$.$year^{-1}$) | Turnover |
|---|---|---|---|
| Summer | 1654.4 | 689.3 | 0.416 |
| Winter | 1461.4 | 64.7 | 0.044 |
| Annual | 1654.4 | 754.0 | 0.456 |

*, Minchen (1907)

Table 8. Annual balance sheet of dry matter.

| Components | Biomass | Components | Biomass |
|---|---|---|---|
| **ANP** | | **SD** | |
| Initial Biomass | 264.4 | Initial Biomass | 255.1 |
| ANP | 586.4 | SD Production | 382.8 |
| Input into the system | 850.8 | Input into the System | 607.9 |
| Transfer to SD | 382.2 | Transfer to litter | 316.3 |
| SD at the End | 231.4 | SD at the end | 289.6 |
| Output | 614.2 | Output | 605.9 |
| Unaccounted for | 236.6 | Unaccounted for | 2.0 |
| **BNP** | | **LITTER** | |
| Initial Biomass | 946.7 | Initial | 66.2 |
| BNP | 754.0 | Litter Production | 316.3 |
| Input into the system | 1700.7 | Input into the system | 382.5 |
| Disappearance of Biomass | 640.9 | Litter at the end | 70.8 |
| Biomass at the End | 1059.7 | Litter Disappearance | 311.8 |
| Output | 1700.7 | Output | 382.5 |
| Unaccounted for | 0 | Unaccounted for | 0 |

## Below ground net primary productivity:(BNP)

BNP, as estimated by summation of the significant positive peaks in the belowground biomass on successive sampling dates, amounted to 754 g$^{-2}$ being higher than ANP as may be expected under arid stressful conditions (Pearson, 1965; Struik and Bray, 1970; Sims and Singh, 1971; Khan *et al.,* 2000).

Table 9. System transfers functions.

| Components | Tfr (Annual) | Tfr (Annual) * |
|---|---|---|
| TNP-ANP | 0.438 | |
| TNP-BNP | 0.563 | |
| ANP-SD | 0.653 | 1.008 |
| SD-L | 0.826 | 0.896 |
| ANP-L | 0.539 | 0.946 |
| L-LD | 0.986 | 0.992 |
| BNP-RD | 0.850 | |
| TNP-TD | 0.711 | 0.889 |

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

Table 10. Calorific values (cal.g-1) of litter and standing dead biomass.

| Month | Litter | Standing Dead Biomass |
|---|---|---|
| February | - | 3781.4 |
| March | 2398.7 | - |
| April | - | - |
| May | 2308.5 | 3688.9 |
| June | - | 3484.3 |
| July | - | - |
| August | 2291.6 | 2468.3 |
| September | 2923.8 | 2452.2 |
| October | 3147.5 | 3019.0 |
| November | - | - |
| December | - | 3263.3 |
| January | 2666.4 | 2884.8 |
| February | - | - |

**Total net primary productivity (TNP):**

TNP of the site was estimated to be 1340.4g$^{-2}$. TNP of *D. annulatum* from India, as cited by Murphy (1975), varied from 650-1420 g$^{-2}$ under 725 mm rains, which is comparable to our estimate under a precipitation regime of merely 110 mm. The high productivity of the community in hand may presumably be due to the reason that this community, being situated in a depression, collected run-off water along with nutrient-rich alluvium. The community production is known to be a function of number of factors such as periodicity of rainfall, rate of evapo-transpiration, 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. (Murphy, 1975; Steen, 1980; Ludwig, 1986; Milkunas and Lauranroth, 1993; Khan *et al.,* 2000; 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 6 ). 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 7). In spite of the fact that turn over was higher in summer, the overall turn over was low (45.6%). Lower turn over values ranging from 0.19 to 0.68 have been reported for nine grass communities by Sims and Singh (1971). Contrary to it, turn-over as high as 0.97 has been reported for *Panicum* community by Singh and Yadava (1974). Lower replacement rate in the present case could perhaps be one of the reason for higher belowground biomass. This is also suggested by constantly increasing dry weight of root tubers of *C. rotundus* from August to December (Fig. **6**).

**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 = (initial amount of litter + litter production) - (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 236.6 g$^{-2}$ 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= (Initial amount of biomass) + ANP ) - (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= (Initial Standing Dead + SD) - (Standing dead at the end)

3. The litter disappearance then will be:
LD =(Initial litter + L) - (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) and 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. (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 619.4, 554.9 and 550.3 g$^{-2}$.

**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 56.3% of TNP was directed towards belowground productivity (Table 9 ). On greater estimate basis nearly all of the ANP was transferred to SD compartment. On normal estimate basis this transfer function was 65.3%. It is, however, obvious from the field observation that great amount of biomass underwent death and decomposition when the site collected run-off water after rains. several dead plants of *I. oblongifolia* were seen in the field in the months of February and March. Nearly 71% (89% on greater estimate basis) of TNP is lost through death and decomposition. LD/L ratio of 0.98 further signifies the greater decomposition activity in this site. 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 and that of composite samples of litter and belowground biomass were determined by adiabatic bomb calorimeter by forming compact pallets of oven dried powdered material and redrying the pallets at 80ºC. The pallets were burnt in bomb under 30 atms. $O_2$ pressure using platinum wire. Ash contents were determined by combustion in muffle furnace. On dry wt. as well as ash free basis, aboveground biomass of *D. annulatum* appeared to be more energy-rich (mean: 3800 ± 42.7 and 4216 ± 142.3 cal.g$^{-1}$, respectively, (Fig. **9**) than that of *C. rotundus* ( mean: 2645 ± 42.7 and 2964 ± 111.3 Cal.g$^{-1}$, respectively). The calorific value of February sample of *I.* oblongifolia was 3924 cal.g$^{-1}$ on ash free basis and 3729 cal.g$^{-1}$ on dry wt basis. The calorific values were generally higher after rains in August and then in February. Peak values were generally associated with peak vegetative and reproductive growth. The calorific values were low for May and November (Fig.**9**). These results are similar to those as reported by Singh and Yadava (1973) for some graminoids of India.

The calorific values on dry wt. basis for litter varied considerably from 2308 cal.g$^{-1}$ in April to 3148 cal.g$^{-1}$ in the month of October and 2292 cal.g$^{-1}$ in August after rainy season growth of plants. The lower value in August appears to be the weathering effect. The calorific values of standing dead material varied considerably (2452.2 to 3781.4 Cal.g$^{-1}$) averaging to 3130 Cal.g$^{-1}$ (Table 10).

In case of belowground biomass (Fig. **10**) the caloric values on D.wt. basis was highest (4257 cal.g$^{-1}$ in post-rain month of September. Root tubers of *C. rotundus* were highly energy-rich material, possibly due to low ash and high organic content in this perennating organ. Two peaks in calorific values were apparent: one in April and another in October. The downward translocation of the photosynthate after winter and summer rains must have laden the root tubers with energy rich material. The belowground biomass showed calorific maxima also after rains when new roots were formed.

The 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. The mean values for aboveground live, standing dead, litter and belowground biomass were 3448 ± 132, 3130 ± 168, 2623 ± 192 and 3251 ± 68 cal.g$^{-1}$, 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 based on photo-synthetically efficient radiation (0.4 - 0.70µm) it is called "absolute efficiency". For calculation of energy capture efficiency, Botkin and Melone (1968) have opined that the actual amount of light intercepted by the canopy should be considered. However, 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 the 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 c. 0.24, 0.29 and 0.53 %, respectively. 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; Khan *et al.*, 2000). 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% (Jordan, 1971). Misra and Misra (1989) have reported efficiency value of 0.81 for perennial *Aristida setacea* dominated community situated in Brahampur on the coastal belt of Bay of Bengal and receiving as high rainfall as 1200 mm. EEC of the site in hand is much close to that reported for *Lasiurus scindicus* community (0.47%) of Karachi (Khan *et al.*, 2000). 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. Their data are, however, based on a time-period of one growing season (one month). When expressed on annual basis their EEC value should decline considerably. However, grasses, particularly $C_4$, are far more efficient $CO_2$ utilizers than legumes ($C_3$ plants) and are better adapted to high insolation and temperature (Mott and Popenoe, 1977).

**Annual Energy Flow (AEF):**

An estimate of AEF through the primary producer compartments is depicted in Fig. **11**. 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 54.8% of the energy fixed in TNP moved towards belowground production and 45.2% stayed aboveground. Some 78.75% of TNP energy is dissipated via root and litter disappearance. This value is comparable to that reported for *Panicum milliare* community of Kurukshetra, India (Singh and Yadava, 1974). Nearly 21% of the total energy fixed in TNP remained as surplus in this site.

The somewhat greater energy allocation in BNP in this site appears related with the effects of aridity and grazing to which this site has been exposed over past years (Pearson, 1965; Smith, 1980). The net surplus of 21% of total energy fixed in this community indicates the tendency to move towards a scrub forest type (Golley, 1972).

As Environmental conditions in arid areas vary considerably over years with intermittent droughts and irregular precipitation, long-term studies should provide more reliable and practically useful production estimates for fragile arid ecological systems. Studies in a net-work of localities, representing different agro-ecological zones of Pakistan, should be undertaken in order to develop better eco-developmental strategy for the arid rangelands.

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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. Cambbridge 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. In: *The Measurement of Grassland Productivity***.** (J.D. Irvins, ed.). Butterworths, London. p 62 - 68.

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. Zobeck. 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., 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 XLII*: 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* XLIV: 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* XLV: 105-117. 2002.

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. *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.

Mott, G.O. and H.L. Popenoe (1977). Grasslands. (p. 157-186). In: *Ecophysiology of Tropical Crops* (P de T. Alvim and T.T. Kozlowski, eds.). Academic Press, Inc. xiv + 502 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. Dep. 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: R. Misra and B. Gopal, eds.). *Proc. Symposium on Recent Advances in Tropical Ecology.*, 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 Kurushetra, 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 Winconsin. *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. In: *Primary Productivity In The Biosphere* (H. Lieth and R.H. Whittaker, eds.). Springer-Verlag. p305-328

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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