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CERTAIN STRUCTURAL AND FUNCTIONAL ASPECTS OF DRY TROPICAL FOREST AND SAVANNA

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ABSTRACT

Besides deseribing the climo-vegetational features and degradation trends in tropical forests in India, attention is focussed on the significance of dry tropical forests and various savanna types derived from them, and maintained, due to anthropogenic pressure. A comparative account of the available information on biomass, net produetion and nutrient (N and P) cycling in three forests (natural *Shorea* in terai, and natural *Anogeissus* and plantation *Tectona* in dry deciduous regions) is given. While the plant biomass among these forests differs considerably (ca. 1:20), the differences in net production are relatively smaller (ca. 1:4). The vegetation, litter and soil nutrient pools are greatest in the *Shorea* forest, as also the aboveground nutrient recycle through litterfall; however, the nutrient return belowground through root mortality is greater in the relatively dry *Anogeissus* forest. Herbs account for bulk of the production and nutrient cycling in savanna; and the savanna in different climatic regions show functional differences.

INTRODUCTION

Tropical forests represent greatest store house of biological diversity in the world. For instance, Indonesian lowland rain-forests contain 3000 tree species, the Malaya Peninsula supports 2500 species, and all seed plants in New Guinea and Malaysian rain-forests are estimated to be more than 20,000 species (Curry-Lindhal 1972). Nearly one half (2-5 million species) of the World's plant and animal species are found in these regions. Tropical forests yield many of the prescription drugs of biological origin. For example, rosy Periwinkle, a tropical forest plant yields two drugs which have increased the chances of recovery from leukemia. A great majority of tropical species are yet to be screened for medicinal purposes. Many tropical forest species are of immense significance to industries providing tannins, resins, gums, oils, dyes etc. In context of the energy shortage the hydrocarbon yielding capacity of tropical species is important. For instance, *Capaifera longsdorfii*, a tree of Amazon basin, yields sap that can be used directly in diesel engines. In dry tropics in India following species are promising hydrocarbon producers : *Euphorbia lathyris, E. terucalli, E. antisyphilitica, Jatropha carcas, Calotropis procera* and *Simmondsia chinensis*, to name a few. From tropical forest regions important new crop plants have also been discovered; for instance, the perennial corn (*Zea diploperennis*) from southern Mexico and winged bean (*Psophocarpus tetragonolobus*) from south-east Asia.

By their capacity to retain water and slowly release it, the tropical forests perform important function of regulating high quality water supply for human use. Also the maintenance of the forest cover reduces the chances of floods and droughts. In high rainfall areas these forests stabilise soil and prevent erosion. They also contribute to the maintenance of the climatic stability. However, due to heavy biotic pressure large tracts of tropical forests have been converted into savanna and open grasslands which support a sizeable cattle population.

In the present report we have confined mostly to the tropical moist and dry deciduous forests and derived savannas which have the largest extent of distribution in India amongst all forest types.

DISTRIBUTION OF TROPICAL FORESTS

About 30% of the earth's surface lies within the geographic tropics, and about 42% of the latter supports a forest cover. Table 1 presents estimates of the extent of tropical forests for the early 70s. On global basis, 52% of the total forests (2800 million ha) are tropical, but in India tropical forests account for ca. 86% of the total. About 560 million ha land in high rainfall regions of the world supports high stature wet evergreen forests where the species diversity, growth rates and nutrient cycling reach maximum levels (Lugo 1973). With decrease in rainfall the proportion of deciduous species increases; and the dense moist deciduous forests found in medium rainfall area grade into lower statured, open-growth, dry deciduous forests with decrease in rainfall. With further decrease in rainfall microphyllous thorn forests take over. The deciduous forests are distributed over 896 million ha in the tropics, of which the bulk (588 million ha) is of dry type. In India, of the total 64.6 million ha tropical forest area, only 6.3 million ha supports wet evergreen and semi-evergreen types, and the remaining area supports deciduous types, 23.9 million ha moist and 34.4 million ha dry.

Table 1. Distribution of Forest Area (million ha) Under Major Forest Formations (Data Source: World—Persson 1974; India—Kaul and Sharma 1971)

Formation	World		India	
	Area	% total	Area	% total
Tropical				
Wet evergreen	560	20	6.3*	8.4
Moist deciduous	308	11	23.9	31.8
Dry deciduous	588	21	34.4**	45.8
Total	1456	52	64.6	86.0
Sub-tropical	234	8	4.2	5.6
Temperate	448	16	4.5	6.0
Boreal/alpine	672	24	1.8	2.4
Grand total	2800	100	75.1	100

*includes semi-evergreen, 1.8 million ha.
**includes thorn forest, 5.2 million ha.

Tracts of wet evergreen forests are found in Kalimantan in Indonesia, Pacific coast of Colombia, the Carribean coast of Costa Rica, Thailand-Burmese border, eastern slopes of the Andes in Ecuador and Peru, and in Western Ghats and parts of Assam in India. Fewer human settlements have developed in these regions due to nutrient-poor, heavily leached soils which are prone to rapid deterioration upon cultivation; therefore, mostly hunting, firewood and fruit gathering and shifting cultivation have been practised in these areas. Examples of moist deciduous forests are Camposo Cerrados in Brazil, much of forests in Amazon and Congo, monsoon forests in Asia, and *terai* forest in India. These forest regions have been preferred as human settlement sites because they contain valuable timber species like teak, and have sustained permanent agriculture and forest plantations for a long time. In dry tropics, where plant growth is severely limited due to prolonged drought through the year, dry deciduous forests develop, and these grade into thorn forests with increasing aridity. Fire and drought are major ecological factors in dry tropics. Miambo woodland in Africa, caatinga in Brazil, central Peruvian Andes forests, Vindhyan and Rajasthan forests in India are examples of dry deciduous or thorn forests. Permanent human settlements are found near water supply sources, and nomadic culture has been commonly practised.

TROPICAL DRY FORESTS

According to the life zone classification of Holdridge (1967), dry tropical and sub-tropical forests and woodlands occur in frost-free areas having mean annual temperature higher than 17°C, mean annual rainfall between 250-2000 mm, and ratio of potential evapotranspiration (PET) to precipitation (P) greater than one. In the absence of accurate estimates of PET/P ratio, Brown and Lugo (1982) suggest the use of ratio of mean annual temperature (T) to mean annual precipitation. Among 18 tropical dry forest sites with markedly different rainfall, the T/P ratio varied between 4.1×10^{-2} °C/mm at the driest site (600 mm rainfall, Udaipur, India) to 1.4×10^{-2} °C/mm at the site with most favourable moisture conditions (1800 mm, La Pacifica, Costa Rica) (Murphy and Lugo 1986). Within such a range of climatic conditions a variety of forests and woodlands occur which are generally transitional between semi-desert or savanna and moist forest. Taking into account these sites, and a few others, Murphy and Lugo (1986) have demarcated the structural and functional characteristics of tropical dry forest relative to tropical wet forests. Table 2 presents some of these characteristics. The dry forests are smaller in stature, lesser in complexity and productivity show annual growth pulses, and have greater resilience.

CLIMATIC CONDITIONS AND FOREST STRUCTURE IN INDIA

Most regions of the country support, or can support, some kind of a forest. The warmer plains and the lower altitudes in the hills are predominantly under one or the other type of tropical forest. The most comprehensive forest type classification in India—first proposed by Champion (1936) and later revised by Champion and

Seth (1968)—recognises seven main tropical types; namely, wet evergreen, semi-evergreen, moist deciduous, dry deciduous, thorn, littoral and swamp, and dry evergreen forests. Of these, the first five have significant distribution and their general characteristics are given in Table 3. The mean annual temperature ranges between 20°-30°C and the mean temperature of January (generally the coldest month) mostly exceeds 15°C. Commonly, the range for mean temperatures broadens in forests of drier regions. Through the spectrum of wet evergreen to thorn forests, the annual rainfall decreases from 2400 to as low 250 mm, and the number of dry months from 3-5 to 7-10. Thus water scarcity prevails to varying degrees in all tropical forests of India; and the various types of forests are mainly determined by the annual rainfall and the seasonality of rainfall distribution.

The wet evergreen forests, discontinuously distributed in south-western and north-eastern region of the country, having 4-6 ligneous layers with emergent trees generally extending 40 m height, are composed almost entirely of evergreen species (Table 3). The species diversity and plant biomass are extremely high. In the Silent valley, for instance, Singh *et al.* (1984) recorded 56 to 84 tree species per 0.4 ha. In

Table 2. Certain Structural and Functional Characteristics of Tropical and Sub-tropical Dry Forests[a] Relative to Tropical and Sub-tropical Wet and Rain Forest[b] (Data Source: Murphy and Lugo 1986)

Trait	Forest type	
	Dry	Wet
Structural		
Number of species	35-90	50-200
Complexity index[c]	5-45	180-405
Canopy height (m)	10-44	20-84
Leaf area index	3-7	5-8
Basal area of trees (m^2 ha^{-1})	17-40	20-75
Plant biomass (t ha^{-1})	78-320	269-1185
Functional		
Net primary productivity (t ha^{-1} yr^{-1})	8-21	13-28
Fine litter production (t ha^{-1} yr^{-1})	3-10	5-14
Tree diameter growth (mm yr^{-1})	1-2	2-5 or more
Growth periodicity	1-2 pulses annually	continuous or intermittent
Successional		
Resistance to disturbance	Low	high
Resilience		
As % original height, 1 yr	9-14	7-10
Taxonomic recovery rate	high	low
Soil seed pool longevity	short to long	relatively short

[a]Annually rainfall 500-2000 mm; strongly seasonal; annually PET/P normally >1.
[b]Annually rainfall >2000 m; little or moderate seasonaly; annually PET/P normally <1.
[c]Calculated as the product of number of species, basal area (m^2/0.1 ha) maximum tree height (m), and number of stems/0.1 ha, times 10^{-3} in a 0.1 ha plot.

Table 3. Certain Climo-Vegetational Features of Tropical Forests in India (Data Source : Champion and Seth 1968; Singh and Misra 1979; Singh and Singh 1984; Singh *et al.* 1984)

	Wet evergreen	Semi-evergreen	Moist deciduous	Dry deciduous	Thorn forest
Climate					
Mean annual temp (°C)	23-27	23-27	20-29	20-29	24-29
Mean January temp. (°C)	15-21	17-25	12-26	16-25	13-26
Annual rainfall (mm)	2400	1800-3000	1200-3000	750-1400	250-900
No. dry months	3-5	4-6	4-8	5-8	7-10
Vegetation Evergreenness	Entirely or nearly so	Dominants include some deciduous elements but evergreens predominate	Dominants predominantly deciduous; subcanopy evergreen	Entirely deciduous or nearly so	Entirely deciduous
Species richness	Extremely rich	Rich	Rich	Poor	Extremely poor
Canopy height (m)	40	25	25	8-20	10
No. ligneous layers	4-6	?	3	2	1
Basal area (m^2 ha^{-1})	40-55	?	35-50	15-20	5
Phytomass (t ha^{-1})	400-600	?	300-350	50-200	10
Net production (t ha^{-1} yr^{-1})	?	?	15-20	10-15	1-4
Shannon-Wiener Index	3.5-4.1	?	?	0.5-1.5	?

these forests in Karnataka, Rai (1981) recorded tree biomass ranging between 400-600 t ha^{-1}, which is probably an underestimate as biomass levels of 1000 t ha^{-1} have been commonly reported in other parts of the world (Lieth and Whittaker 1975). The transition zone between evergreen and moist deciduous forests is occupied by the semi-evergreen forests (synonym : semi-deciduous) whose canopy dominants include many deciduous trees. These ecotonal forests are species—rich, but information is lacking on their functional characteristics.

In the moist regions, the deciduous forests attain high dimensions and contain good number of evergreen species in the sub-canopy. These species-rich, 3-4 storey forests, generally contain 300 t ha^{-1} plant biomass and elaborate 15-20 t ha^{-1} yr^{-1} net production (Singh and Singh 1984). In old growth forests the biomass may reach upto 700 t ha^{-1}. Several important species of moist deciduous forests (e.g., *Shorea robusta, Tectona grandis*) extend into dry deciduous zone with much reduced stature. Species-poor forests in dry regions are low statured and almost entirely deciduous. The plant biomass decreases from 50-200 t ha^{-1} in dry deciduous forests to 10 t ha^{-1} in thorn forests. While the net production in thorn forests is very low, in dry deciduous forests it is considerable (10-15 t ha^{-1} yr^{-1}) relative to plant biomass (Singh and Misra 1979).

FOREST DEGRADATION

In the developing countries of the tropics and sub-tropics, land use surveys for the period 1970 to 1980 (FAO, 1981a, b) indicated an increase of land area under arable land, permanent crops and pastures by 17%, and a decreases of 4.2% in the area under forests and woodlands (loss of 9.2 million ha per annum). The Department of Space has mapped the forest cover of India using LANDSAT data of 1972-75 and 1980-82 (Table 4); the total forest (55.5 million ha) in India (geographical area=328.779 million ha) was 16.89% in 1972-75. Of the total forest, 14.12% was closed forest, 2.67% open forest area and 0.099% mangrove forest. During 1980-82 the forest area decreased to 46.33 million ha, being composed of 10.96% closed forest, 3.06% open forest and 0.081% mangrove forest. Thus, in about eight years. India lost 10.79 million ha closed forest and 0.06 million ha mangrove forest. On the other hand, the open forest area increased by 1.29 million ha due to degradation of the closed forest. In this period, the total cover was reduced by 16.52%, and as the fraction of the geographic area the forest cover was reduced by 2.79%. On average, the states having predominantly tropical forest lost a quarter of their closed forests in about eight years. In most states the forest cover loss ranged between 20-30%. Especially significant was the loss in arid region; for instance, Rajasthan lost 61% of its closed forests.

The estimates of the total forest cover by traditional land records (64.4 million ha, Table 1) and by aerial survey (55.5 million ha, Table 4) differ significantly by aerial survey (55.5 million ha, Table 4) differ significantly by about 9 million ha. This discrepancy could be as much due to the forest destruction during the time gap between the two surveys as due to the relative accuracies of the two survey methods. In land records, generally, the forest area refers to the land under the legal control of the State Forest Departments rather than the actual forest cover.

Table 4. Forest Area (Million ha) Changes in India (Data Source: NRSA 1983)

Category	1972-75		1980-82		
	Area	% geographic	Area	% geographic	% change
Closed forest	46.42	14.12	36.02	10.96	—22.40
Open forest	8.76	2.67	10.04	3.06	+14.72
Mangrove forest	0.32	0.099	0.26	0.081	—18.75
Total	55.5	16.89	46.33	14.10	—16.52

Total geographical area=328.779 million ha.

Table 5. Plant Biomass and Net Production in Moist and Dry Deciduous Forests in India (Data Source: *Shorea robusta*, Singh and Singh 1984; *Anogeissus latifolia* and *Tectona grandis*, Singh and Misra 1979)

	Moist deciduous		Dry deciduous	
	Shorea old growth	*Shorea* seedling coppice	*Anogeissus**	*Tectona*** Plantation
Biomass (t ha^{-1})				
Trees	323	286	97	17.5
Shrubs	5.1	4	2.2	0
Herbs	1.9	1.5	1	2.1
Total	330	291	100	19
Net production (t ha^{-1} yr^{-1})				
Trees	15.4	18.8	12.5	4.3
Shrubs	1.2	0.9	0.5	0
Herbs	2.3	1.4	1.0	6.2
Total	18.9	21.1	14 0	10.5

*Mixed deciduous forest; associate trees pecies: *Diospyros melanoxylon, Buchanania lazan, Flacourtia indica, Emblica officinalis, Pterocarpus marsupium, Milieusa tomentosa, Eriolaena hookeriana, Lagerstroemia parviflora, Acacia catechu* etc.

**19 year old plantation of *Tectona grandis* raised after clear felling the mixed deciduous forest.

FUNCTIONING OF INDIAN TROPICAL DECIDUOUS FORESTS

Quantitative analysis of forest function in India was first undertaken in the tropical deciduous forest zone (e.g., Singh 1968, 1969a, b). Table 5 shows the distribution of plant biomass and net production in the three main components of deciduous forests in moist and dry regions. The total biomass in *Shorea robusta* dominated moist forest (ca. 300 t ha^{-1}) is over three times greater than the biomass in *Anogeissus latifolia* dominated dry forest. In both forests the shrubs and herbs account for 3% of total biomass. A 19-year old *Tectona grandis* plantation in the dry deciduous zone, however, shows much less biomass, larger fraction of which (ca. 12%) is formed by the herbs. The total net production in all forests and the plantations varies within narrower range (10-20 t ha^{-1} yr^{-1}) compared to their biomass. The contribution of shrubs and herbs is significant, generally 10-20% of total net production, and increasing up to 60% in open, young plantations.

Nutrient Cycling

Very few comprehensive nutrient cycling studies are available for the dry tropical forests (e.g., Singh and Pandey 1981). As examples, the N and P budgets for trees in both deciduous forest zones are summarised in Table 6. As a whole, on ha basis the *Shorea* forest contains 7336 kg N and 401 kg P, compared to 3662 kg N and 175 kg P in *Anogeissus* forest. The total quantity of nutrients in all component pools decreases considerably from moist to dry forests. The amount of N, for instance, stored in moist forest exceeds that of dry forest by over four times in the tree crop, by over three times in the litter, and by about one and a half times in the soil.

The forest vegetation growth results in the accumulation of nutrients absorbed from the soil, and part of the accumulated nutrients are recycled through litterfall, canopy wash and root mortality. The range of accumulation in annual growth is 56-140 kg N and 4-13 kg P (Table 6). The dry deciduous forests appear to accumulate and recycle greater fractions of nutrients through the activity of the belowground parts. In general, about one-half of the nutrients accumulated annually are recycled and the balance retained in relatively permanent parts of the vegetation. Fine roots of woody species significantly affect the storage and transfers of organic matter and nutrients in the forest soil. Singh and Singh (1981) showed seasonal dynamism in fine roots (<10 mm diameter) in tropical dry deciduous forests. In these forests the bulk of fine roots found to be confined to 10-30 cm depth in soil. Recently, Singh, Srivastava and Singh (1984) have estimated 5000-7000 kg ha^{-1} yr^{-1} net production in fine roots in young *Tectona grandis* plantations in the same region, which is significantly high when compared with the allometric net production estimates. Evidently, fine roots in dry region add huge amounts of organic matter and nutrients to the soil annually; this addition is significant compared to the litterfall contribution. Information on fine roots is, however, lacking from moist forests.

SAVANNA

Having originated from such diverse woodlands as wet evergreen forests on the one hand and desert thorn scrub on the other, savanna is found in extremely varied climates. Equally wide is the range of physiographic and edaphic conditions. The four major tropical and subtropical types found in India are; *Dichanthium-Cenchrus-Lasiurus*, *Sehima-Dichanthium*, *Phragmites-Saccharum-Imperata*, and *Themeda-Arundinella* (Dabadghao and Shankarnaryan, 1973); these represent respectively, semiarid, the dry subhumid, the moist subhumid, and moist subhumid to humid montane zones. However, a large number of seral and semi-stable communities occur within the potential area of each of the above major types.

The ligneous components in these savannas are highly variable and represent the residuals from native forests. In semi-arid to subhumid savannas the small trees such as *Prosopis cineraria*, *Ziziphus nummularia*, *Balanites aegyptiaca*, *Capparis decidua*, *Acacia catechu*, *A. leucophloea*, *Butea monosperma* and *Mimosa rubicaulis* may account for up to 30% ground cover.

Biomass and Productivity

Data from a large number of sites in the Indian subcontinent indicate that

Table 6. Nitrogen and Phosphorus Budgets for Tree Layer in Moist and Dry Deciduous Forest Zones (Data Source: Moist Deciduous—Singh and Singh 1984; Dry Deciduous—Singh and Misra 1979)

	Moist deciduous		Dry deciduous			
	(*Shorea robusta*)		*Anogeissus latifolia*		*Tectona grandis* plantation	
	N	P	N	P	N	P
1. Components pools (kg ha^{-1})						
Vegetation						
Above ground	2333	217	510	41	177	9
Below ground	489	36	146	12	21	2
Total	2822	253	656	53	138	11
Litter	133	8	36	3	13	1.7
Soil (30 cm)	4401	140	2970	119	2426	144
Total	7336	401	3662	175	2577	156
2. Accumulation in net production (kg ha^{-1} yr^{-1})						
Aboveground	140	12	100	7	56	3.7
Belowground	16	1	26	2	3	0.3
Total	156	13	125	9	59	4
3. Return (kg ha^{-1} yr^{-1})						
Leaf litter	60	5	47	4	21	1.2
Non-leaf litter	12	1	14	1	1.4	0.1
Total	72	6	61	5	22	1.3
4. Removal from canopy (kg ha^{-1} yr^{-1})						
Throughfall	3.5	0.5	—	—	—	—
Stemflow	0.3	0.2	—	—	—	—
5. Root mortality (kg ha^{-1} yr^{-1})	6	0.4	21	2	—	—
6. Total (3+4+5)	81.8	7.1	82	7	22	1.3
7. Retention in vegetation (kg ha^{-1} yr^{-1}) (2—6)	74.2	5.9	44	2	37	2.7

the biomass of live shoots actively builds up following the onset of rainy season and peaks between July and October. The temporal veriation exhibited in attaining peak biomass in different grasslands is related to the quantity and frequency of rainfall. In dry grasslands peak biomass may occur as early as July, while in more humid grasslands the peak biomass occurs during late September-October. The peak in belowground plant biomass precedes, synchronises with or succeeds the peak live growth of live shoots, occuring in either the monsoon or winter season. Maximum live shoot biomass in the tropical Indian grasslands ranges between 76-1974 g m^{-2}, and the maximum belowground biomass between 86-2368 g m^{-2}. In these grasslands, the annual aboveground net primary production varies between 98-3396 g m^{-2} and belowground net production between 61·1972 g m^{-2}. These values for the arid to semi-arid grasslands are lower than those for the more humid grasslands (Singh and Joshi 1979, Yadava and Singh 1977).

Little information exists on the biomass and productivity of the ligneous component of savannas. Recently, Misra (1983) has reported in a *Ziziphus* shrub savanna the total aboveground biomass 1940 g m^{-2} and the total belowground 240 g m^{-2}. The shrub component shared 28% of the aboveground biomass and 43% of the belowground biomass. Litter biomass was 147 g m^{-2} of which about 3% was contributed by the shrub. Of the total net production (TNP) (1318 g m^{-2} yr^{-1}), 20% was shared by the shrub layer and 80% by the herb layer. In the shrub component 72% of the TNP stayed aboveground compared to 70% of the herb layer, although the ratio live shoot: root was 1.2 in the herb layer and 5.3 in the shrub component. From this system 52% of the TNP was dissipated through litter disappearance; thus ecosystem net increment was 628 g m^{-2} yr^{-1}.

Shankar, Dadhich and Saxena (1976) investigated the dry matter yield of natural ground vegetation in a semi-arid range under 12 year old plantations of *Prosopis cineraria, Acacia senegal, Albizzia lebbek, Tecomella undulata*, and *Prosopis juliflora*. The yield was, respectively, 230, 78, 132, 166 and 85 g m^{-2}. Woody species, allowing 78-92% sunlight, gave the same biomass yield (665 g m^{-2}) of herbaceous flora (dominant grass, *Heteropogon contortus*) as obtained in tree-free area (Patil 1983). Heavy infestation by bushes (3575 bushes ha^{-1} comprising *Mimosa hamata, Butea monosperma, Zizyphus nummularia* and *Cassia himalayana*), however, reduced the grassland production to 550 kg ha^{-1} compared to 4200 kg ha^{-1} in bush-free area (Kanodia and Patil 1982).

Singh, Singh and Yadava (1979) have synthesized the information on energy flow and cycling of nitrogen and phosphorus for Indian grasslands studied under the International Biological Programme. They treated the data ln groups of sites, viz., semi-arid, dry subhumid, moist subhumid and humid grasslands, with mean rainfall of 492, 942, 1190, and 1381 mm, respectively: some of the important findings concerning the energy flow are: (i) energy fixation is at a minimum (3871 KJ m^{-2} yr^{-1}) in the strongly water-limited grasslands of the semi-arid zone and is maximum (36213 KJ m^{-2} yr^{-1}) in the dry subhumid zone; (ii) energy is fixed at a maximum rate during the rainy season in all grasslands; (iii) the proportion of solar energy fixed is 0.5, 0.2, 0.26, and 0.05%, respectively, for dry subhumid, moist subhumid, humid and semi-arid grasslands; (iv) the net energy fixed is partitioned equally between roots and shoots in the moist subhumid grasslands, while roots receive a larger proportion under semi-arid (64%) and humid conditions (67%), and shoots (66%) under dry subhumid grasslands; (v) in general, the root disappearance rate exceeds the rate of litter disappearance; and (vi) all grasslands show an energy accumulation (11-33%) over the annual cycle.

Nutrient Cycling

The annual uptake of N ranges between 25.58 g m^{-2} in dry subhumid and 2.93 g m^{-2} in semi-arid grasslands (Singh, Singh and Yadava 1979). The semi-arid and humid climates promoted recycling of N through belowground parts (53-66% of the uptake) while the subhumid grasslands cycled N more through aboveground parts (53-73%). Approximately 63-78% of N absorbed by the plants is returned to soil each year. P uptake was also maximum for the dry subhumid (4.96 g m^{-2}) and minimum for the semi-arid (0.49 g m^{-2}) grassland. Approximately 15, 44, 61 and 98% of P absorbed was returned to the soil, respectively, in humid, moist subhumid, dry subhumid and semi-arid grasslands.

Nutrient uptake : energy capture ratios (Table 7) indicated that the grasslands of the dry region (semi-arid and dry subhumid) appear to need less N to support the same magnitude of energy flow than the grasslands in relatively humid regions. In other words, more energy is needed in the drier zones to pump similar amounts of N in the biological system as compared to the humid zones. In the case of P, the situation is reversed.

Table 7. Relationship Between Annual Nutrient Uptake (mg m^{-2}) and Energy Flow (10^3 KJ m^{-2}) Savannas in Various Climatic Zones (Data Source: Singh, Singh and Yadava 1979)

Nutrient ratio	Dry Region		Humid Region	
	Semi-arid	Dry sub-humid	Moist sub-humid	Humid
Nitrogen				
Nutrient uptake : Energy capture	0.76	0.71	0.98	1.06
Nutrient release : Energy dissipated	0.66	0.67	0.72	0.58
Phosphorus				
Nutrient uptake : Energy capture	0.13	0.14	0.08	0.10
Nutrient release : Energy dissipated	0.14	0.12	0.04	0.02

In a majority of ungrazed grasslands annual total net production is greater than the annual decomposition. Recently, Gupta and Singh (1982) studied the annual carbon balance for three protected grassland stands at Kurukshetra. A comparison of total decomposition and TNP indicates an annual net accumulation of 16-33% of plant organic matter, Further, the comparison of total CO_2 output from the soil-litter indicates that 19-51% of the plant organic matter processed through primary decomposition is not mineralized but is conserved as new soil organic matter. This build up of organic matter in ungrazed grasslands may move them towards a woodland situation.

Succession

Release from grazing and/or burning dramatically increases the woody component. This response is more marked in relatively humid environment. A tree stratum develops within 5-6 years of complete protection and the grasses begin to be shaded out. Even in desertic climate, a small tree-shrub stratum can develop within 4-6 years on sandy, undulating plains with buried piedmont and on old alluvial plains, and in 12-18 years on rocky habitats and sand dunes. Bush control measures may become necessary thereafter, for maintaining the productivity of the range (Kanodia and Patil 1982). While in the humid-climates, continued protection changes the savanna into a forest rather quickly, in drier areas the change is slow and the herbaceous component always remains important due to the open-ness of the overhead canopy.

Bharucha and Shankarnarayan (1958) have described the changes induced by cutting and grazing for a tropical semi-evergreen forest. Unrestricted cutting of trees induces a shrub stage with *Holarrhena antidysenterica, Pogostemon purpurescens, Lasiosiphon eriocephalus, Randia brandisii,* etc. Further cutting facilitates growth of grasses, such as *Arthraxon meeboldi, Ischaemum ciliare, Sehima nervosum,* etc. On continuous grazing *Arthraxon* persists but *Ischaemum* is replaced by a more hardy grass, *Heteropogon contortus*. This is the most predominant stage found in the area. Overgrazing leads to recruitment of more hardy grasses such as *Eragrostis unioloides* and then of useless weeds.

Saxena (1977) has examined the changes in community on sandy undulating plains of the semi-arid region of India in response to cutting and grazing. The *Prosopis cineraria* woodlands is successively degraded to a predominately annual herbaceous community through a series of stages, and when the grazing pressure is released shrubs and trees start re-establishing. Several successional patterns consequent to grazing and no-grazing are reported by Dabadghao and Shankarnarayan (1973).

A unified model of successional changes is given in Fig. 1. S_{1-4} represent states of savanna through time, after originating from the forest (F) due to cutting, burning, etc. The increase in the intensity of disturbance leads from one state to the other. At each stage some species are recruited (R in Fig. 1) while others are subdued or eliminated through biotic interactions (BI) and changes in the environment (EC). Sustained level of disturbance results in semi-stable states (SS_{1-4}), while relaxation from the disturbance (P) initiates back cycling through R, BI, and EC. However, the new states, S_{3-1}' —F; may be broadly similar to, but not exactly the same, as states S_{3-1} or F. These various stages account for the myriad of communities within a single potential savanna type (Singh, Hanxi and Sajise, 1985).

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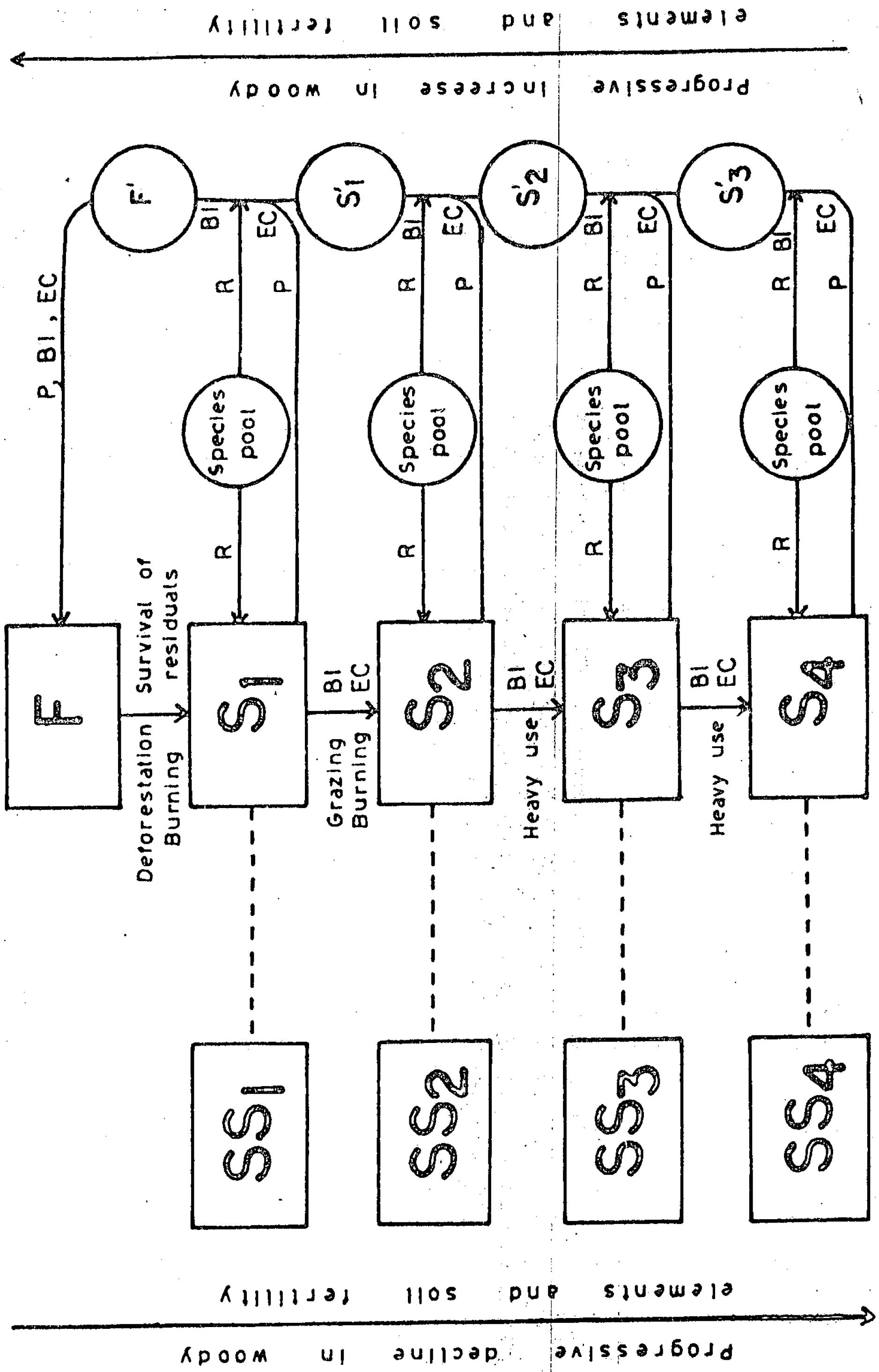

Fig. 1. A unified model of successional changes in Savanna ecosystem (from Singh *et al.* 1985).

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