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STRUCTURE, COMPOSITION, PHYTOMASS AND NET PRIMARY PRODUCTIVITY IN A CENCHRUS SETIGERUS VAHL. DOMINATED COMMUNITY IN A MOIST–SALINE HABITAT OF KARACHI, PAKISTAN

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ABSTRACT

The variation in composition, structure, phytomass and net primary productivity was analyzed in a *Cenchrus setigerus Vahl.* dominated community in a moist-saline site of Karachi, Pakistan. Phyto-ecological parameters of vegetation were studied at monthly interval for a year. Only 41 species were recorded from this site. On the basis of phytomass, *C. setigerus* was the leading dominant throughout the year. Initial density of this site, in the month of May, was 16 live plants.m$^{-2.}$ The Maximum density occurred in August when it reached to 95.5.plants.m^{-2}. Around 34.3% of the density at this point of time was contributed by *Dactyloctenium. scindicum* Boiss. (32.8 plants.m^{-2}). This species exhibited two peaks of density – one in August and other in February – coinciding with rains. The density of *Cenchrus setigerus* was quite low initially (around 5 plants.m^{-2}). It increased to around 12 plants.m^{-2} after rains in August, then, with the rise of salinity, declined slowly to reach to 7 in February and 3 plants.m^{-2} in post-winter rains period. The changes in the aboveground live plant biomass (LB), standing dead (SD), litter (L) and belowground biomass were studied. LB proportion of grasses was high round the year (85.5 to 99.2% of the total LB). The live biomass of legumes was negligible except in November when it was 9.85% of the total LB due to the growth of *Rhynchosia schimperi Hochst Ex. Boiss*. LB was maximum (507.1 ± 90.9 g.m $^{-2}$) in September. The effects of rainfall remained noticeable for not more than up to 50- 60 days. SD was maximum in March (593.03 ± 94.8 g.m $^{-2}$). Litter was maximum in October (193.18 ± 10.69 g.m $^{-2}$) and minimum in May (95.84 ± 9.07 g.m $^{-2}$). Above- ground net primary productivity (ANP) as evaluated by various methods. It varied from 415.7 to 748.9 g.m^{-2}.year^{-1} (average = 603.88 ± 71.10g.m $^{-2}$.year $^{-1}$; CV = 23.5%). Belowground net productivity (BNP) was 1137.12 g.m $^{-2}$.year $^{-1}$ (up to 30 cm depth). System transfer function data indicated that some 63.08% of Total Net Primary Productivity (TNP) was directed towards belowground productivity. Annual efficiency of energy capture by the primary producers was estimated to be 0.72% on the basis of half total solar radiation. Annual energy flow diagram through primary producer compartments is presented.

Key Words: *Cenchrus setigerus Vahl.*, Moist-saline site, Community structure and composition, Phytomass, Net primary productivity, Energy efficiency, Annual energy flow.

INTRODUCTION

Data on structural and functional characteristics of many plant community types have accumulated during past few decades from many countries of the world (Golley, 1965; Pearson, 1965; Singh, 1968; Sims and Singh, 1971, 1978; Singh and Yadava, 1974; Lieth and Whittaker, 1975; White *et. al.*, 1978; Saxena *et.al.*, 1996; Khan *et. al.*, 2000; Ross *et. al.*, 2001; Halin *et. al.*, 2002; Huenneke *et. al.*, 2002; Osem *et al.*,2003, 2004; Saleem *et. al.*, 2009, etc.). Some data on vegetation and phytomass dynamics of various grass communities of Pakistan have been published by Johnston and Hussain (1963), Khan *et. al.* (1999, 2000, 2001, 2002, 2005, 2006), Khan and Shaukat (2005), Saleem *et. al.* (2009) etc. but there remains a great 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 grass community dominated by *C. setigerus Vahl.* in a sandy moist-saline site of Karachi, Pakistan.

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 global radiation (beam + diffused radiation) varied from 3580.87 Kcal.m^{-2}.day^{-1} for December and 5609.40 Kcal.m^{-2}.day^{-1} in May. The diffuse radiation remained 20 - 30% of the global radiation.

The site under study, situated in the premises of Karachi University campus was relatively low lying and subject to waterlogging due to seepage from a damaged waterline leading to the city. It stretched over an area of 200 x 50m. The soil was sandy (sand: 89.9%, silt: 2.1%, clay: 8.0%), slightly calcareous (calcium carbonate: 19.82%), and basic (pH: 8.0). Salinity of the soil changed seasonally (Saturated Extract's EC: 7.20 ± 1.98 $dS.m^{-1}$ initially but increasing gradually during study period to 19.3 ± 3.8 $dS.m^{-1}$. Sodium and chloride contents as determined in the final month of observation were – 278 and 311 meq /l, respectively. Organic content was relatively high (H_2O_2 oxidizable organic matter – 4.92%). The site has been subject 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 each 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 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 80 ^oC 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^o C and weighed. The belowground biomass was expressed as biomass per 0.3 m^{-3} monolith of soil i.e., biomass in an area of $1m^2$ 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 IVI and biomass were plotted (Whittaker, 1965).

The general diversity was ascertained by information theory function ($H = - \Sigma$ pi.log pi) where pi is the proportion of density or standing live biomass belonging to the i^{th} species (Margalef, 1957). The equitability was measured by $e = H / H_{max}$ where $H_{max} = \log S$ (Pielou, 1969). The species richness was calculated as $d=S/\sqrt{N}$ (Menhinick, 1964). And d' = S-1 / log N (Margalef, 1957), where S is the number of species in the sample and N is the total density or the total standing live biomass for the sample month. The diversity was also measured by McIntosh's (1967) index of diversity ($Mc = 1 - \sqrt{\Sigma ni^2} / N$) where ni is the density or live biomass of the i^{th} species. Dominance was estimated by Simpson's (1949) index and MacNaughton (1968) index of community dominance as $c = \Sigma pi^2$ and CDI = Y1 + Y2 / Y * 100, respectively. Here Y1 is IVI or biomass of the leading dominant, Y2 , the IVI or biomass of subordinate species and Y, the total IVI or live biomass of the sample. The dominance-diversity curves (Whittaker, 1965), based on IVI and live biomass were plotted.

OBSERVATION, RESULTS AND DISCUSSION

Vegetation dynamics

Only 41 species were encountered in this site during the sampling period (Table 1). Among these species, there were eleven grasses, seven legumes, two sedges and twenty one other species. The species occurring in 3 or less than three times a year were twenty eight - constituting around 68.3 % of the total species where as the species occurring in ten or more than ten times a year were six only (c 14.6%). There were initially eight species contributing to the live biomass which increased to twenty four in August, after rains. The field became greener in August and September. The site was dominated by *C. setigerus* throughout the year on the basis of phytomass – *Dactyloctenium scindicum* being the second dominant. On the basis of importance value index, *D. scindicum* remained the leading dominant for most part of the year.

The initial density of this site, in the month of May was 16 live $plants.m^{-2.}$ The density maxima occurred in August when it reached to 95.5 $plants.m^{-2}$ (Fig. 1). Around 34.3% of the density at this point of time was contributed

Table 1. Mean live biomass (g.m-2) and the occurrence of species encountered during year long sampling of *Cenchrus setigerus* dominated moist- saline site.

Species	**LIVE BIOMASS**			**Occurrence (Months out of 13)**
	Minimum	Maximum	Mean	
Aerua javanica (Burm. f.) Juss.	0.21	5.12	2.23	4
Blepharis sindica T. And.	0.06	1.04	0.43	3
Boerhavia verticillata Poir	0.71	0.71	0.71	1
Cenchrus pennisetiformis Hochst. & Steud ex. Steud.	2.66	55.17	11.13	10
C. setigerus Vahl	54.78	359.68	158.81	13
Chloris barbata SW.	0.03	2.18	0.60	4
Commelina albescens Hasskari	1.28	1.28	1.28	1
Convolvulus sindica Stocks	0.002	0.002	0.002	1
Corchorus depressus (L.) Stocks	0.01	0.01	0.01	1
C. tridens L.	0.03	0.03	0.03	1
Cucumis callosus (Rotte.) Cogn.	0.001	0.001	0.001	1
Cyperus atkinsonii Clarke	0.01	0.19	0.07	4
C. bulbosus Vahl	2.11	2.11	2.11	1
Dactyloctenium aegyptium(L.) Beauv.	16.58	16.58	16.58	1
D. scindicum Boiss.	28.03	109.28	60.82	13
Dichanthium annulatum (Forssk.) Stapf.	4.51	4.51	4.51	1
Digera muricata (L.) Mart.	0.006	0.006	0.006	1
Eragrostis minor Host.	0.002	0.002	0.002	1
Fagonia indica Burm.f.	1.12	19.20	7.25	4
Heliotropium ramossissimum Sieb	0.10	13.12	5.68	3
Indigofera cordifolia Heyne ex Roth	0.002	0.003	0.0015	2
I. linifolia (Linn.f.) Retz.	3.89	3.89	3.89	1
Lasiurus scindicus Henr.	2.98	39.54	13.93	13
Launaea nudicaulis (L.) Hk. f.	0.11	12.00	2.83	12
Leptothrium senegalensis (Kunth) W.D. Clayton	0.31	0.31	0.31	1
Lycium edgeworthii Dunal	0.13	0.13	0.13	1
Ochthocloa compressa (Forssk.) Hilu	0.91	22.89	8.87	10
Peristrophe bicalyculata (Retz.) Nees	0.15	0.15	0.15	1
P. erioptera DC.	1.33	1.33	1.33	1
Portulaca sp.	0.10	0.12	0.11	2
Prosopis juliflora Swartz.) DC.	0.002	0.09	0.03	3
Rhynchosia minima (L.) DC.	11.07	11.07	11.07	1
R. schimperii Hochst ex Boiss.	2.40	20.60	14.87	3
Salsola baryosma (R. and S.) Dandy	0.012	0.10	0.06	2
Sericostema pauciflorum Stocks ex Wightii	3.13	5.81	4.47	2
Suaeda fruticosa (L.) Forsk.	5.99	12.86	9.42	2
Sida pakistanica S. Abedin	1.22	17.48	5.09	8
Tephrosia strigosa (Delz.) Sant. & Maheshw	0.08	0.15	0.12	
T. subtriflora Baker	0.016	0.32	0.19	4
Tragus roxburghii Panigrahi	0.02	0.02	0.02	1
Tribulus terrestris L.	0.007	0.007	0.007	1

by *D. scindicum* (32.8 plants.m^{-2}). This species exhibited two peaks of density–one in the month of August and other in February – coinciding with rains. *Blepharis sindica* was second highest in density (23 plants.m^{-2}) but it survived up to September only. After struggling for six months, *Fagonia indica* disappeared in October. The density of

Cenchrus setigerus was quite low initially (around 5 plants.m^{-2}). It increased to around 12 plants.m^{-2} after rains in August, then, presumably with the rise

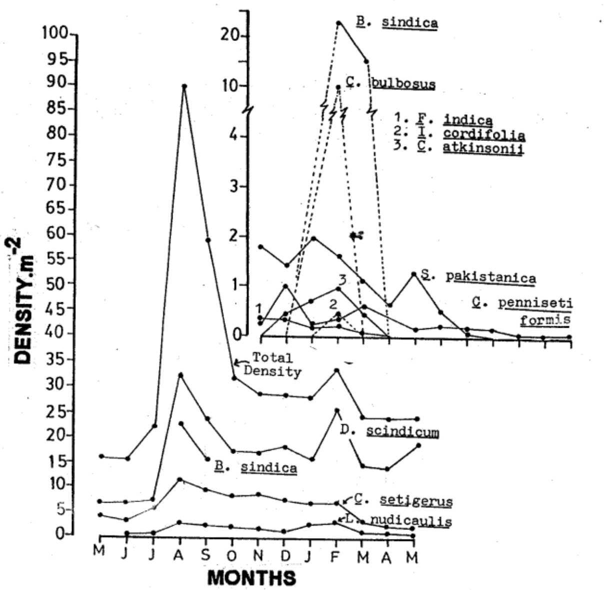


Fig. 1. Variation in density of some species occurring in moist-saline site dominated by *C. setigerus*.

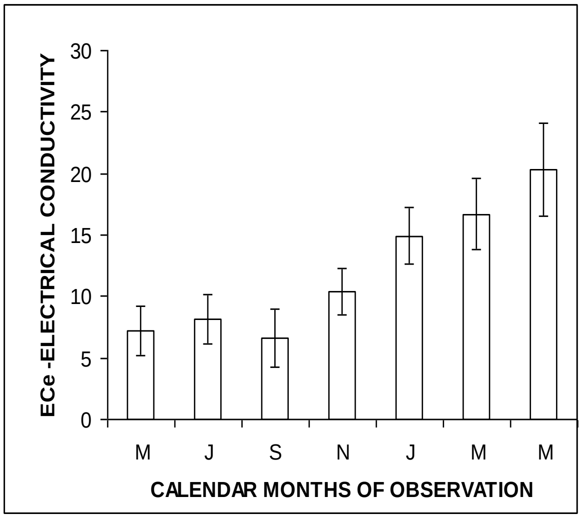


Fig. 2. Temporal variation of salinity (ECe: dS.m-1) in upper 10 cm layer of soil of *C. setigerus* site during observation period of one year.

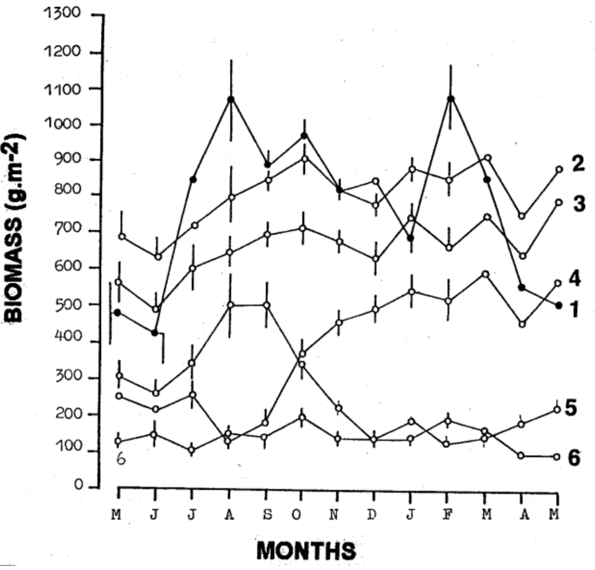


Fig. 3. Variation in biomass components. 1. Belowground biomass, 2. Aboveground standing crop (live + litter + dead), 3. Total aboveground biomass (live + dead), 4. Aboveground dead biomass, 5. Aboveground live biomass, 6. Litter. The belowground biomass was expressed in g per 0.3 m^3.

of soil salinity declined slowly to reach to 7 in February and 3 plants.m^{-2} in post -winter rains period. *Sida pakistanica* exhibited maximum density during July and following a declining trend disappeared from the field in

February presumably due rise in salinity (Fig. 2). *Launaea nudicaulis* which invaded the field in July had density lower than 5

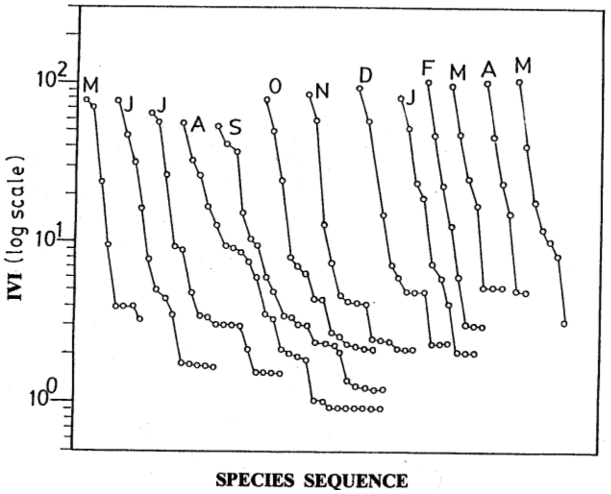
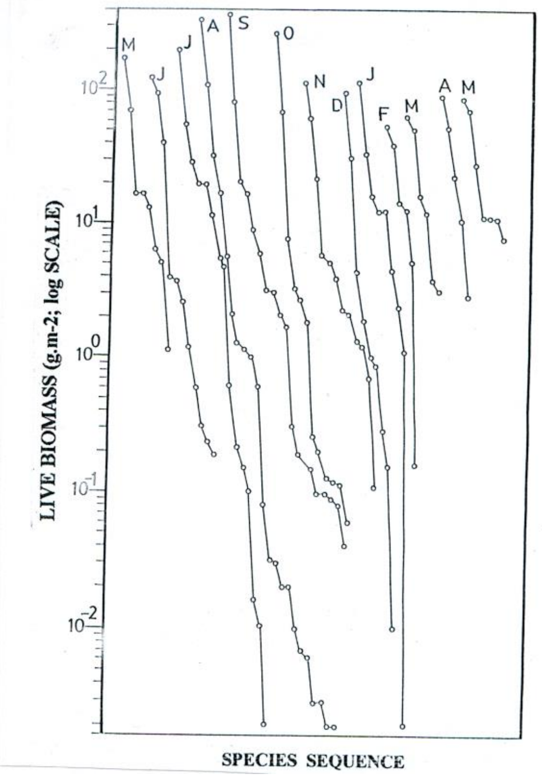


Fig. 4A. Dominance- diversity curves for moist-saline site of *C. setigerus* drawn on a semi-log plot of values of importance value index of the constituent species.

plants.m^{-2} but persisted in the field with increasing phytomass. Its leaves became thick and succulent admeasuring at times around 2mm in thickness – presumably due to salt accumulation in older leaves (salt sink), a trait exhibited by several plants growing in salinity-affected soil (e.g., *Indigofera oblongifolia*, Khan and Ahmad, 1998). *C. atkinsonii* and *C. bulbosus* germinated after summer shower in August but couldn't survive.



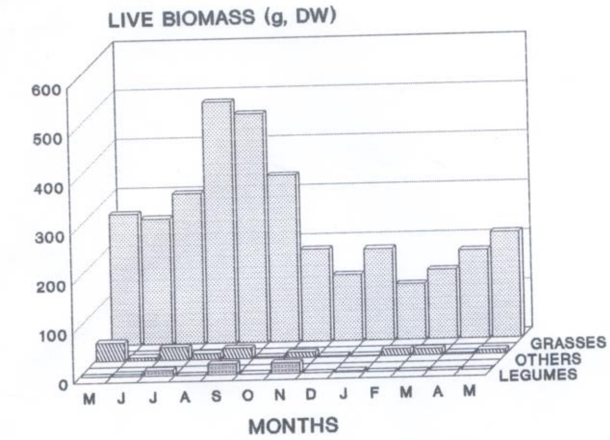


Fig. 5. Apportionment of aboveground live biomass into grasses, legumes and other species.

Fig. 4B. Dominance- diversity curves for moist-saline site of *C. setigerus* drawn on a semi-log plot of live biomass of the constituent species.

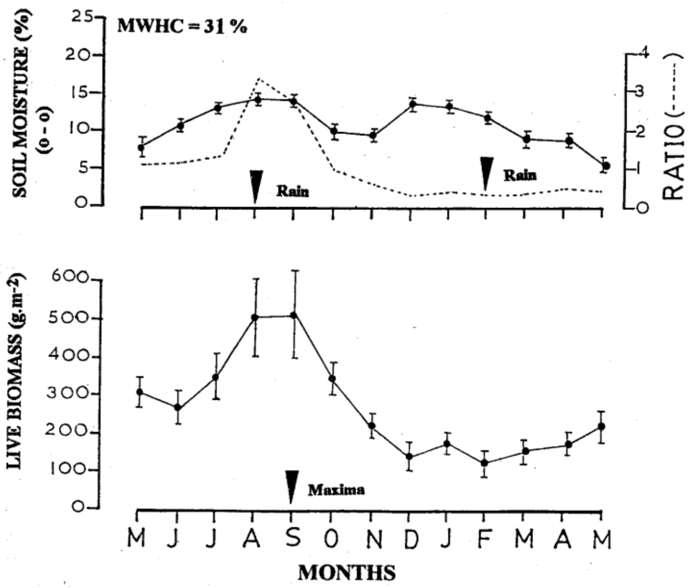


Fig. 6. Relationship between soil moisture content and live standing biomass of *C. setigerus* community in a moist-saline site. Dotted line represents live / dead biomass ratio.

No direct correlation of total density and rainfall P (in mm) was observed (r = 0.2730). However, a time lag phenomenon was indicated between these parameters as given below. Some leaching of salts must have occurred due to rains, although slowly under waterlogged conditions, prior to seed germination of such glycophytic species as *B. sindica, C. bulbosus, C. atkinsonii, I. cordifolia, S. pakistanica* and others could take place.

$$\text{Density.m}^{-2} = 27.162 + 0.8766\, P\,(-1) \pm 10.73$$
$$(t = 6.10)$$
$$r^2 = 0.7883,\ \text{Adj. } r^2 = 0.7671;\ F = 37.23,\ p < 0.001$$

Biomass dynamics

Aboveground Live biomass (LB)

The aboveground live biomass varied considerably through different months and among and within various species Initially. LB was 301.8 ± 70.1g.m^{-2} (in May) which after summer rains attained maxima in September (507.1 ± 90.9g.m^{-2}) (Fig. 3). There was no significant difference between August and September harvests. After September, LB declined regularly up to February (126.3 ± 28.04 g.m^{-2}). After winter rains, mostly in February (19.5mm) and little in January (3mm) and March (2mm), LB again increased substantially.

Species diversity and dominance

The vegetation of the site was simple in its organization as the species diversity was (s, d, e, H, Mc) remained low. The dominance was generally high (Table 2). Diversity based on density (H) increased after rains but declined in winter and post-winter and hot summer months. Biomass-based H exhibited an irregular pattern and varied around 24% round the year (mean = 0.5112). Dominance declined after summer rains and varied around 25% during the observation period. The number of live species harbouring the field was much higher in August and September (25and 20, respectively), which declined thereafter significantly to six to seven in April and May. The sharp exclusion of species in post-rain period appears to be associated with the rise in soil salinity (Fig.2) due to evaporative loss of moisture.

The curves drawn on the basis of IVI and biomass remained linear throughout the year (Fig. 4A and B), which indicated that 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 stressful situations and monopolization of the resource largely by a few species (Whittaker, 1975). The geometric distribution of biomass among species of this site appears to be due to monopolization of this site by *C. setigerus* and *D. scindicum.* Geometric distribution of biomass among species stressful situations such as grassland vegetation in sodic soils of Northern India (Sinha *et. al.,* 1988), among species constituents of communities dominated by different grasses in salt-affected habitats along the Pakistan coast (Khan *et. al.*, 1989), and among species of dry sandy habitat of Karachi (Khan *et. al.,* 2000) have been reported.

Climatic relations of diversity

None of the species diversity and dominance measures except the number of species, S, exhibited significant correlation any of the climatic factors. Around 30% variation in S was explained by precipitation, 67% by the temperature and solar radiation collectively and 72% variation by linear combination of temperature, precipitation and solar radiation as evident from the following equations.

$S = 9.653 + 0.145912\ P\ (mm) \pm 4.455$
$t = 2.465\ (p\ ,\ 0.031)$
$r^2 = 0.3558$, Adj. $r^2 = 0.2973$, $F = 6.08$ ………… (Eq. A)

$S = 20.722 + 1.51315\ T - 2.5186\ SR \pm 3.043$
$t = 4.89 \quad t = -4.92$
$p < 0.001 \quad P < 0.001$
$r^2 = 0.7268$, Adj. $r^2 = 0.6721$, $F = 13.30$ ……….. .(Eq. B)

$S = 17.569 + 1.3295\ T + 0.0713\ P - 2.1234\ SR \pm 2.42$
$t = 4.31 \quad t = 1.74 \quad t = -4.09$
$p < 0.001 \quad p < 0.116 \quad P < 0.001$
$r^2 = 0.7954$, Adj. $r^2 = 0.7273$, $F = 11.67$ …………(Eq. C)

Table 2. Seasonal variation in diversity, equitability, species richness and dominance in vegetation of moist-saline site.

Months	S	H	Mc	e’	d	d’	c	CDI
M	a 8	0.5561	0.4725	0.6157	0.5882	3.0878	0.3540	76.6950
	b 8	0.5620	0.3778	0.6223	0.4605	2.8229	0.3871	80.0030
J	13	0.6411	0.4304	0.5755	0.8062	4.9690	0.3224	62.2340
	11	0.5374	0.4085	0.5160	0.6763	4.1271	0.3498	80.1750
J	17	0.6918	0.4611	0.5622	0.9193	6.3141	0.2904	61.2170
	15	0.6124	0.3907	0.5207	0.8116	5.5270	0.3714	73.6230
A	25	0.8088	0.5316	0.5786	0.6604	7.6045	0.2193	41.5290
	22	0.4505	0.3020	0.3356	0.8931	7.7778	0.4882	87.7570
S	20	0.6800	0.4457	0.5181	0.6833	6.3077	0.3133	51.9450
	20	0.4590	0.2707	0.3528	0.8822	7.0242	0.5319	86.8460
O	14	0.5473	0.3623	0.4775	0.7062	5.0108	0.4073	58.0650
	12	0.3296	0.2235	0.3054	0.6493	4.3427	0.6030	95.0956
N	14	0.4556	0.3432	0.3978	0.6606	4.8780	0.4294	72.2640
	12	0.5983	0.4010	0.5461	0.8104	4.6988	0.3588	79.7370
D	11	0.4598	0.3092	0.4416	0.5323	3.8023	0.4742	74.9390
	9	0.2081	0.2484	0.2162	0.7658	3.7383	0.5649	93.6350
J	10	0.5080	0.3508	0.5080	0.5013	3.4618	0.4215	66.9050
	9	0.5517	0.3535	0.5781	0.6543	3.5134	0.4116	79.3040
F	8	0.3685	0.2533	0.4080	0.3854	2.6576	0.5576	74.9900
	6	0.5836	0.4446	0.7500	0.5339	2.3798	0.3099	74.2850
M	7	0.3984	0.2709	0.4714	0.3601	2.3283	0.5337	74.0400
	6	0.5830	0.4359	0.7492	0.4850	2.8830	0.3170	76.7030
A	6	0.4169	0.2379	0.5291	0.3107	1.9440	0.5196	73.1200
	5	0.5182	0.3954	0.7414	0.3703	1.7691	0.3636	79.9110
M	7	0.3534	0.2155	0.4181	0.3064	2.2075	0.6154	73.9300
	7	0.6606	0.4707	0.7817	1.4799	2.5565	0.2802	72.0881
Mean	a 12.31	0.5296	0.3635	0.5001	0.5708	4.1980	0.4199	66.4700
	b 10.92	0.5112	0.3637	0.5228	0.7287	4.0435	0.4108	81.4800

It is apparent that T and SR have been more important climatic variables than P in this moist site community (equation # C). Taken together the interactive model as given above, reduced beam radiation due to overcast sky and moderate temperature coupled with precipitation (which had al least leached down some salts from upper soil layer) could have allowed the seeds of some species to germinate after summer rains in this otherwise moist-saline habitat, thereby increasing the number of species entering the community composition. Nearly all such species, however, died and disappeared from the field in next few months, presumably due to rise in soil salinity (Fig. 2).

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

LB proportion of grasses was always high ranging from 85.5 to 99.2% of total LB (Fig. 5). The site was poor in legume flora and LB component for legumes remained negligible throughout the year except for the month of November when it amounted to 9.85% due to the growth of *Rhynchosia schimperii.* This may be due to general paucity of halophytic / salt tolerant legumes in our local flora (Khan *et. al*., 2002). No alive legume was recorded from the site from February to May. The LB proportion for species other than grasses and legumes fluctuated round the year with the species-compositional fluctuation at least partly be presumably governed by changing soil salinity.

Relationship between aboveground LB and soil moisture content and climatic variables

Being moist due to seepage, hydric resource of this site remained substantially elevated round the year and only little increase in soil moisture took place on rains (Fig. 6). The ratio of live /dead biomass was maximum in August (3.47). LB of site exhibited significant correlation with temperature (r = 0.5399), relative humidity (r = 0.5338), and rainfall (r = 0.5071) and insignificant correlation with solar radiation (-0.0839) and soil moisture (0.2920). The variation accounted for by each of the above variables was low (less than 23%). The linear combination of temperature and rainfall and temperature and soil moisture, however, accounted for 44.4 and 64.4% variation in LB, respectively as indicated by the following equations.

$$LB = -122.732 + 14.113\ T + 2.884\ P \pm 94.24$$
$$t = 2.46 \qquad t = 2.30$$
$$r^2 = 0.5370;\ adj.\ r^2 = 0.4444;\ F = 5.79$$

$$LB = -745 + 24.10\ T + 35.519\ SM \pm 75.44$$
$$t = 4.56 \qquad t = 3.73$$
$$r^2 = 0.7033,\ adj.\ r^2 = 0.6439,\ F = 11.85,\ p < 0.001$$

Growth patterns of species

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

log ratio = $\log_{10}$ *[D. Wt.*m^{-2} *at a later date / D. Wt.*m^{-2} *in the initial date].*

C. setigerus exhibited only one peak of growth during August to October and its performance declined thereafter progressively (Fig.8). *S. pakistanica* struggled to survive until January and then disappeared completely from the field. *C. pennisetiformis* and *D. scindicum* showed just one peak of positive growth only – in July & August, respectively. *L. scindicum* grew rapidly initially but from September onwards gradually lost the ground. On the contrary, *Launaea nudicaulis* appeared to be relatively more salt tolerant, which colonized the site rapidly and produced substantial amount of biomass.

August, September and October were the months of the hectic activity (Fig. 7). After rains, 11 new species entered the field in August and 7 in September. The major disappearance of species was also noted in September (12 spp.) and October (7spp.) when several species died while still in seedling stage. After October/ November, arrival of the new species was practically zero. Disappearance of the species, however, continued slowly with the result that number of species in the field in the final month of observation was of the same order as in the initial month. It was observed that with the increase of average soil salinity from ECe:7.20 $dS.m^{-1}$ to 19.3 $dS.m^{-1}$ in upper 10 cm profile of soil over a period of one year, the final month's vegetation was adversely affected in comparison to the initial month's vegetation. Several species (probably salt sensitive) disappeared from the field completely (e.g., *A, javanica, F. indica, S. pakistanica, S. pauciflorum, etc.*) and aboveground live biomass of several species declined substantially (e.g. 48.57% in case of *C. setigerus* and 34.58 % in case of *L. scindicum*). The overall live biomass of the site was reduced by a quantum of 26%. The total standing dead biomass increased 2.24-fold and litter declined by 23% i.e., much of the litter formed was rapidly decomposed. The final vegetation, as evaluated by Czekanowski's (1913) index of similarity on the basis of aboveground LB of the constituent species, was dissimilar to the initial vegetation by a quantum of 33.04%. However, some new potential salt tolerant species (*C. barbata, L. nudicaulis* and *O. compressa,*) appeared which constituted 17.84% of the standing live biomass.

Standing dead biomass, litter and Total above ground biomass:

The standing dead biomass varied greatly with different months and increased substantially in winter months (Fig. 3) when LB gradually entered the dead compartment. The amount of litter fluctuated considerably. It was maximum in October (193.2 ± 10.69 g.m^{-2}). The litter was lowest in April and May (99.2 ± 6.74 and 95.84 ± 9.07 g.m^{-2} , respectively). The total standing crop (live + dead + litter) was maximum in October (903.84 ± 40.29 g.m^{-2}) followed by in February (850.61 ± 69.92 g.m^{-2}) and minimum in June (632.07 ± 99.7 g.m^{-2}). These trends were more or less similar to that reported for dry *Lasiurus-Cenchrus* community of Karachi (Khan *et. al.*, 2000).

The dead biomass proportion in *C. setigerus* which was around 50% until September increased to around 75% in winter and post-winter period gradually due to increasing atmospheric temperature and increased soil salinity presumably (Fig. 9). *C. pennisetiformis* generally exhibited higher live biomass. *D. scindicum* behaved like *C. setigerus. L. scindicum* also represented higher dead biomass in winter. *S. pakistanica* disappeared from the field in January, F. indica disappeared in post-monsoon month of October and *C. atkinsonii* in September. *O. compressa* remained alive round the year with low amount of associated dead biomass in October and December. Its live biomass proportion generally fluctuated around 50% round the year except October and December when most part of it was alive (Fig.9). Our data indicates some degree of salt tolerance in *O. compressa, L. nudicaulis, D. scindicum* and *L. scindicum*, which need to be evaluated experimentally. *C. setigerus* is reported to be a salt tolerant species within a range of 8 – 16 dS.m^{-1} (CAZRI, 1987).

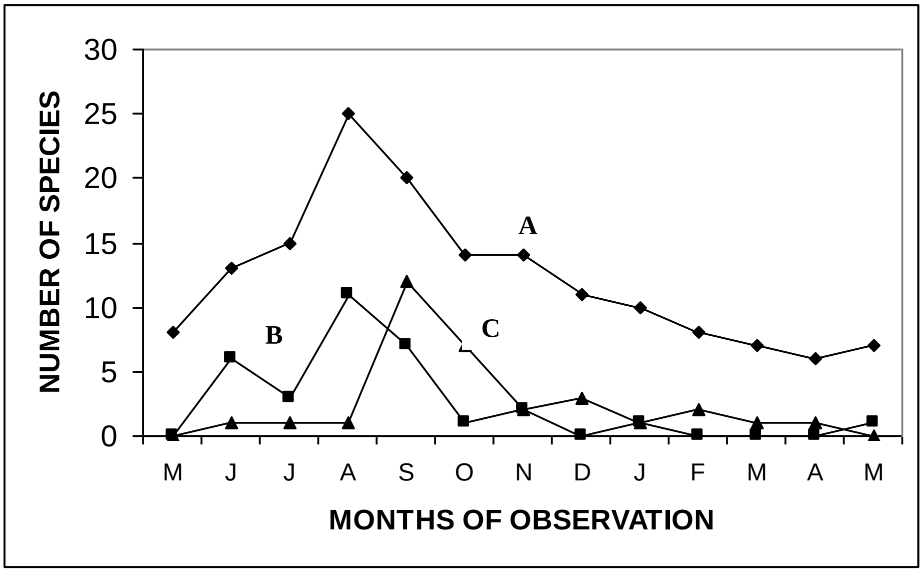
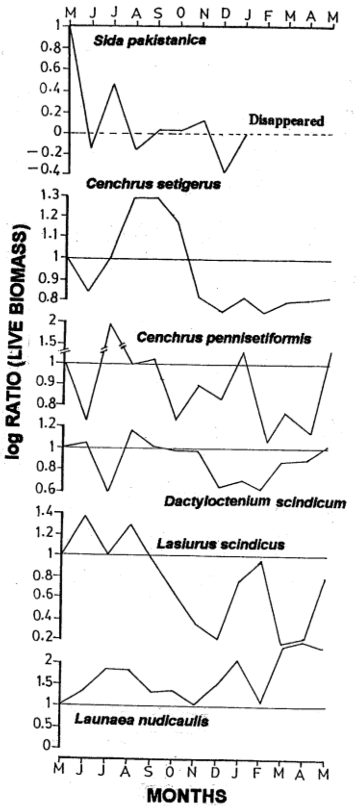


Fig. 7. Number of total live species present (A), number of new species appearing (B) and number of species disappearing from the field (C) in various calendar months of observation.

Belowground biomass:

The below ground biomass remained fluctuating round the year and was relatively higher for the rainy month of August (1038.56 ± 478.2g.m^{-2}) and February (1218.0 ± 333.8g.m^{-2}) (Fig. 3). The below- to aboveground biomass ratio varied considerably (0.65 to 1.61; CV: 28.6%) and averaged to 1.167 ± 0.093. Most of the grasses in



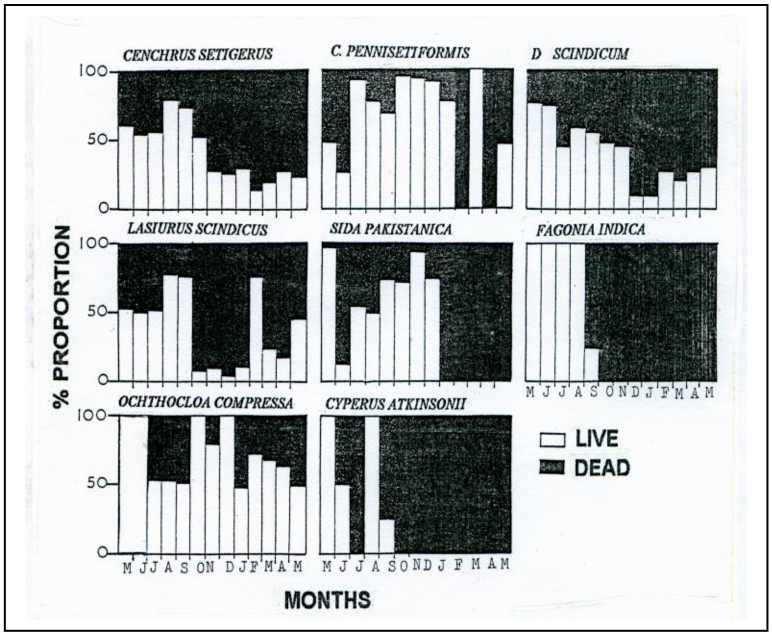


Fig. 9. Percent Proportion of live and dead biomass of some species occurring in moist-saline site of *C. setigerus*.

Fig. 8. Changes in live standing biomass of some species occurring in moist-saline site dominated by C. setigerus.

arid region are bunch forming in habit which are known to have high 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 facts that this community is composed of arid flora and has been subject to grazing in the past.

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 585.4, 415.7, 748.9 and 665.5 g.m^{-2} .year $^{-1}$ (mean = 603.88 ± 71.10 g.m^{-2} .year $^{-1}$; CV=23.5%), . Therefore, production rate, on annual basis, varied from 1.14 to 2.05g.m^{-2} .day^{-1} (mean = 1.65 ± 0.195g.m^{-2}.day^{-1}) which is substantially larger than that of a similar community abounding a dry habitat (*L. scindicus* and *C. seigerus* community with mean production rate of 1.00 to 1.61g.m^{-2}.day^{-1} (mean = 1.23 g.m^{-2}.day^{-1}) (Khan *et. al.*, 2000). The variation around 23.5% in ANP estimates based on various methods appears to be 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 estimate for a dry site dominated by *Lasiurus scindicus* and *Cenchrus setigerus* and 36.5% in *Dichanthium annulatum* dominated coastal community have been reported by Khan *et. al.* (2000, 2005) when evaluated by these methods. However, for further discussion in present study, estimate obtained by method (iv) has been used because this method suits well for further partitioning of production in seasons (Singh and Yadava (1974).

Our estimate of ANP (mean = 603.88 ± 71.10 $g.m^{-2}.year^{-1}$) for this site is comparably higher than the estimates reported for other arid lands grass communities. ANP for a similar local community dominated by *L. scindicus* and *C. setigerus* abounding to a dry habitat is reported to be 448 $g.m^{-2}.year^{-1}$ (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 ± 8.9 $g.m^{-2}$. The productivity of deserts and semi-deserts is reported to vary between 10 to 250 $g.m^{-2}.year^{-1}$ (Whittaker and Likens, 1975). ANP for nine grass community types of American desert (Sims and Singh, 1971) varied from 107 $g.m^{-2}$ for ungrazed shortgrass prairie at Pentex, Texas to 512 $g.m^{-2}$ for the grazed tallgrass at Osage, Oklahoma. Our estimate for moist site is higher than that of an unburned prairie (462 $g.m^{-2}.year^{-1}$) of Texas, USA, composed of several grasses and (Harcombe *et. al.,* 1993) but lower as compared to the production of *Sporobolus virginicus* salt marsh in Australia amounting as large as 852 $g.m^{-2}.year^{-1}$ (Clark and Jacoby, 1994). 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 10-200 $g.m^{-2}$ in south and North facing slopes, hill tops and Wadi shoulders but considerably high (up to 700 $g.m^{-2}$) in Wadi with improved hydric resource and abounding species of relatively larger size. Our estimate of ANP is comparable to the production of *Brachiaria mutica* in mixed tree stand (665$g.m^{-2}.yr^{-1}$) in Northern India. In open field the productivity was, however, low (590$g.m^{-2}.yr^{-1}$) (Saxena *et. al.,* 1996). Relatively higher ANP of the site in hand is perhaps attributable to higher moisture availability and some degree of salt tolerance in some species of the site. Deleterious effects of rising salinity were, of course, apparently visible on the performance of several species.

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 1137.12 $g.m^{-2}$ $year^{-1}$. The TNP of the site was estimated to be 1802.0.m^{-2}, which was considerably larger than that of similar local grass community under dry condition (TNP = 1210 $g.m^{-2}.year^{-1}$; Khan *et al*, 2000). TNP of *D. annulatum* community from India, as cited by Murphy (1975), varied from 650-1420 $g.m^{-2}$ under 725 mm rains, which is comparably low 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, however, of very few species only. The high productivity of community in hand may presumably be due to elevated moisture availability and larger number of species harboring the community. The productivity of a community is known to be a function of number of factors such as magnitude and 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. (cf. Murphy, 1975; Steen, 1980; Ludwig, 1986; Milkunas and Lauranroth, 1993; Khan *et al* 2000; Halin *et. al.,* 2002; Osem *et. al.,* 2003, Khan *et. al*., 2000, 2005, 2006).

ANP, BNP and TNP as well as their production rates were higher in summer growing season than winter (Table 3). 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; Presumably it may be due to high temperature and rapid microbial activity in summer. The overall turn over was 93.4% (Table 4). The turn over values ranging from 19 to 68% have been reported in nine grass community types by Sims and Singh (1971). Turn-over as high as 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. 10). 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 5). It may be observed that an amount of 165.99 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= (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 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 should ultimately transfer the 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). A couple of rabbits were once seen in the area. Some other random events like removal of biomass by nest-forming birds and during gales, etc. could also be important in this respect (Struik, 1965, Singh and Yadava, 1974; Khan *et. al* ., 2000).

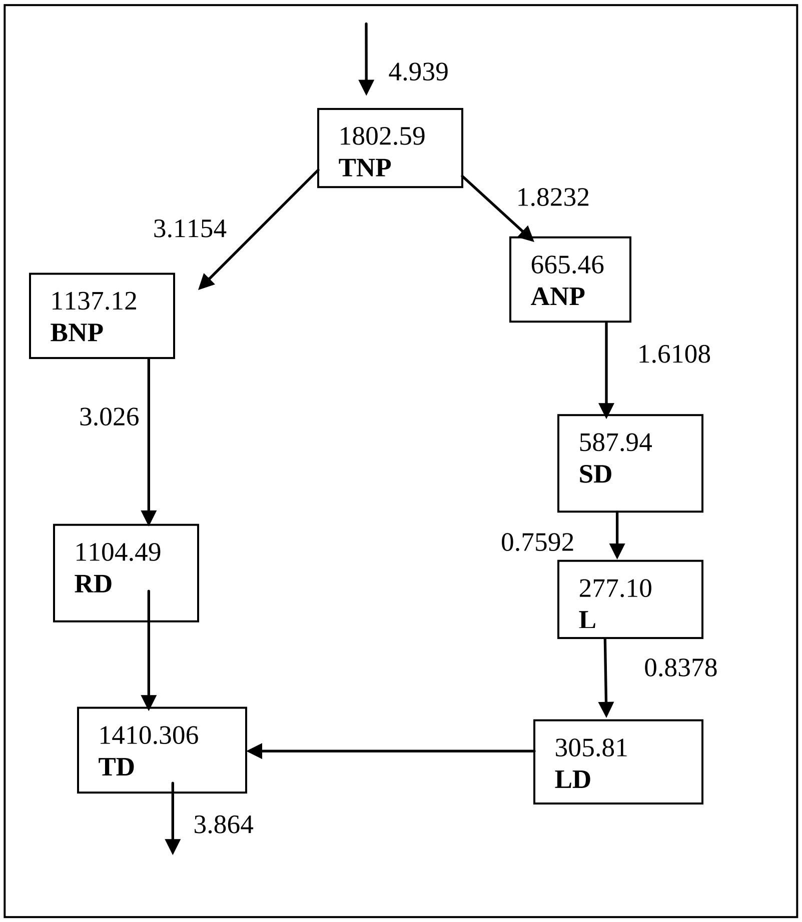


Figure 10. Net primary production, accumulation and disappearance rate during the whole year period in a moist-saline site. Compartment : g.m^{-2} . Accumulation and disappearance rates: g.m^{-2}·day^{-1}. Belowground accumulation and disappearance rates = g.day^{-1}·0.33m^{-3}

The greater estimates for SD, L and LD calculated in accordance with the above-given assumptions amounted to 653.01, 437.87 and 466.51 g.m^{-2}, respectively.

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. 10) 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 63.08% of TNP was directed towards belowground productivity (Table 4). On greater estimate basis 98.3% of the ANP was transferred to SD compartment. On normal estimate basis this transfer function was 88.35%. It was obvious from the field observation that great amount of biomass underwent death and decomposition. Nearly 78% (87.2% on greater estimate basis) of TNP is lost through death and decomposition. LD/L ratio of 1.104 indicated greater decomposition activity in this site due to higher moisture regime (Table 6). LD/L ratio greater than 1 was indicative of the fact that in addition to the total amount of litter produced during current year, some litter carried over from previous year growth has also undergone decomposition during the observation period. TNP to TD transfer was as high as 78 to 87%. Higher rates of decomposition as observed here are also reported by White *et. al. (1978*) 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. The decomposition, however, varied with species. Most of the species disappearing from the field (*S. pakistanica, F. indica, C. atkinsonii, T. subtriflora, T. strigosa, A. javanica, C. tridens, R. minima, B. sindica*) were decomposed rapidly except *B. sindica* which appeared to be quite resistant to decomposition as the hardy stems and the tap roots of this species left over from the summer growth of preceding year were found standing relatively intact even after 20 months of exposure to moist conditions. The decomposition rate as observed here (1.278g.litter.m^{-2}.day^{-1}) may further be expected to increase because the lower parts of the grasses (*C. setigerus* and *D. scindicum*) in contact with moist soil underwent decomposition while still attached to the plant.

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 employed, which have appeared in our earlier publications (Khan *et. al.*, 2000, 2005, 2006)

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, 3413.12 ± 111.11 cal.g^{-1} (CV: 13.42%), 3020.09 ± 105.68 cal.g^{-1} (CV: 9.9%), 2603.51 ± 48.38 cal.g^{-1} (CV: 6.4%), and 3299.90 ± 182.29 cal.g^{-1} (CV:19.13%), respectively.

Table 3. Seasonal apportionment of above-, belowground and total production and production rates.

Seasons *	Net Production (g.m^{-2})	Production rate (g.m^{-2}.day^{-1})	Rainfall (mm)
Aboveground Production			
Summer	433.84	2.358	86.8
Winter	231.62	1.280	26.3
Annual	665.46	1.823	113.1
Belowground Production			
Summer	618.96	3.364	86.8
Winter	518.16	2.863	26.3
Annual	1137.12	3.115	113.1
Total Production			
Summer	1052.80	5.722	86.8
Winter	749.790	4.143	26.3
Annual	1802.59	4.939	113.1

*, after Minchen (1907)

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 photo-synthetically efficient radiation (0.4 - 0.7 µm), 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 was considered 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).

Table 4. Maximum belowground biomass and turn over in different seasons.

Seasons *	Maximum Belowground biomass (g.m^{-2})	BNP (g.m^{-2}.year^{-1})	Turn Over
Summer	1038.56.	618.96	0.5940
Winter	1218.00	518.16	0.4254
Annual	1218.18	1137.12	0.9336

*, after Minchen (1907).

Table 5. An annual balance sheet of dry matter for moist-saline site.

Compartments	Biomass (g.m^{-2})	Compartments	Biomass (g.m^{-2})
ANP		**SD**	
Initial Biomass	310.840	Initial biomass	254.320
ANP	665.466	SD Production	587.940
Input into the system	976.306	Input into the system	842.260
Transfer to SD	587.940	Transfer to litter	277.170
Biomass at the end	222.370	SD at the end	570.390
Output	810.310	Output	847.560
Unaccounted for	165.996	Unaccounted for	5.300
BNP		**Litter**	
Initial biomass	480.000	Initial biomass	124.480
BNP	1137.12	Litter Production	277.170
Input into the system	1617.120	Input into the system	401.650
Disappearance of biomass	1104.496	Litter disappearance	305.810
Biomass at the end	512.524	Litter at the end	95.840
Output	1617.120	Output	401.650
Unaccounted for	Nil	Unaccounted for	Nil

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 0.2705, 0.4467 and 0.7171%, respectively. EEC values for ANP, BNP, and TNP for a similar community dominated by *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) and in a semi-moist but non-saline site with more or less similar community composition EEC for these parameters was found to be 0.325, 0.354 and 0.679, respectively (Khan *et. al*., 2006). 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 being 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 legume under cultivation (*Phaseolus acontifolius*) from Peshawar to be 0.26 and 0.56 % on the basis of total solar incident and photosynthetically available radiation, respectively, for one growing season. However, grasses, particularly C_4, are considered far more efficient CO_2 utilizers than legumes (C_3 Plants) and better adapted to high insolation and temperature (Mott and Popenoe, 1977).

Table 6. System transfer functions.

Components	Tfr (annual)	Tfr (annual) *
TNP to ANP	0.3692	
TNP to BNP	0.6308	
ANP to SD	0.8835	0.9826
SD to L	0.4713	0.6705
ANP to LD	0.4595	0.7010
L to LD	1.1035	1.0654
BNP to RD	0.9713	
TNP to TD	0.7824	0.8715

*, Based on greater estimates of SD, L, LD, and TD. TNP, Total net primary production ; ANP, aboveground net production; BNP, belowground net production; SD, standing dead; L, litter; LD, litter disappearance; RD, belowground biomass disappearance; TD, Total disappearance.

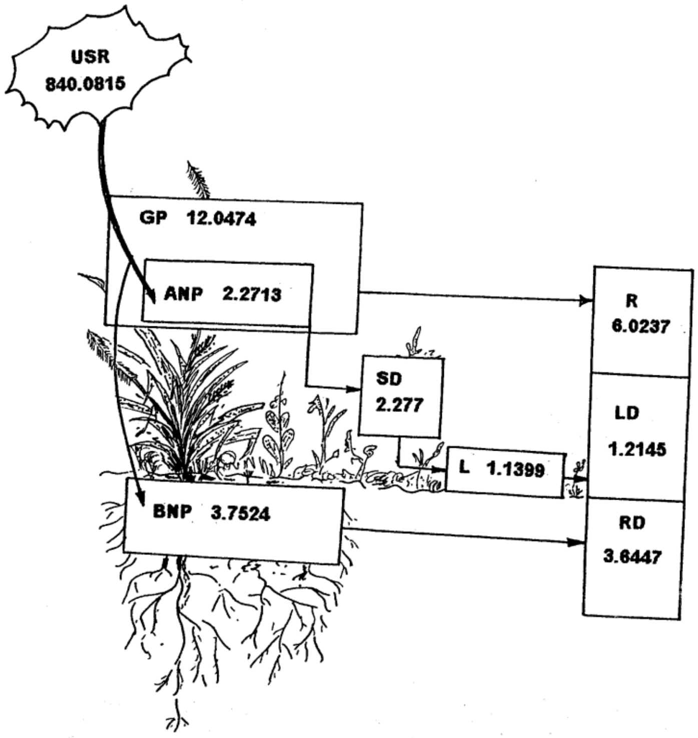


Fig. 11. Annual energy flow through primary producer compartments in a moist-saline site dominated by *C. setigerus*.

Annual Energy Flow (AEF):

An estimate of AEF through the primary producer compartments is depicted in Figure 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 62.29% of the energy fixed in TNP moved towards belowground production and 37.71% stayed aboveground. The energy that dissipated through root and litter disappearance constituted 80.67%. Nearly 19.3% 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 19% of total energy fixed in this community indicates its tendency to move towards a low forest type (cf. Golley, 1972). In arid regions this process is obviously be very slow. Energetics in grass-dominated systems in a network of localities representative to different agro-ecological zones of Pakistan needs to be investigated to develop better eco-developmental strategies for our rangelands

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