BIOLOGY OF *CENTELLA ASIATICA* (LINN.) URB., A MEDICINALLY IMPORTANT CLONAL PERENNIAL

By

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I certify that the thesis entitled "Biology of Centella asiatica (Linn.) Urb. - a medicinally important clonal perennial", submitted by Miss Borabell Wankhar, M.Sc., for the Degree of Doctor of Philosophy of the North Eastern Hill University, Shillong, embodies the record of original investigation carried out by her under my supervision. She has been duly registered and the thesis presented is worthy of being considered for the award of the Ph.D. Degree. The work has not been submitted for any Degree of any other University.

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CONTENTS

CHAPTER I

General Introduction and Review of Literature

Centella asiatica (Linn.) Urb. is among the most important medicinal plants of India. For a long time it has been used in the indigenous system of medicine. Perusal of the literature reveals a long list of diseases cured by C. asiatica, of which the most remarkable is the treatment of leprosy. The plant grows wild under a wide range of climatic conditions and thrives well in presence of other weedy species. It forms localized patches as a result of clonal multiplication wherever it grows. The clonal growth habit of the plant is one of the interesting aspects which attracts one's attention.

Clonal perennials have, by defination, ramets derived from a single genet.The clonal growth of a rhizomatous plant involves the continued reduplication of discrete modular units, the 'ramets' - the sum of these units representing the 'genet' or product of a single zygote (Harper & White 1974, Kays & Harper 1974, Harper 1977).The ability of a single genotype to form fragmented phenotypes is just one of the variants in the life-history patterns of modular organisms (Harper & Bell 1979). A unique feature of clonal plants is that rooting at nodes of individual shoots may create physiologically distinct plants with independent fates. This developmental feature has important physiological and ecological implications because it affects how the plant functions as a single physiological unit and interacts with its environment (Bazzaz *et al*. 1987).

Clonal plants exhibit a range of strategies, from a very conservative with short internodes and overlapping rosette, as in *Soliva valdiviana*, to highly exploratory as in *Ranunculus repens* (Ginzo & Lovell 1973,a,b, Lovett Doust 1981 a). The two categories have been called 'phalanx' and 'guerrilla' by Lovett Doust (1981 a). In phalanx type for example, *Bellis* sp., genets expand slowly and modules (rosettes) are tightly aggregated within genets, whereas in guerrilla type for example, *Prunella* sp.,clonal expansion is fast and modules are loosely aggregated within genets (Schmid & Harper 1985). Different growth forms require different energy expenditures (Lovell & Lovell 1985). They argued that a prostrate habit permits maximum ground cover at minimum cost as the requirement for supporting tissue is reduced, while Pickett & Kempf (1980) have commented that the clonal form of some shrubs may permit exploitation of a broad horizontal area relatively cheaply.Furthermore,Lovell & White (1986) argued that the prostrate habit(plagiotropic shoots, psuedo - rhizomes, stolons, runners and rhizomes) encourages vegetative spread because these organs are prolific producers of adventitious roots essential for the establishment of independent ramets. However, the pattern of growth may be greatly affected by environmental conditions (Lovell & Lovell 1985).

In clonal plants, persistence of clonal connections and extent of resource sharing after establishment of ramets vary greatly among species (Antos & Zobel 1984, Callaghan 1984).In some species (e.g., *Aster acuminatus* and *Clintonia borealis*) connections among ramets decay or cease transport soon after new ramets establish, which might reflect selection against continued resource sharing under certain conditions (Ashmun *et al*. 1982, Pitelka & Ashmun 1985), while other species e.g., *Solidago canadensis*,*Agave salmiana* and *Agave deserti* exhibit facultative integration in which reduced photosynthetic capacity or increased demand for carbon induces import of photosynthates from other connected ramets (Hartnett & Bazzaz 1983, Pitelka & Ashmun 1985, Martinez-Morales & Meyer 1985, Raphael & Nobel 1986). Several studies have shown that connection among ramets can increase total growth of clonal groups for example, *Ranunculus repens*, *Fragaria chiloensis* and *Agave deserti* (Lovett Doust 1981 b, Salzman & Parker 1985, Alpert & Mooney 1986, Raphael & Nobel 1986) or at least of individual established ramets within groups e.g., *Carex arenaria* and *Solidago canadensis* (Noble & Marshall 1983, Hartnett & Bazzaz 1983,1985 b).Salzman & Parker(1985) measured growth of pair of connected established ramets of a rhizomatous herb when one, both or neither of the pair was subjected to high salinity.When just one was stressed,connection appeared to increase growth of the stressed ramet and to a lesser degree, to decrease growth of the unstressed ramet.

In the case of clonal plants, the major advantage appears to be the potential for physiological integration of connected rosettes via translocation of resources such as water, minerals and photosynthates as pointed out by Hartnett & Bazzaz (1983),Noble & Marshall (1983), Callaghan (1984), Pitelka & Ashmun (1985 , 1986),Salzman & Parker (1985), and Alpert & Mooney (1986).Added costs of continued integration might include maintenance of connections and long term support of injured, abnormal or poorly situated ramets. Current studies suggest that benefits may be high in habitats where resource availability varies on the scale of individual ramets, such that sharing can compensate for localized resource scarcity, salinity or other potential stress (Hartnett & Bazzaz 1983, 1985 b, Pitelka & Ashmun 1985, Salzman & Parker 1985).

The relative investment into reproduction and clonal growth under different environmental conditions has been one of the main problems in life history studies of clonal plants(Tripathi & Harper 1973, Ogden 1974, Abrahamson 1975, Holler & Abrahamson 1977, Harper 1978,Douglas 1981, Armstrong 1982, 1984). Generally these two functions have been regarded as antagonistic (Salisbury 1942,Harper

1977, Abrahamson 1980). However, Armstrong (1982,1984) has proposed that allocations to reproduction and clonal growth depend on the growth form of the plant, and are not expected to be inversely related. Watson (1984) has recently presented an elegant study of reproduction and clonal growth in water hyacinth (Eichhornia crassipes), in which she showed that the ramet production is constrained by the development of inflorescences. This was not the result of resource limitation, but instead it was due to the developmental morphology of the shoot. Kingsolver (1986) reported that the blooming rosette of Yucca glauca apparently expends a fixed effort on sexual reproduction and then allocates its remaining resources to vegetative growth. Reproduction and clonal growth in Potentilla anserina was studied by Erikson (1985), who emphasized that in the investigation of resource allocation in clonal plants growth form should also be considered. Variation in biomass allocation whether it is genetic or environmentally induced, is usually presumed to reflect adaptive response of individual to variation in environmental factors (Ashmun et al. 1985). Bazzaz et al. (1987) emphasised that the allocation pattern of a plant defines its ecological roles and is, therefore, an important factor in understanding plant distribution and adaptation. Hence, studies of biomass allocation patterns are likely to be very useful in understanding the ecology of a species.

Centella asiatica is a clonal perennial plant which is widely spread in Meghalaya under a variety of conditions. Although the plant reproduces both through vegetative and sexual means, the latter mode of reproduction is negligible. Local patch expansion occurs primarily as a result of clonal growth. Growth period extends from March to November and the plant carpets the ground completely during rainy season. Throughout the altitudinal range it occupies a variety of habitats e.g., wasteland, garden, roadside, streamside, fallows, open forest canopy, relatively dense forest canopy etc. The environment of the individual patches varied widely in terms of light intensity, soil moisture, texture and nutrients and accordingly, there are differences in population density (Table 1.1) which is a function of clonal growth in this species. Patches of Centella asiatica flourish under high light whereas in closed habitats plants were observed to have thin and smaller leaves, and also longer petiole. It can be described as a variable species, tolerant of a wide range of climatic and edaphic conditions, however, it prefers comparatively open and moist habitats.

The plant bears a well defined rosettes on above ground stolons, which are borne in the axils of older leaves, and they give rise to rosettes at every node. Connections between rosettes persist throughout the growing

Table 1.1. Features of a few selected habitats of *Centella asiatica* in Meghalaya, alongwith its density on these habitats.

Habitat	Density of *C. asiatica* /m^{-2}	Light intensity (Lux)	Nutrient level					Soil moisture content (%)	Soil texture
			Organic matter content (%)	N (%)	P (Kg/ha	K (kg/ha	p^H		
Open wasteland	53	55000 - 61000	1.77	0.15	2.24	61.60	5.6	25.4	Clay loam soil
Shaded wasteland	40	31700 - 33500	1.80	0.15	2.24	51.60	5.5	27.7	Clay loam soil
Cropland	26	34600 - 37100	1.22	0.18	2.69	168.0	6.2	25.8	Sandy loam soil
Jhum fallow	42	39200 - 41000	2.37	0.18	3.20	122.0	5.2	27.5	Sandy loam soil
Open forest canopy	39	30200 - 34000	2.20	0.16	7.85	226.0	6.5	26.6	Clay loam soil
Relatively dense forest canopy	22	20100 - 21000	2.29	0.16	7.85	226.0	6.5	28.4	Clay loam soil
Stream side	43	40800 - 42500	1.85	0.17	27.35	61.60	5.8	34.5	Sandy loam soil

period except in winter when the above ground plant part is killed due to cold. A rosette produced at each node serves as unit of both perennation and multiplication (clonal growth). The sprouting of shoot from plants that were apparently dried up during winter, begins in March. The plant initiates stolon production in spring and this continues throughout the growing season. Actual ages cannot be determined in nature, although overall trend in ramet number or density may be easily determined. The underlying pattern of mortality and clonal growth in nature are also not easily measured.

As an important medicinal plant Centella asiatica has engaged the attention of several workers in the past. Its medicinal applications have been recorded in many books and journals. A glycoside called asiaticoside isolated from the plant has been shown to possess activity against leprosy. In fact every part of this plant is used in Indian medicine(See 'Review of literature').The tribals dwelling in the interior places in Meghalaya use this plant for curing stomachache,dysentery and also as blood purifier and nerve tonic.

In India ecological studies on several medicinal plants have been made. Of these, the works of Biswas (1964) on Rauvolfia tetraphylla and R. serpentina, Sah (1966) on

Bacopa monnieri, Pathak (1967) on *Tribulus terrestris*, Shetty (1967) on *Biophytum sensitivium*, and Singh *et al*. (1982) on *Silybum marianum* are worth mentioning.

The clonal habit of *C. asiatica* and its high medicinal value make this species an attractive material for detailed ecological study. Several reports have been published on its chemical composition and few reports on the pharmacological action, however, the ecology of this important medicinal plant has not been touched so far. The present study on the ecology of *C. asiatica* fills the gap.

The study covers the following aspects of the ecology of *C. asiatica* :

(i) Seed germination.

(ii) Phenology and growth of *C. asiatica* in relation to altitude, season and associated species.

(iii) Population dynamics on jhum fallows of different ages.

(iv) Competitive interaction between individuals raised from seeds and cuttings.

(v) Growth behaviour in relation to light regime, NPK level, soil moisture and soil texture under controlled conditions.

The 'General Introduction'outlines the objectives of the present study. It is followed by the 'Review of Literature'. Description of the study sites and general biology of Centella asiatica are given in Chapter II. The experimental data on various aspects mentioned above have been presented in Chapter II to VII. The results of each chapter have been discussed separately, however, the major findings of the thesis have been discussed under 'General Discussion' in an integrated manner.

Clonal growth habit is one of the most widespread form of asexual reproduction in plants (Cook 1983, Hartnett & Bazzaz 1983).Salisbury (1942) showed that many widespread species often have vegetative multiplication as an alternative and argued that these species have a considerable range of tolerance of climatic conditions and efficient reproduction under suboptimal conditions. Clausen _et_ _al_. (1947) suggested that plants with efficient vegetative reproduction are better equipped to tolerate extreme environmental conditions. Vegetative spread and its possible adaptive significance has been discussed by Bell (1974, 1976), Harper & White (1974), Harper (1977), Harper & Bell 1979, Bell _et_ _al_. (1979) and Bell & Tomlinson (1980). Recruitment by vegetative means is independent of external pollination and a single plant is completely equipped to colonize a given area. Ramet population can expand or contract depending on the prevailing environmental conditions (Sarukhan 1976). Another advantage of vegetative reproduction is the increased longevity and perennation of the genet. However, there are of course, inherent costs such as the lack of genetic recombinations and reduced ability to disperse to far away places (Schellner _et_ _al_. 1982).

Harper (1967) has suggested that sexual and asexual reproduction are competitive within the plant. Because sexual and vegetative reproduction are dependent on the same limited resources, and since physiological conditions best favourable to one are not identical with those most favourable to the other, the two modes appear competitive (Salisbury 1942). However, it is more useful to view the two modes of reproduction as constituting an essentially inseparable system in the life history of the plants (Kawano 1975). The sexual reproduction produces new genetic recombinations and allows dispersal to new sites, while asexual reproduction perpetuates the successful genotypes in the local populations (Abrahamson 1980) and the optimal balance between the two modes of reproduction depends on a variety of abiotic and biotic factors.

Despite dominance of ramet individuals (cloning plants) in aquatic, forest floor, grassland communities etc., there is little information available on the population biology of ramets. There are numerous problems associated with such plants, for example, the occurrence of overlapping generations (Sagar & Mortimer 1976), the difficulty of defining the individual plant (Jansen 1977), the existence of both vegetative and seed reproduction (Thomas & Dale 1975), the long pre-reproductive period (Tamm 1956) and the non-appearance in some years of above-ground parts (Well 1967). Further, acquiring ramet data from natural populations of cloning plants is difficult. First, ramet linkages are frequently underground, secondly ramet linkages usually decay in a relatively short time (Dickerman & Wetzel 1985). The demographic analysis of clonal perennial plants growing in natural habitats has been done by some workers, for example, Sarukhan & Harper (1973) on *Ranunculus* spp., Noble *et al.* (1979) on *Carex arenaria*, Solbrig *et al.* (1980) on *Viola sororia*, Barkham (1980) on *Narcissus* sp., Lovett Doust (1981 a,b,c,) on *Ranunculus repens*, Newell *et al.* (1981) on *Viola blanda* and *V. pallens*, Schellner *et al.* (1982) on *Viola* spp., Pitelka *et al.* (1984) on *Clintonia borealis*, Raphael & Noble (1986) on *Agave deserti* and few others. However, wide gaps in our knowledge remain.

Based on his study on the population dynamics and local specialization in *Ranunculus repens*, Lovett Doust (1981 b) reported that germination and establishment of the new genets was rare in grassland and mixed deciduous woodland. Further, the birth - rate of ramets was apparently density - independent, but death-rate of the rosettes was density - dependent. Poor recruitment of seedlings in many other species was also reported by Anderson & Loucks (1973), Whigham (1974), Raynal (1979), Barkham (1980) and Pitelka *et al.* (1984). Populations maintaining their numbers by vegetative propagation typically show Deevy Type II survivorship curve (Sarukhan 1976). The effects of hoeing and rototilling on population dynamics of pure stands of *Portulaca oleracea* were studied by Miyanishi & Cavers (1981).

They found that soil disturbances resulted in decreased dry matter yield per unit area. Froud - Williams et al. (1984) studied the effects of seed burial and soil disturbance on emergence and survival of arable weeds and observed that such disturbances increased the total number of seedlings which emerged. Jurik (1985) observed that the production of runners and plantlets in strawberry population was greatest in open and recently disturbed habitats than in closed habitats.

The studies made by various workers (e. g. Sarukhan & Harper 1973, Hawthorn & Cavers 1976, Yadav & Tripathi 1981) on several plant species revealed that the plant mortality is maximum in the active growing season of population. William (1970), Bazzaz & Harper (1976), Yadav & Tripathi (1981), Silvertown & Dickie (1981), Weiss (1981), Law (1981) and Rai & Tripathi (1984) reported that heavy mortality occurs during the seedling state, while Canfield (1957) found high mortality during old age. Subsequent studies (Cook 1979, Meagher & Antonovics 1982) have shown that mortality is frequently more closely associated with size than the age of the plant. Regehr & Bazzaz (1979) worked on the population dynamics of Erigeron canadensis and observed 16-86% plant mortality due to frost heaving. Yadav & Tripathi (1981) also observed some mortality during winter for both seedling and adult populations of Eupato-

rium odoratum, and they ascribed it to the prevailing low temperature and high moisture stress.

Late emerging plants have to face severe competition from established adult plants of their own or of other associated species. Many workers (e.g. Tamm 1956, Cavers & Harper 1967, Putwain & Harper 1970, Friedmann 1971, Kushwaha *et al*. 1981, Yadav & Tripathi 1983, Rai & Tripathi 1985, Tripathi 1985) have reported that seedling establishment was relatively poor in established community. Tripathi & Dwivedi (1978) suggested that the fundamental niche of a species may be restricted to a smaller hyper volume due to the interference caused by the presence of associated species. Sagar (1970) reported a better vegetative and reproductive growth of *Plantago lanceolata* when the associated vegetation was removed. Titus & Stephen (1983) found that total dry weight, leaf length, stolon length, rosette number and winterbud production in *Vallisneria americana* had higher mean values for individuals in a monospecific stand of *Vallisneria* than at sites dominated by *Potamogeton amplifolius* or *Chara vulgaris*. The effects of experimental removal of species was also studied by Raynal & Bazzaz (1975) and Fowler (1981).

Studies on the growth of mixed populations established from tillers and from seeds were made by Tripathi & Harper (1973) and Kushwaha *et al*. (1983 a). They found that plants established from tillers were more vigorous and aggressive than their counterparts produced from seeds. Genetic variation and plasticity between and within populations of *Bellis perennis* and *Prunella vulgaris* was studied by Schmid (1985 b). Clay and Levin (1986) studied the relative success of six populations of *Phlox drummondii* raised under conditions of intra-specific conditions and observed that pure stands had higher means for flower production than mixed stands.

Werner (1975) studied the fate of teasel (*Dipsacus fullosum*) raised from the rosettes of different size and reported that the probability that an individual will die, remain vegetative or flower during a particular growing season is highly correlated with the size of its vegetative rosette. He also found that the rosette size provides better predictions of fate than age. Similar study was made by Gross (1981). Many workers (e.g. Cook 1980, Pitelka *et al.* 1980, Bradbury 1981, Solbrig 1981, Thompson & Beattie 1981) have shown that plant or ramet size proved to be an important component of fitness in many plants. Brown *et al.* (1985) studied variation in vegetative phenology in two forest herbs, *Aster acuminatus* and *Clintonia borealis*, and reported that large ramets tended to emerge earlier, mature more slowly, live longer and die later. The relationship between seasonal variation in light intensity, ramet size and sexual reproduction in natural and experimental populations of Aster acuminatus was studied by Pitelka et al. (1985). The results provide new insight into the general phenomenon of size - dependent reproduction in herbs.

The differences between plant populations along an elevational gradient were studied by Mooney (1963), Ward (1969) and Rochow (1970). Reduction in total biomass with increasing altitude has been reported by Kira & Shidei (1967), Yoda (1968) and Maruyama (1971). The functional dynamics of Artemisia vulgaris at different altitudes was studied by Todaria & Purohit (1979) who observed a significant reduction in the extension growth and leaf area expansion with increasing altitude. Jolls (1980) studied the pattern of biomass allocation in Sedum lanceolatum at four elevation sites and found a significant difference in biomass allocation to asexual and sexual tissues amongst populations. The balance between vegetative and sexual reproduction of Mimulus primuloides at different altitudes in California was studied by Douglas (1981) who argued that increased allocation to reproduction at high altitude may be an adaptation for greater potential dispersal or seedling establishment.

Studies on seasonal productivity and growth dynamics in response to the prevailing climate may provide useful indication about the time at which the harvest would be maximum. The seasonal changes in biomass allocation in eight winter annuals of Majove desert was studied by Bell et al. (1979). They found that there was no rapid change in biomass allocation during the life cycle. In the case of Chilean shrubs, Montenegro et al.(1982) found a significant seasonal change in biomass allocation. Seasonal change in biomass was also studied by Westlake (1966) and Hussey & Long (1982).The productivity, caloric content, and chemical composition of a population of Spartina alterniflora in relation to change in season were studied by Squiers & Good (1974), and they found that the amount of nitrogen that the plant accumulated in its aboveground parts early in the growing season was directly related to the peak of dry matter standing crop.

The effect of light intensity on the growth of purslane, Portulaca oleracea, was studied by Zimmermann (1976) who found that the higher the light intensity, the greater the fresh weight yields. The number of capsules produced was also positively correlated with the amounts of light received. Dennis et al. (1970) showed that high light intensity increased flowering but had no effect on vegetative reproduction in cultivated strawberries.Paterson(1980) studied the partitioning of **dry matter in** Cogon grass (Imperata cylindrica) from shaded and exposed habitats and found that allocation to reproductive activities was greater under exposed situation. Light-induced variations in the growth and dynamics of transplanted ramets of the understorey herb, *Aster acuminatus* were studied by Ashmun & Pitelka (1984) who observed that ramet growth and flowering were positively correlated with the level of light but not at all with soil moisture. The effects of light and nitrogen on dry matter allocation in Chaparral shrub, *Diplacus aurantiacus* have been studied by Gulmon & Chu (1981). Growth and reproductive strategies of two annual weeds as affected by soil nitrogen and density levels was studied by Trivedi & Tripathi (1982 a). Tripathi & Yadav (1982) studied the effect of population density, soil nitrogen and light intensity on population regulation of *Eupatorium adenophorum* and *E. riparium* and found that both species were favoured by soil nitrogen, however, nitrogen requirement was reduced under low light intensity. The growth of *Elymus repens* and *Agrostis gigantia* at different light intensities was studied by Skuterud (1984). Both species responded to reduced light by increased stem length and decrease in number of aerial shoots. The effect of shade on *Crotolaria juncea* and *C. sericea* was studied by Pandey & Sinha (1977), on *Oxalis acetosella* by Packham & Willis (1977) and on *Acchillea millefolium* by Bourdot *et al.* (1984). Rajeswara Rao *et al.* (1983) studied the effect of nitrogen, phosphorus, and potassium on pyrethrum (*Chrysanthemum cinerariifolium*) and found that pyrethrin concentration was not influenced by various rates of nitrogen, phosphorus, and potassium applications and sources of phosphorus.

Interacting influence of soil types and soil moisture plays an important role in determining the growth of the plant. Cunningham *et al*. (1979) studied the aboveground production and biomass allocation to reproduction in *Larrea tridentata* and found that enhanced soil moisture during the period of active growth reduces the allocation of biomass to reproductive structures, while, Abrahamson & Hershey (1977) found that reproductive allocation in *Impatiens capensis* remained unchanged due to soil moisture. However, Werner and Platt (1976) reported that in *Solidago* there is an increase in allocation of biomass to vegetative propagation with increased soil moisture. Differences in root and shoot development of tomato (*Lycopersicum esculentum*) varieties across contrasting soil environments were studied by Gulmon & Turner(1978).Trivedi & Tripathi(1982 b) studied the effect of soil texture and moisture on reproductive strategies of *Spergula arvensis* and *Plantago major* and found that daily watering on sandy soil gave the greatest dry weight in *S. arvensis* while, fortnightly watering gave the greatest in *P. major*. Similar studies were made by Rai & Tripathi (1983) on *Galinsoga* species and Davies (1984) on *Erica* species. The effect of moisture stress on stolon and adventitious root development in white clover (*Trifolium repens*) was studied by Stevenson & Laidlaw (1985) who found that growth of young roots and nitrogen fixation were adversely affected by drought.McIntyre (1976) emphasized the importance of water availability and showed that in *Agropyron repens* the degree of inhibition of buds on the rhizomes is inversely related to internal water content of the segment of rhizome bearing buds. When the supply of water to individual rhizome was increased, vigorous root production occurred at the nodes. The examples given illustrate the importance of the environmental factors in determining the plant growth and development.

Work done on *C. asiatica* :

Centella asiatica enjoys considerable reputation in Indian system of medicine and its virtues have been recorded in many books and journals on medicinal plants (Dymock *et al*. 1891, Kirtikar & Basu 1935, Sastri 1950, Chopra *et al*. 1956, Chopra *et al*. 1958,Basu & Rastogi 1967, Chopra *et al*. 1969, Heywood 1971, Grieve 1974, Dey 1980, Kharkongor & Joseph 1981,Bhattacharjee *et al*. 1981, Rastogi & Dhawan 1982,Rao & Jamir 1982, Biswas & Chopra 1982,Chopra *et al*. 1984, Ambasta 1986).

A great variety of medicinal application has been recorded for *C. asiatica*. While some of the uses are localized, others have been employed around the world. For example, in India (Malabar coast) and Madagascar, the plant is used for treating leprosy (Dymock et al. 1891, Kirtikar & Basu 1935, Sastri 1950). In Coromandel coast, the leaves are used for blows and bruises, in Java and Indo-China it is used as diuretic and in Konkan, juice is applied for skin eruptions (Dymock et al. 1891). In Ceylon it is used against digestive disorder, nervousness, dysentery and as a tonic and blood purifier (Kirtikar & Basu 1935). In Meghalaya, the plant is used for curing stomachache, dysentery and as a blood purifier. The plant is widely used against these ailments even today by the people in rural areas where modern medical facilities have not yet reached. The medicinal uses of C. asiatica are summarised in Table 1.2.

As recorded in Pharmacographia Indica (1891), the chemical screening of Centella asiatica began with the work of Lepine who found a substance named vellarine which is obtained from the dried plant to the extent of 0.8-1%. Beside this, resin fat (8.9%), tannin and sugar (24.5%), gum and salts (11.5%), albuminoid matter (12.5%) and ash (2.4%) were also present. Since then, many investigators have studied the chemical constituents of C. asiatica and many compounds have been charactesised. Wali and Katli (1937) reported the presence of an essential oil, sitosterol, tannin, glucose, a large amount of resinous material and

Table 1.2. Summary of the medicinal uses of C. asiatica.

Ailment/Uses		Reference No.
Anaemia	-	12
Loss of Appetite	-	2,12
Asthma	-	2,12
Blood disease	-	2,4,5,6,7,11,12
Boils	-	11
Blows & Bruises	-	1,8
Bowel complaints & Diarrhoea	-	7,8,9
Brain tonic	-	2,3,12
Bronchitis	-	12
Cholera	-	12
Cough	-	7,11
Dysentery	-	7,8,11,13
Eczima	-	1,5
Eye lesion	-	5,7,14
Fever	-	2,8,9,12
Gonorrhea	-	8
Headache	-	2,12
Inflammation	-	2,12
Jaundice	-	8
Leucoderma	-	2,12
Leprosy	-	3,4,5,7,8,9,10,15
Lupus	-	15

Weak memory	-	2,5,7,8,9,10,12
Nervous disease	-	1,4,5,6,7,12
Piles	-	1
Rheumatism	-	1,6,9
Smallpox	-	12
Spleen trouble	-	2,12
Skin diseases	-	1,3,4,5,6,7,8,10,12,15
Syphilitic ulcer	-	1,5,9
Stomachache	-	3,13
Tumour	-	11
Urinary discharge	-	2,8,11

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1 - Atal & Kapur 1977, 2 - Babu 1977, 3 - Biswas & Chopra 1982, 4 - Chopra *et al.* 1956, 5 - Chopra *et al.* 1958 6 - Chopra *et al.* 1984, 7 - Dey 1980, 8 - Dymock *et al.* 1891, 9 - Grieve 1974, 10 - Heywood 1971, 11 - Kharkongor & Joseph 1981, 12 - Kirtikar & Basu 1935, 13 - Rao & Jamir 1982, 14 - Sastri 1950, 15 - William Boericke 1971.

oleic, linolic, linolenic, palmitic, stearic acids. An alkaloid, hydrocotyline ($C_{22}H_{33}NO_8$) has been isolated from the dried plant by Basu & Lamsal (1947).

Bontems (1941) obtained from the fresh leaves a glycoside, named asiaticoside consisting of a colourless needle (m.p. 232°C), the yield being 0.7 to 1.2 g per Kg of the fresh leaves. Crystalline form of asiaticoside has been obtained from specimens grown in Madagascar. This glycoside is a rhamnose - glucose derivative of a triterpene acid-aciatic acid. The 'oxidised form' of asiaticoside may be present in the fresh plant. Melting points, optical rotations, chemical and physical behaviour of different derivatives of asiaticoside show greater similarity with those of triterpene acids of the β- amyrin group (Boiteau et al. 1949). Boiteau et al. (1949) noted the chemical constitution of asiaticoside ($C_{51}H_{88}O_{23}$). Singh & Rastogi (1969) investigated the asiaticoside from C. asiatica growing in India and Rahandraha et al. (1963) determined anthrone asiaticoside from the plant.

Bhattacharyya & Lythgoe (1949) could not isolate the glycoside from the dried specimen, instead, three amorphous triterpene acids were obtained in pure condition. These are centoic acid ($C_{30}H_{48}O_6$, m.p. 245-61°C decomp.), centellic acid ($C_{30}H_{48}O_6$, m.p. 160-95°C decomp.), and centic acid ($C_{30}H_{48}O_5$, m.p. 230-55°C decomp.). Lythgoe & Trippet (1949) examined the fresh plant from Ceylon and found that it contained a pale yellow glycoside named centelloside, which resembles asiaticoside. On hydrolysis it yields centellic acid, glucose and fructose in the proportion of 1 : 10 : 2 (mol.). The chemical **constituents of the** Ceylonese material was analysed by Bhattacharyya (1956 a) and it contained centic, centoic and centellic acids and centelloside. Reducing sugar, salts, pectin and essential oils were also present. The plant of the Indian origin was, however, found to contain salts, sugars, essential oils, pectins and a mixture of triterpene acids. The major triterpenic constituents are indocentoic acid which appears to be isomeric with centoic acid and a water soluble glycoside identified as 'indocentelloside' (Bhattacharyya 1956 b, 1956 c).

Rastogi et al. (1960) found that the alcoholic extract of 10 kg air-dried plant powder gave two triterpene acids (9.7 g brahmic acid- $C_{30}H_{48}O_6$, m.p. 293° and 9.0 g isobrahmic acid- $C_{30}H_{48}O_6$, m.p. 263°), two saponins (37.5 g brahmoside m 242° decomp., and 16.0 g brahminoside m 223° decomp.), betulic acid and stigmasterol.

Malhotra et al. (1961) reported the presence of alkaloids, glycosides, sterols, **tannins** and **sugar**. Triterpene glycoside, thankuniside and terpenic acid, thankunic acid were reported by Dutta & Basu (1962). The brahmosides and brahminosides are said to be tri- and tetra-glycosides of brahmic acid (Rastogi & Dhar 1963). Chemical formula of brahmic acid- $C_{30}H_{48}O_6$, was given by Singh & Rastogi (1968). The triterpenoid saponins and sapogenins were isolated by Basu & Rastogi (1967). Rastogi & Dhawan (1982) concluded that saponins from this plant proved to be rich sources of new triterpenoids.

Medicinal uses of C.asiatica are many and several compounds have been isolated from the plant but so far, very few clinical tests have been conducted. As mentioned in the Pharmacographia Indica (1891), the use of the plant in the treatment of leprosy was first brought to notice by Boiteau (1859). Dr. A. Hunter tried it in Madras Leper Hospital and concluded that it is useful in ameliorating the symptoms and improving the general health of the patient. Dr. Daruty observed that the application of this drug to leper causes at first a sensation of warmth and pricking to the skin especially of the hands and feet, followed by a general sensation of warmth, sometimes unbearable. The capillary circulation is accelerated and after about a week the appetite improves, in time the skin becomes softer, throws off the thickened epidermis and recovers its transpiratory function. In the Pharmocopoeia of India it has been made official and it is described as an alternative, tonic and local stimulant more specially useful in syphilitic skin diseases in which it may be used both as an internal and local remedy. Directions for making a powder and poultice are given. Reports from Europe in 1885 confirmed this, and there has been some enquiry for the drug in Bombay which has led to its cultivation on a small scale.

Drs. Boiteau & Grime quoted by Chopra et al. (1958) isolated glycoside from the Madagascar variety and they found that in doses nearing a toxic level, it gave encouraging results in leprosy.They are of the opinion that the glycoside acts as solvent on the waxy covering of the bacillus leprea which becomes softened and could be easily destroyed by the tissue or an adjuvant drug. Results from clinical trials include softening, breaking down of nodules followed by cicatrization proved its powerful action against leprosy. Healing of whitlows and perforating ulcers and gradual improvement of anaesthesia and muscular atropy are also said to occur. Still more remarkable is the claim that eye lesions are rapidly cured if treated before the posterior chamber is involved. The most hopeful features of the present account of the work is the success in breaking down leprosy nodules, and still more the clearing up of hitherto intractable eye lesions.However, further work needs to be undertaken on modern scientific line.

CHAPTER II

Description of the study site, climate, soil and vegetation and general biology of *Centella asiatica*

STUDY SITE

The present investigation was carried out in and around Shillong ($25^{\circ}34'N$, $91^{\circ}56'E$), the capital of Meghalaya state in North-Eastern India. *Centella asiatica* is an important medicinal plant. It occurs as a weed in croplands and disturbed habitats. It also grows abundantly in grasslands and under sparse forest canopy in the region. Field studies were carried out mostly in Shillong (alt. 1500m) and Upper-Shillong (alt. 1700m). Some studies were also conducted at Shillong peak (alt. 1955m) and Barapani (alt. 900m).

Pot experiments were conducted on the campus of the School of Life Sciences, North Eastern Hill University, Shillong under net house conditions.

Climate :

The south-west monsoon and the north-east winter wind influence the climate of Shillong. The average rainfall and temperature data recorded during the study period are given in Fig. 2.1 a & b. The climate of the year can be divided into four main seasons (1) Spring (March to April), (2) summer (May to September), (3) Autumn (October to November) and (4) Winter (December to February). The spring season is characterised by gradual increase in temperature accompanied by occasional showers in April. The spring gives way to the summer which is characterised by rise in temperature, strong winds, abundant rainfall and high humidity.

Fig. 2.1. Rainfall & temperature (Fig.2.1 a) and relative humidity (Fig. 2.1 b) data for the study area during June 1983 to June 1986. △ , average rainfall; ● , mean maximum temperature; ○ ,mean minimum temperature.

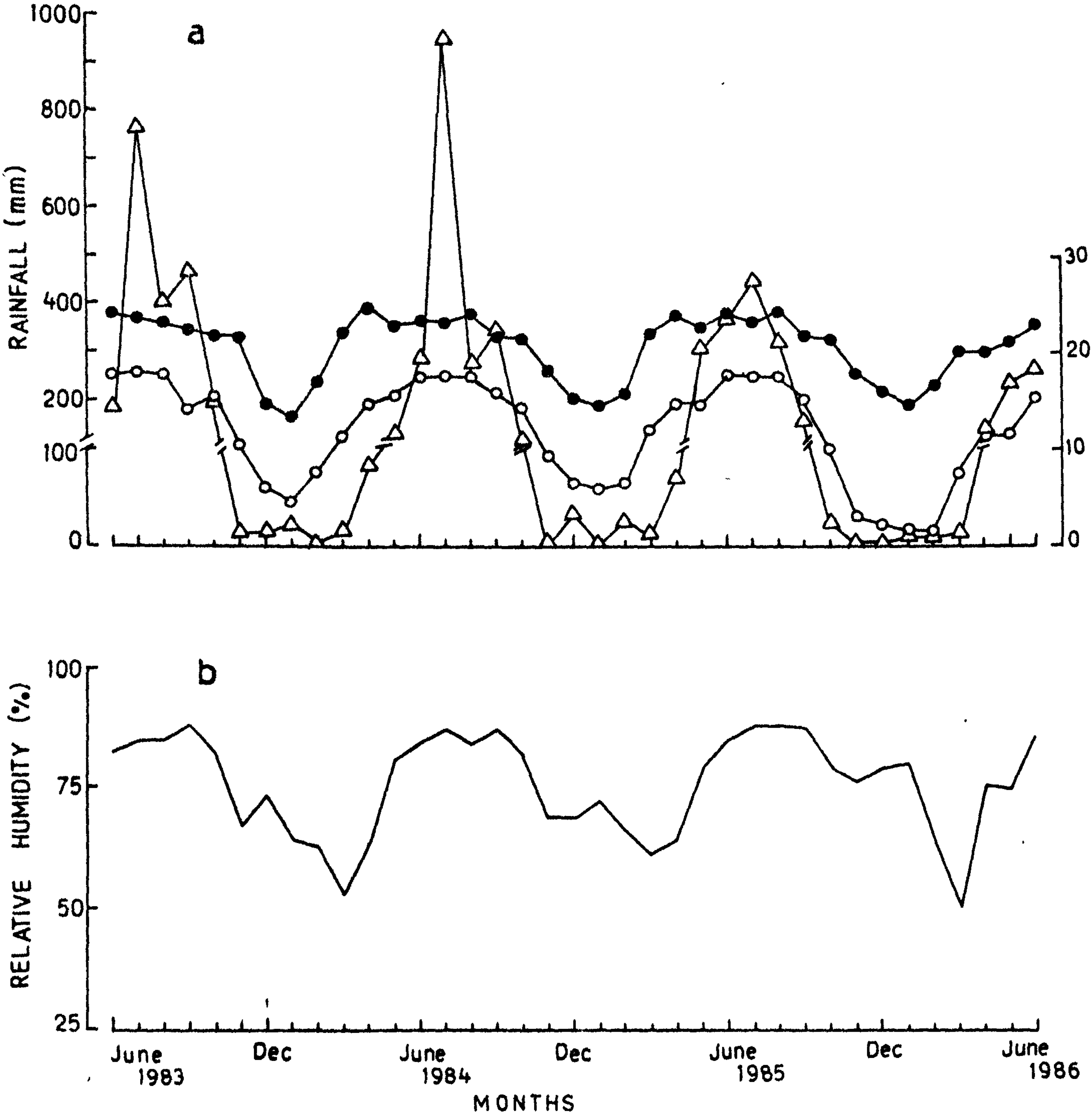

a
RAINFALL (mm)
1000
800
600
400
200
100
0
TEMPERATURE (°C)
30
20
10
0
b
RELATIVE HUMIDITY (%)
100
75
50
25
June 1983
Dec
June 1984
Dec
June 1985
Dec
June 1986
MONTHS

Fig. 2.1

October and November experience mild cold and relatively dry weather. The winter season is characterised by low temperature and dry spell of weather lasting from December to February. Clear winter days are usually followed by frosty nights.

Soil :

The Shillong plateau embracing the Garo, Khasi and Jaintia Hills of Meghalaya is made up largely of precambrian rocks acutely folded and steeply dipping, with an overturned fringe of mesozoic and tertiary sediments. The soil is lateritic with reddish brown colour and its texture is sandy loam at the surface and silty loam in deeper layers. It has originated from the hard rocks representing gneises, schists and granite. It is believed that the hills of Shillong plateau and its surroundings were uplifted from the sea bed called 'Tethys sea' during the mesozoic and early tertiary times along with the origin of the great Himalayas (Zimba 1977). The soil is acidic in nature and is rich in organic matter, nitrogen, phosphorus and potassium (See Chapter I, Table 1.1).

Vegetation :

The vegetation of Shillong predominantly comprises evergreen tree species, the commonest of which is

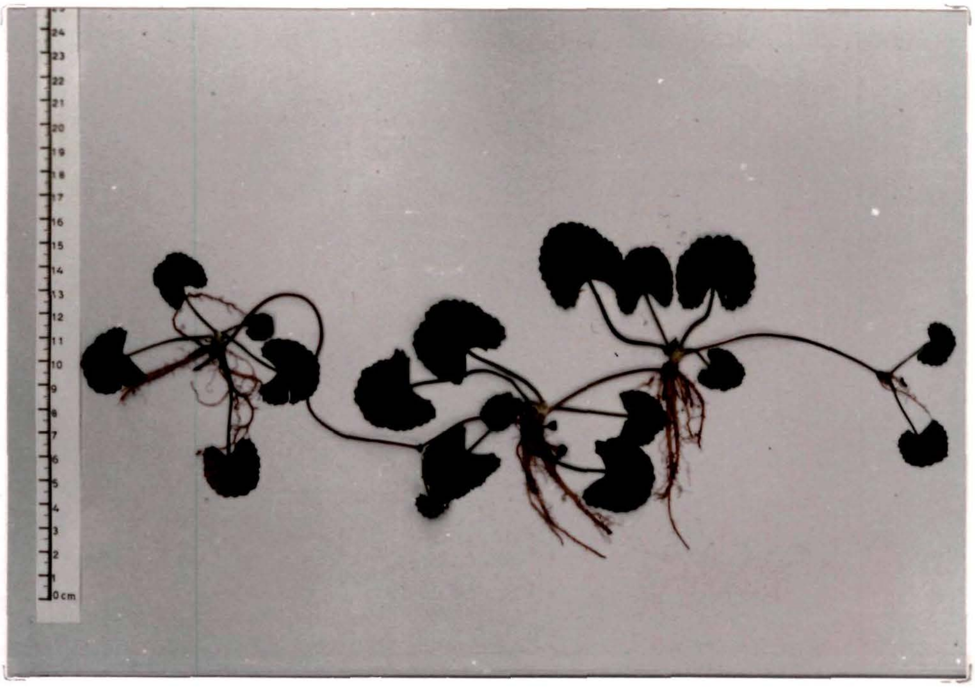
Pinus kesiya. Besides, fallowlands and grasslands are also common. An important reason for the formation of fallowland in this region is the practice of slash and burn agriculture (shifting cultivation) locally called the 'Jhum' cultivation. Due to pressure of biotic disturbances the forest vegetation is not allowed to develop on the fallows. *Centella asiatica* is an important component of the grasslands and ruderal vegetation developing on these fallows. Densities of species growing in association with *Centella asiatica* in fallows of different ages are given in Chapter IV, Table 4.2.

Description of the species :

Centella asiatica belongs to the family Umbelliferae (Apiaceae). Earlier it was known by the name *Hydrocotyle asiatica* Linn. but later on, in the year 1879, the name was changed to *Centella asiatica* (Linn.) Urb. (Babu 1977). The plant has got many synonyms such as 'Indian pennywort', 'marsh penny', 'white rot', and 'thick leaved penny' (Heywood 1971, Grieve 1974). It is known by the name 'Brahmi' in Hindi and by various other names in different Indian languages as given below :

Plate 1 A - Photograph showing the growth habit of *Centella asiatica*.

B - A unit considered as individual plant.



A

PLATE I

B

Plate 2 - Photograph showing the growth of *Centella asiatica* in its natural habitat.

PLATE 2

<u>Language</u>	<u>Name</u>
Bengali	Thankuni
Telugu	Manduk Brahmi
Tamil	Vallarikiri
Sanskrit	Brahmi
Urdu	Brahmi
Assamese	Manimuni
Nepali	Kalyenhok
Garo	Manimuni
Khasi	Khling syiar/Bat pyllon
War Jaintia	Jia thynrewrkia

<u>C.asiatica</u> is a perennial creeping herb with long stolons (0.4-12 cm) which produce leaves, roots and fruits at the nodes. Leaves borne in rosette, are reniform and dentate. Petioles and peduncles are fascicled. Petiole length varies from 0.7 cm to 13 cm. Inflorescence, simple umbel bearing 1-5 peduncles in the axil of small bracts, flowers, sessile 3-6 in each head, petals 5, ovate and red in colour, fruit shallowly 2 lobed and seed (0.25-0.35mm) laterally compressed.

<u>Distribution</u> :

The plant is indigenous to Southern United States and it is widely distributed in Asia and Southern Africa

(Heywood 1971, Grieve 1974). It prefers the tropical and sub-tropical climate (Hooker 1879).The plant is widely distributed in India and it can grow even up to an altitude of 6000 ft (Chopra *et al*. 1984).

C.asiatica is a moisture-loving creeping herb and found mainly in wasteland, roadsides, grasslands, fallows, stream side, open forest canopy etc.

SEED GERMINATION

INTRODUCTION

C. asiatica reproduces both by vegetative and sexual means. Although the former type of reproduction is more important, the production of seeds ensures successful invasion of new and distant areas by this weed. Majority of the seeds produced, tend to fall around the parent plant. The seeds have been observed to germinate in nature, but establishment of the seedlings is very poor. The studies carried out on *C.asiatica* centre around its medicinal value and consequently, other aspects of study including germination ecology have been grossly neglected.Germination is one of the most important events that govern the population growth of a species. Therefore, a study was conducted to understand the germination behaviour of the fresh and buried seeds of *C. asiatica* as influenced by different factors of the environment.

MATERIALS AND METHODS

Mature seeds of C. asiatica were collected from the three sites viz. Shillong Peak, Shillong and Barapani, which are located at different altitudes. Details of the collection sites are given in Chapter III.

Germination of the fresh seeds :

The viability of the fresh seeds was tested by soaking the seeds in 1% triphenyl - tetrazolium chloride overnight. A preliminary study on seed germination indicated that the freshly collected seeds of C. asiatica do not germinate **readily.** Therefore, the seeds were subjected to chilling and scarification treatments. For chilling treatment the seeds were placed in petridishes filled with moist sand and these petridishes were then kept in a refrigirator maintaining a temperature of $5^{o}C \pm 1^{o}C$. At intervals of approximately 45 days, seeds were removed and tested for germination. In scarification treatment, seeds were treated with 50% sulphuric acid for 5 minutes. The seeds were then washed thoroughly with water and tested for germination.

20 seeds were placed on Whatman filter paper underlain with cotton in the petri-dishes. The filter paper was moistened with distilled water. The germination was tested under the following temperature and light conditions:

1. At constant temperatures of 20°C, 25°C and 30°C in light.

2. At constant temperatures of 20°C, 25°C and 30°C in dark.

3. At alternating temperature and uniform light treatment the plates were exposed to:
   - (i) 8 hours at 20°C alternating with 16 hours at 10°C in light.
   - (ii) 8 hours at 25°C alternating with 16 hours at 15°C in light.
   - (iii) 8 hours at 30°C alternating with 16 hours at 20°C in light.

4. At constant temperature in intermittent light treatment, the plates were exposed to 8 hours in dark and 16 hours in light at 20°C,25°C and 30°C.

5. For alternating light and alternating temperature treatment, the plates were exposed to:
   - (i) 8 hours light at 20°C alternating with 16 hours dark at 10°C.
   - (ii) 8 hours light at 25°C alternating with 16 hours dark at 15°C.
   - (iii) 8 hours light at 30°C alternating with 16 hours dark at 20°C.

The petri plates were moistened regularly during the course of the experiment. The germination was recorded over a period of 40 days. The effect of dark was studied by wrapping the dishes with a black aluminium sheet. Petri-dishes meant for light treatment were exposed to a light intensity of 300 lux supplied by incandescent light.

The seed was considered to have germinated when the radicle first emerged. Germinated seeds were counted and removed at each periodic observation.

Germination of the buried seeds :

Five soil samples (25 cm^2 x 2 cm depth) were collected in December, 1985 from each of the three study sites and the seeds of *C. asiatica* present in soil were separated out. Seed viability was tested as described earlier. Seeds were scarified with 50% sulphuric acid and tested for germination. The treatments were same as described for the germination of the freshly collected seeds.

RESULTS

The viability of the fresh seeds ranged from 80% in the seed population from Shillong Peak to 86.5% in that from Barapani. The seed population in soil was maximum at Shillong Peak, while the viability was maximum for the seeds collected from Barapani (Table 2.1).

Table 2.1 Seed population of <u>Centella asiatica</u> in soil (no. of seeds/m^2, ± S.E.) and viability of the buried and fresh seeds.

Study site	Seed No/m^2	Viability of the buried seeds (%)	Viability of the fresh seeds (%)
Shillong Peak	2512 ± 139.6	69.5 ± 5.8	80.0 ± 6.2
Shillong	2208 ± 116.2	72.3 ± 4.8	83.2 ± 5.9
Barapani	1792 ± 89.6	80.6 ± 5.8	86.5 ± 5.4

Among the various treatments, only alternating light and alternating temperature was found to be suitable for seed germination. The seeds that were subjected to chilling, gave no germination at all. The seeds collected from the lower altitude showed better germination than those from the higher altitude. Buried seeds of C. asiatica germinate earlier and gave greater germination percentage than freshly collected seeds (Fig. 2.2 & 2.3). The germination of all the three seed populations increased on scarification with dilute sulphuric acid. Seeds of all the populations gave better germination at higher temperatures.

DISCUSSION

C. asiatica displays relatively complex germination behaviour. The chilling treatment is well known as means of breaking dormancy, but it did not stimulate seed germination in C. asiatica. Grime et al. (1981) reported that favourable effect of chilling treatment on germination is a characteristic of the Umbelliferae,however,C. asiatica though belonging to the same family exhibited different behaviour.

Better germination of the seeds collected from the soil samples compared to the fresh seeds as observed in the present study indicates that as the seeds age in soil they show quick and better germination.The lack of substan-

Fig. 2.2. Germination of fresh seeds of *C. asiatica* under alternating temperatures in light and dark. Filled circles(●) for the unscarified seeds and open circles(○)for the scarified seeds. Seeds collected from Shillong Peak(——), Shillong(- - -), and Barapani (-·-·-).

a - At 20^{o}C for 8 hrs. in light alternating with 10^{o}C for 16 hrs. in dark.

b - At 25^{o}C for 8 hrs. in light alternating with 15^{o}C for 16 hrs. in dark.

c - At 30^{o}C for 8 hrs. in light alternating with 20^{o}C for 16 hrs. in dark.

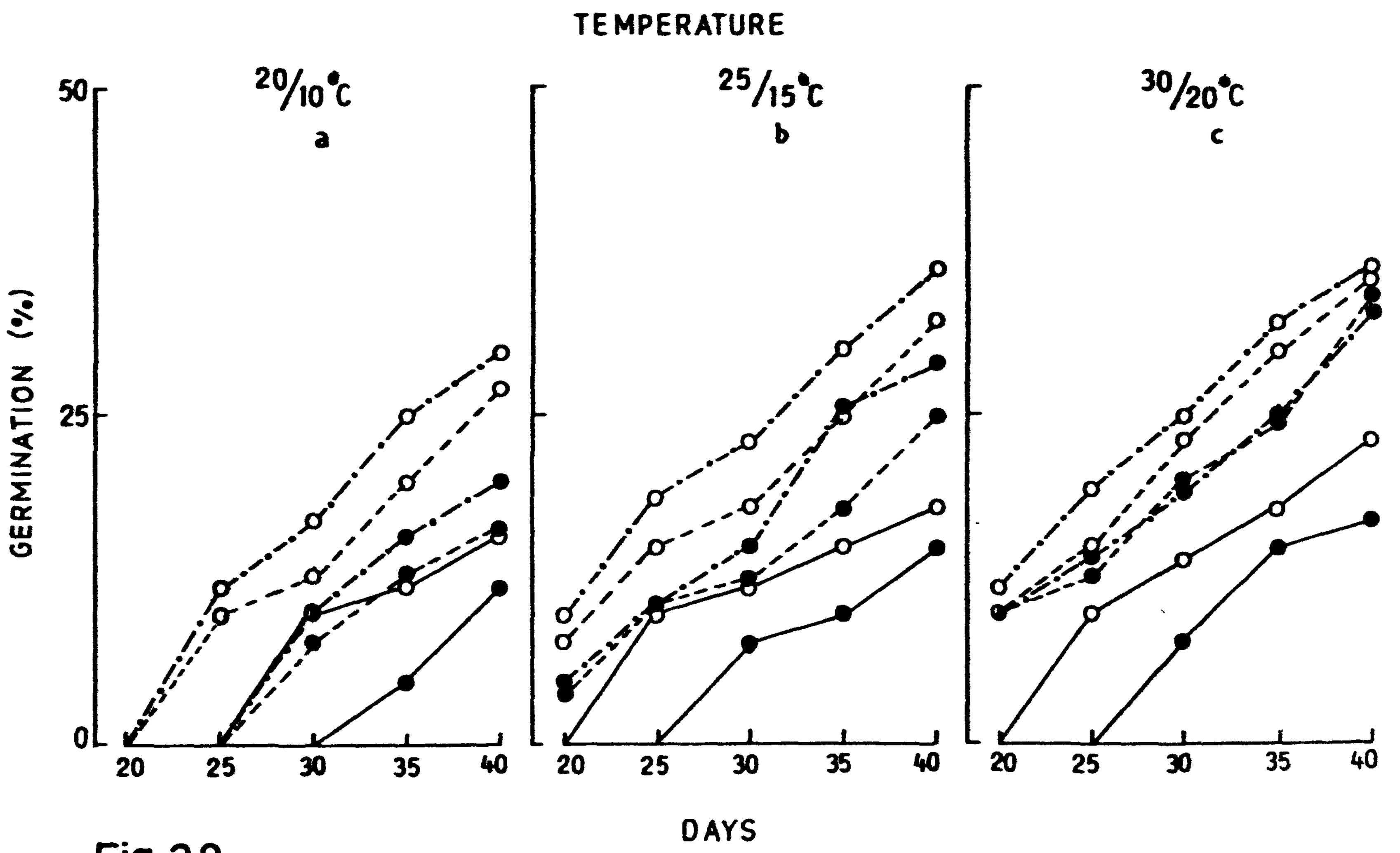

TEMPERATURE
20/10°C
a
25/15°C
b
30/20°C
c
GERMINATION (%)
50
25
0
20
25
30
35
40
DAYS

Fig. 2·2

Fig. 2.3. Germination of buried seeds of *C. asiatica* under alternating temperatures in light and dark. Symbols as in Fig. 2.2.

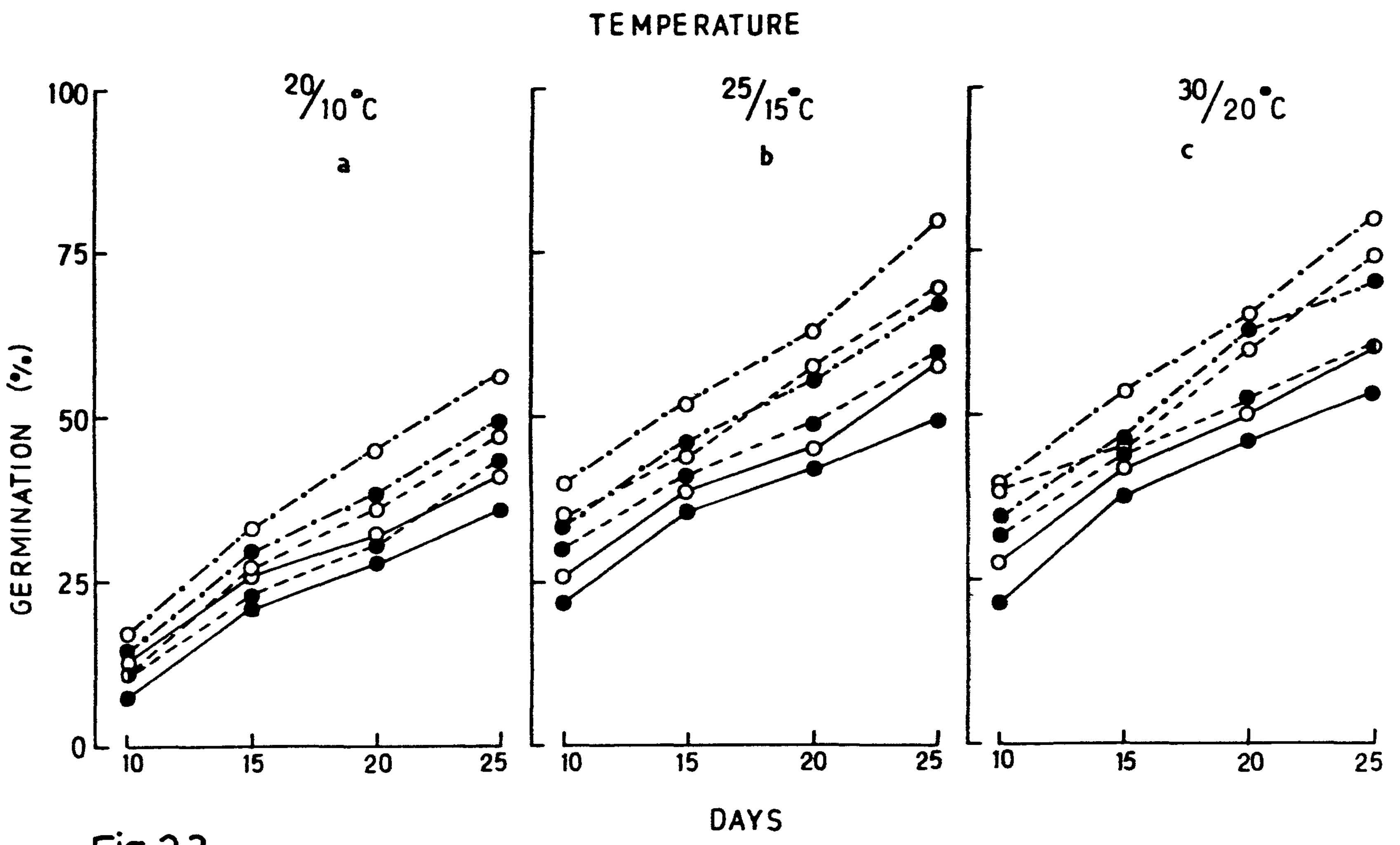
TEMPERATURE
20/10°C
a
25/15°C
b
30/20°C
c
GERMINATION (%)
100
75
50
25
0
10
15
20
25
DAYS

Fig. 2.3

tial emergence of seedlings from freshly collected seeds indicates a period of innate dormancy.

Although more seeds are produced at higher altitude, weight per hundred seeds (Chapter III Table 3.3) and seed viability (Table 2.1) were more at lower altitude. Larger seed size has been associated with a decrease in altitude (Clausen and Hiesey 1958 , Baker 1972). In the present study germination of the seeds collected from lower altitude was more as compared to higher altitude seeds. Wuff (1986) reported that an increase in seed size is positively correlated with emergence capacity and similar results were reported by Werner (1977, 1979) and Rai and Tripathi (1982).

C. asiatica seems to depend mainly on vegetative propagation for maintaining and increasing its population size. This confers a great adaptive advantage on the species as it can escape the adverse effect of environmental hazards on the sensitive seedling phase by laying least emphasis on reproduction by seeds. In a comparative study of biennial and perennial species of Umbelliferae, Lovett Doust (1980) found that the seed production in the biennials was eight times that of perennial species. At present the factors contributing to a successful germination strategy within the species is quite obscure. Further, no specific information for comparison is available in the literature on the germination response of this species. The experimental conditions used for the germination study were extremely simple compared to the complex fluctuations of many factors and their interactions in nature. Therefore, a detailed study of germination ecology of *C. asiatica* is called for.

CHAPTER III

Phenology and growth of *Centella asiatica* in relation to altitude, season and associated plant species

INTRODUCTION

Plant growth is directly related to environmental factors. Phenology, and its relation to the climate and changes in season, is a central focus of several aspects of ecology (Kelman-Weider et al. 1984). Phenological behaviour of few species have been described by Caldwell (1969), Morgan (1971), Anderson & Loucks (1973), Whigham (1974), Brovillet & Simon (1979) and Mahall & Bormann (1980). The study of plant species in relation to elevational gradient has greatly aided the understanding of plant growth and reproduction (Jolls 1982). Many workers (e.g. Mooney 1963, Ward 1969, Rochow 1970, Pearcy & Ward 1972, Todaria & Purohit 1980, Woodward & Jones 1984) have studied the differences between plant populations along an elevational gradient. Resource allocation patterns at different altitudes have also been studied by Clausen et al. (1940, 1948), Johnson & Cook (1968), Kawano & **Masuda** (1980) and Jolls (1984). Again, by documenting seasonal changes in biomass and its allocation amongst plant parts, the appropriate season for getting a good harvest can be clearly identified as pointed out by Titus & Stephen (1983). Seasonal fluctuations in growth and productivity of a few species have been worked out by Squiers & Good (1974), Montenegro et al. (1982) Naruhashi & Kobayashi (1982), Caye & Rassignol (1983) and Bulthuis et al. (1983).

Plants, due to their sedentary nature experience the environment only in their immediate fixed neighbourhood (Antonovics & Levin 1980). The space closely surrounding a plant may be viewed as representing a zone of light, water and nutrients that may be encroached on by neighbours (Matlack & Harper 1986). The relative fitness of individuals in plant communities is influenced mainly by the activity of other organisms, particularly neighbouring plants (Hartnett & Bazaaz 1985 b). Some workers have used either removal or addition experiments to assess the relationship of a single species to groups of other species e.g. grasses, in the community (Sagar & Harper 1961, Putwain & Harper 1970, Dwivedi & Tripathi 1980, Yadav & Tripathi 1984). When individuals have many neighbours close enough to compete with them, there will be positive as well as negative interaction amongst the individual as a result of competition (Fowler 1981, 1984). The presence of neighbours had a significant influence on the growth pattern of Vallisneria americana leading to taller plants with fewer rosettes (Titus & Stephen 1983). Yadav & Tripathi (1984) observed that the associated species caused spectacular reduction in survival and growth of the transplants of the three Eupatorium spp.

In view of the above, a study was conducted to investigate the effect of altitude, season and associates on the pattern of growth and biomass allocation in *C. asiatica* in the field condition. Such study might permit us to understand its growth at different altitudes, the appropriate season for getting good harvest and also how it reacts with its neighbours.

MATERIALS AND METHODS

(i) Effect of altitude :

Three study sites viz.Shillong Peak, Shillong and Barapani located at 1955, 1500 and 900 m altitude respectively, were chosen for studying the effect of altitude on *C. asiatica*. *C. asiatica* grows well on all the three locations. The study plots on each site represented open wastelands. Temperature and rainfall data and certain physical and chemical characteristics of the soil on the three sites are given in Table 3.1.

For phenological study five permanent quadrats of 1m^2 were positioned at the three study sites. Densities of *C. asiatica* and other associated plant species were determined by quadrat method (Table 3.2). Each node with a rosette of leaves and root system in case of *C. asiatica* and each tiller in case of grasses was considered as individual plant. The size of the quadrats used for density determination was 1m^2. In each plot individuals of *C. asiatica* present at the beginning of the study were marked.

Table 3.1. Altitude, light condition, temperature, annual precipitation, soil moisture content, soil texture, and chemical properties of the soils of the three study sites.

	Shillong Peak	Shillong	Barapani
Altitude (m)	1955	1500	900
Light intensity (lux)	53700	52800	54400
Temperature (^{o}C)	Max.14.0-24.5 Min. 5.3-18.0	Max.14.0-24.5 Min. 4.7-16.5	Max.18.2-26.3 Min. 8.2-18.7
Annual precipitation (mm)	2626	2626	2457
Soil moisture content (%)	27.4	27.7	27.5
Sand (%)	75.8	78.0	88.0
Clay (%)	17.5	9.0	5.0
Silt (%)	9.7	13.0	5.0
Organic carbon (%)	2.29	1.77	0.86
P_2O_5 (Kg/Ha)	7.85	32.28	1.35
K_2O (Kg/Ha)	226.24	28.0	Trace
N (%)	0.18	0.19	0.14
p^H	4.6	4.7	4.75

On each observation date, shoots that came up subsequently from seeds or from stolon nodes were also marked. Number of individuals showing different growth phases such as seedling emergence, sprouting phase, vegetative growth and flowering and seedling phase were counted at every three months interval during March, 1983 to December, 1984. Leaf area, leaf number and length of petiole and stolon were also determined. For determining the growth of C. asiatica, 20 plants were uprooted randomly with the help of soil corer at each observation period from the areas adjacent to the permanent quadrats. Each harvest plot was sampled only once.

For determining the seed weight, five lots of hundred seeds each were taken from the seed populations collected from each site in the month of September and weighed. For the study of dry matter allocation pattern, the plants were washed in running water, the component parts were separated, oven-dried to a constant weight and weighed. Data for two years were averaged.

(ii) Effect of season :

The study was done at Shillong. The physical and chemical characteristics of the soil are given in Table 3.1. and the list of associated species in Table 3.2.

Table 3 2. List of plant species growing with *C. asiatica* and their density per m^2 (±S.E.) at the three study sites.

Plant species	Study sites		
	Shillong Peak	Shillong	Barapani
Anaphilis adnata DC.	4.4 ± 0.6	-	-
Ageratum conyzoides Linn.	-	3.1 ± 0.4	6.3 ± 0.9
Argemone mexicana Linn.	2.3 ± 0.4	-	-
Bidens pilosa (Linn.) D.Don	-	0.8 ± 0.1	0.4 ±0.05
Brunella vulgaris Linn.	9.7 ± 1.2	-	-
Commelina paludosa Bl.	8.1 ± 1.4	0.6 ± 0.1	-
Cynodon dactylon Pers.	22.2 ± 3.7	10.6 ± 1.3	16.4 ± 2.0
Cyanotis cristata Linn.	-	-	3.3 ± 0.6
Cyperus cyperinus (Retz.) Vahl.	2.4 ± 0.2	-	15.5 ± 2.2
Eupatorium adenophorum Spreng.	2.1 ± 0.4	2.1 ± 0.4	-
Geranium nepalensis Sw.	6.4 ± 0.9	-	-
Hypochaeris radicata Linn.	6.0 ± 0.7	5.6 ± 0.8	3.2 ± 0.5
Hydrocotyle rotundifolia Roxb.	2.1 ± 0.3	3.0 ± 0.4	-
Imperata cylindrica Beauv.	10.3 ± 1.7	13.1 ± 1.6	17.2 ± 2.2
Oxalis corniculata Linn.	14.4 ± 1.8	18.8 ± 2.0	19.6 ± 2.5
Oxalis latifolia HBK.	1.2 ± 0.2	6.3 ± 0.8	-
Osbeckia nepalensis Hkf.	3.9 ± 0.5	-	-
Plantago major Linn.	-	3.4 ± 0.4	-
Panicum indicum Linn.	-	-	16.6 ± 2.8
Paspalum dilatatum Poir.	-	8.2 ± 1.2	6.3 ± 0.7
Pennisetum clandestinum Hochst ex chior	-	18.0 ± 3.1	23.1 ± 2.9
Setaria glauca (Linn.) P. Beauv.	-	6.4 ± 0.9	-

The permanent quadrats which were marked for studying the effect of altitude were used for the present study as well. However, phenology and growth parameters were recorded at monthly intervals over a 2-year period from June, 1983 to May, 1985. In the month of February the above ground parts are killed during winter months due to prevailing soil moisture stress and low temperature. Therefore, only standing dead material and belowground parts could be harvested during winter months. The roots were excavated by digging the soil, washed thoroughly with fine jet of water before determining the oven-dried weight. Growth parameters for which data were recorded during different seasons are same as described under part (i) of materials and methods. Data for two years were averaged.

(iii) Effect of associates :

The field experiment was performed in an abandoned plot on the campus of the School of Life Sciences, North Eastern Hill University, Shillong. The experiment continued for two years from June, 1983 to May, 1985.

The study plot had a uniform vegetational cover. Ten permanent quadrats of $1m^2$ were laid in the plot. From five quadrats all plant species except C. asiatica were removed at frequent intervals. In the remaining five quadrats all the plant species were allowed to grow as such and their density was recorded in August, 1983 & 1984. (Table 3.3). The area was fenced with bamboos to protect it from any external disturbances. Density and growth of C.

Table 3.3. List of plant species growing with *C.asiatica* in the untreated plot and their density m^{-2} ($\pm$ S.E.) in August.

Plant species	Density
Cynodon dactylon Pers	14.0 ± 1.6
Digitaria adscendena (HBK.) Henr.	3.5 ± 0.4
Fimbristylis complanata (Retz.) Linn.	4.4 ± 0.6
Hypochaeris radicata Linn.	2.6 ± 0.4
Mariscus sumatrensis (Retz.) Koyama	4.9 ± 0.7
Oxalis corniculata Linn.	10.4 ± 1.3
Oxalis latifolia HBK.	5.3 ± 0.9
Paspalum dilatatum Poir	20.5 ± 2.6
Plantago major Linn.	2.6 ± 0.4
Setaria glauca Beauv.	3.8 ± 0.5
Trifolium repens Linn.	19.2 ± 2.7

asiatica were determined at monthly intervals over a 2-year period. Each node with a rosette of leaves and root system was considered as an individual plant. In the second year of study, four harvests were taken for dry weight estimation. Growth parameters and manner in which data were recorded on these, **were same as** described under part (i) of materials and methods.

RESULTS

(i) Effect of altitude :

The effect of altitude on phenology of C.asiatica is presented in Fig. 3.1. The plants that were dried up during winter start sprouting in March soon after the first showers of the season are received and weather becomes warmer. The individuals that show sprouting represent more than 50% of the total population. The seedlings appear in June and most of them are killed before the onset of cold season. The seedlings constitute a very low percentage of the total population. By December majority of the individuals had attained maturity. December also represents the close of the growing season, and the plants begin to turn brown and the aboveground parts become dried up in winter. The phenology of C.asiatica does not seem to be affected by the altitude.

Plants at lower altitudes produced longer petioles and stolons and greater leaf area and biomass as

Fig. 3.1. Percentage of total individuals of *C. asiatica* populations in different growth phases at different study sites representing three altitudes. Total density m^{-2} of *C. asiatica* is indicated above the corresponding bar. Growth phases ⁙ , sprouting (apparently dried plants showing sprouting after winter); ■ , seedling; ▥ , pre flowering; □ , flowering; ▨ , seeding.

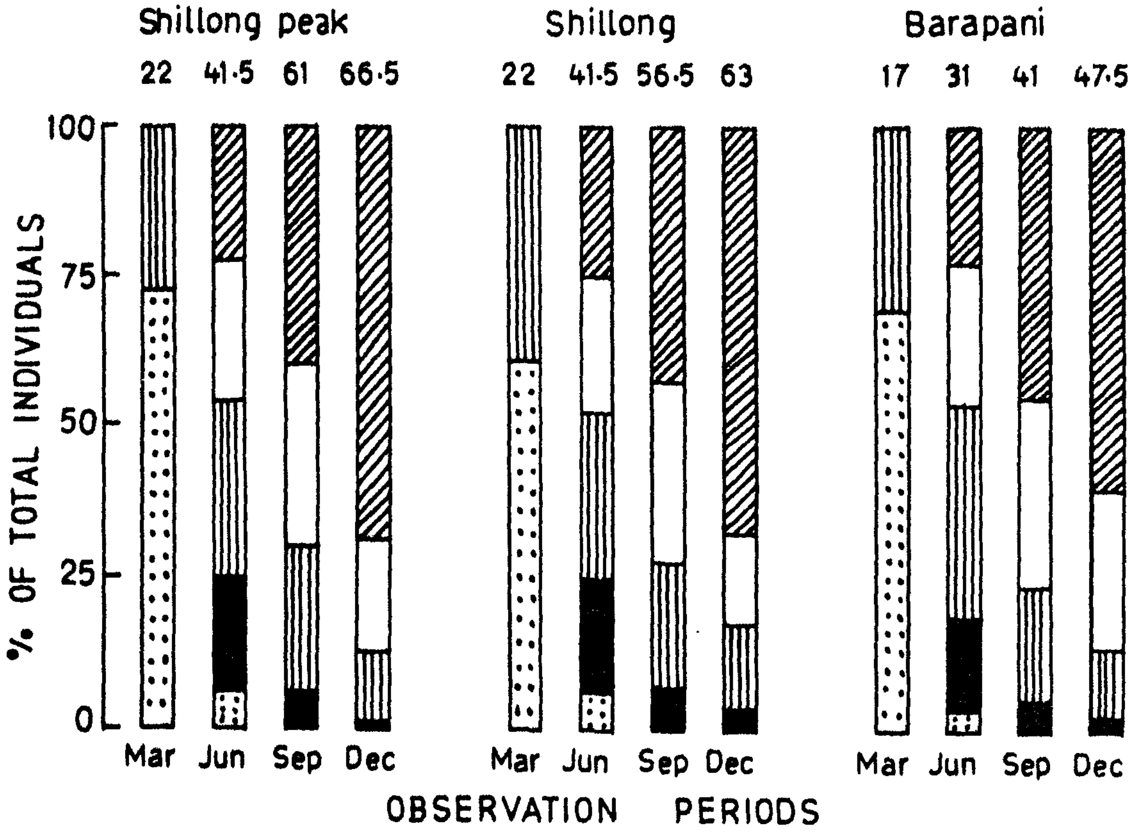

Shillong peak
22
41·5
61
66·5
Shillong
22
41·5
56·5
63
Barapani
17
31
41
47·5
% OF TOTAL INDIVIDUALS
100
75
50
25
0
Mar
Jun
Sep
Dec
Mar
Jun
Sep
Dec
Mar
Jun
Sep
Dec
OBSERVATION PERIODS

Fig. 3·1

compared to plants growing at higher altitudes (Fig.3.2, 3.3 & 3.4). Initially, there was no significant effect of altitude on the length of petiole and stolon, however, as the growth advanced the differences due to altitude became wider.

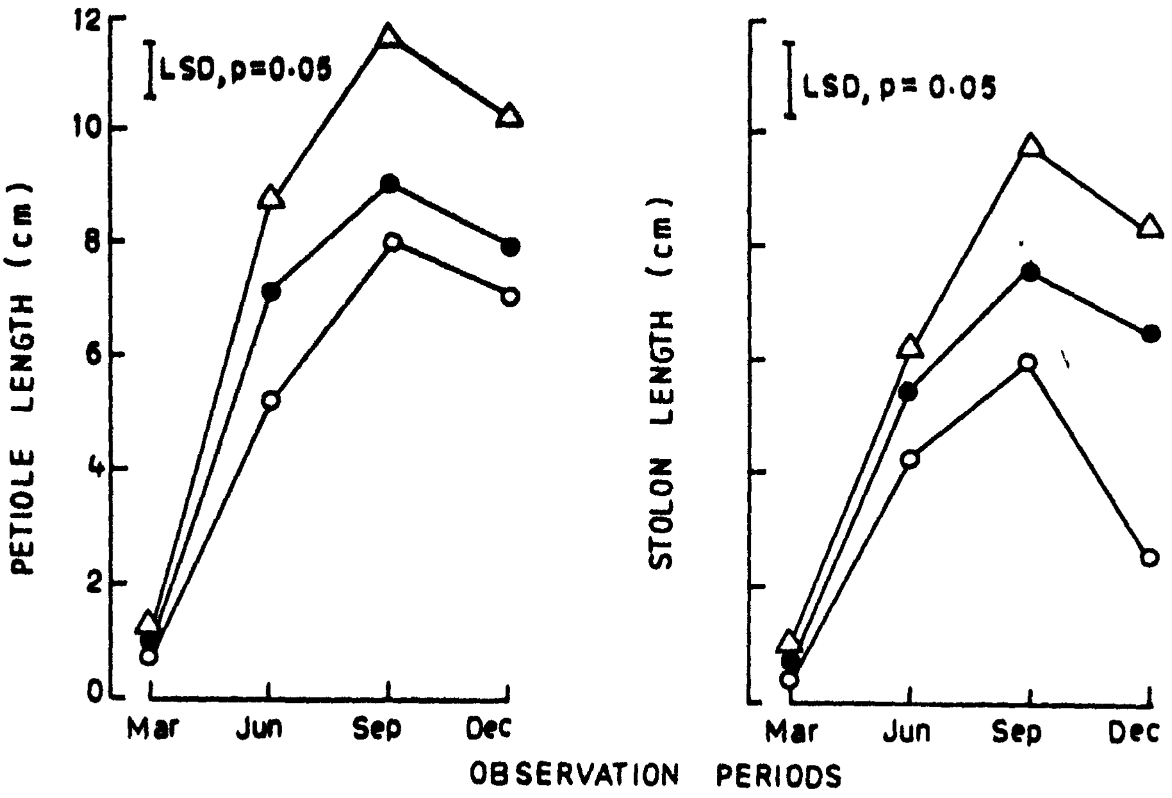
The number of seeds per plant was maximum in Shillong **Peak** population followed by Shillong population. However, the average weight per hundred seeds was maximum at Barapani (Table 3.4).

Table 3.4. Seed output per plant and weight per hundred seeds (± S.E.) of *C. asiatica* at the three study sites.

Study site	Number of seeds per plant	Per hundred seed weight (g)
Shillong Peak	19.0 ± 3.0	0.098 ± 0.015
Shillong	18.2 ± 2.7	0.112 ± 0.018
Barapani	14.4 ± 1.9	0.130 ± 0.021

Percentage dry matter allocation at all the three altitudes was maximum in leaves and roots and minimum in flowers and fruits. The allocation towards flowers and fruits was, however, greater at higher altitudes (Fig. 3.5).

Fig. 3.2. Length of petiole and stolon of *C. asiatica* at the three study sites. ○——○, Shillong Peak; ●——●, Shillong; △——△, Barapani.



12
10
8
6
4
2
0
LSD, p=0.05
PETIOLE LENGTH (cm)
Mar
Jun
Sep
Dec
LSD, p= 0.05
STOLON LENGTH (cm)
Mar
Jun
Sep
Dec
OBSERVATION PERIODS

Fig. 3·2

Fig. 3.3. Total leaf area per plant of *C. asiatica* at the three study sites. Symbols as in Fig. 3.2.

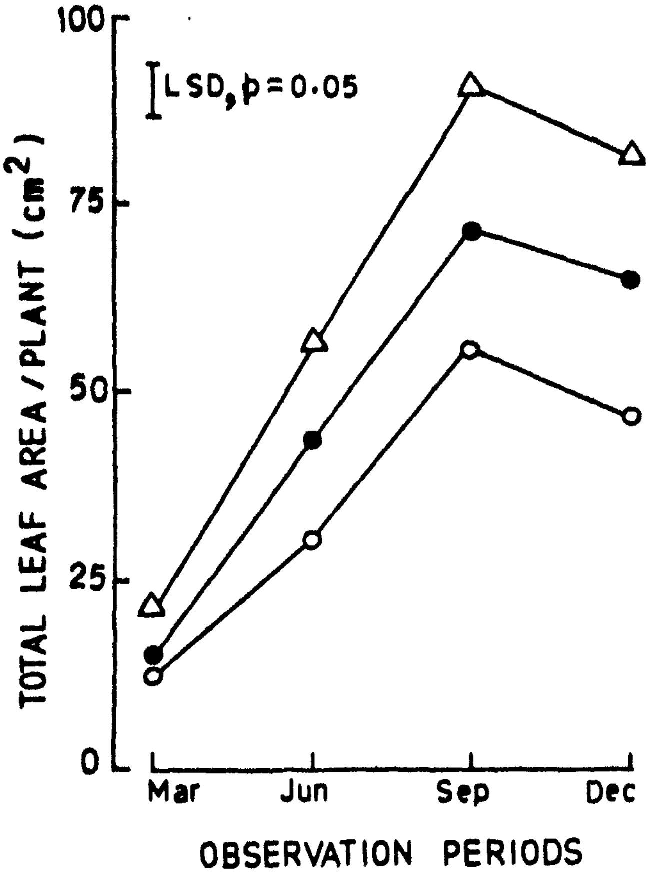
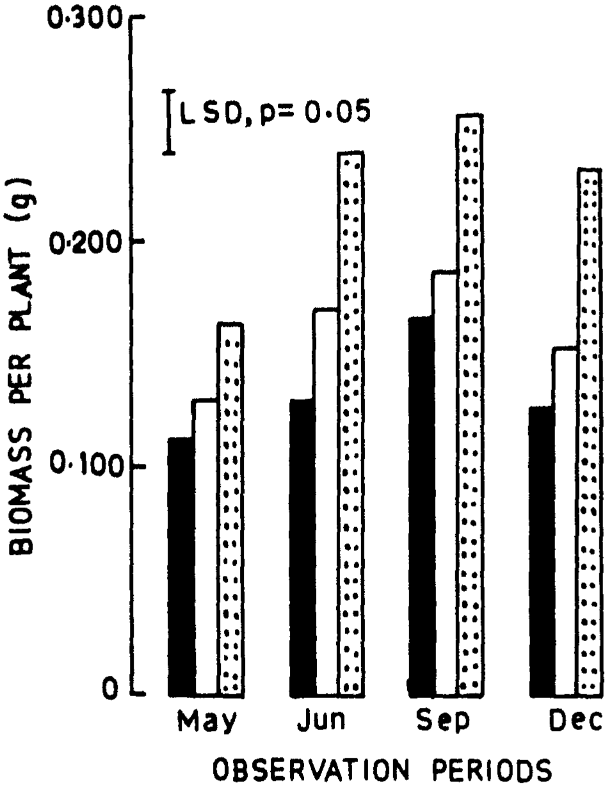

100
75
50
25
0
LSD, $p = 0.05$
TOTAL LEAF AREA / PLANT (cm^2)
Mar
Jun
Sep
Dec
OBSERVATION PERIODS

Fig. 33

Fig. 3.4. Biomass per plant of *C. asiatica* at the three study sites. ■ , Shillong Peak; □ , Shillong; ▦ , Barapani.


0·300
0·200
0·100
0
BIOMASS PER PLANT (g)
LSD, p= 0·05
May
Jun
Sep
Dec
OBSERVATION PERIODS

Fig·3·4

Fig. 3.5. Dry matter allocation to different plant parts of *C. asiatica* at the three study sites. ▥ , Root, ■ , stolon; □ , leaves; ▦ , standing dead; ▒ , flowers and fruits.

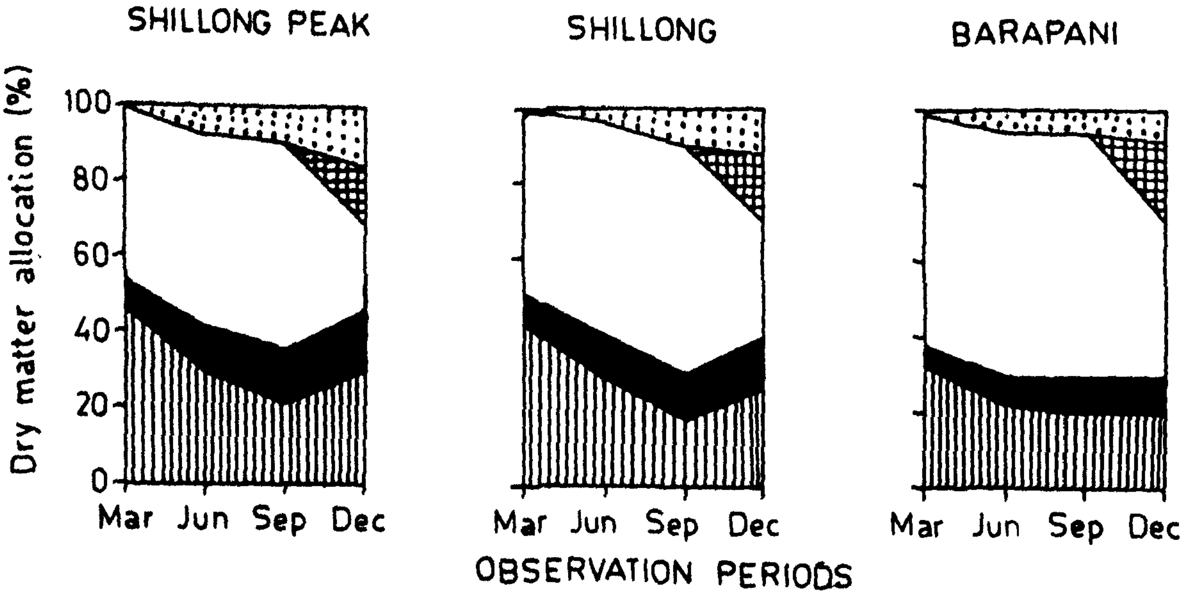

SHILLONG PEAK
SHILLONG
BARAPANI
Dry matter allocation (%)
100
80
60
40
20
0
Mar
Jun
Sep
Dec
OBSERVATION PERIODS

Fig. 3·5

(ii) Effect of season :

The phenology of *C. asiatica* as related to temperature and rainfall in different seasons are summarised in Table 3.5. The percentage of individuals at sprouting phase was > 50% in March after which it declined gradually. The plant reproduces by vegetative and sexual means. Those individuals that sprout early (i.e. March) start producing stolons which give rise to rosette at each node followed by flowering. That is why the percentages of individuals at flowering and seedling stages are higher as compared to individuals at other stages throughout the growing period except during March and April. Seedlings came up in June, but they constitute a very small percentage of the total population (Fig. 3.6). There were large seasonal variations in the leaf area and total biomass per plant over the experimental period (Fig.3.7). The values increased rapidly from June to September after which there was gradual decrease attaining minima in February. The above and belowground biomass allocation differed with time (Fig. 3.8). In general, accumulation of biomass was more in the aboveground parts than in belowground parts.

(iii) Effect of associates :

Surprisingly enough, length of petiole and stolon, leaf area and biomass were greater in the plots from where

Table 3.5. Growth activity of *C.asiatica* in relation to rainfall and temperature.

Months	Growth stage	Temperature range °C	Rainfall mm
Dec-Feb	Dormant or inactive state of growth	6.2-15.5	50.6
Mar-Apr	Sprouting of new leaves from the plants that had dried up in winter	13-23.4	94.2
May-Sep.	Active vegetative and reproductive growth phase	16.9-22.9	1930.65
Oct.-Nov.	Progressive decline in growth	11.9-20.0	172.05

Fig. 3.6. Percentage of total individuals of *C. asiatica* in different growth phases in natural population at Shillong. Growth phases - ░ ,sprouting (apparently dried plants showing sprouting after winter); ■ , seedling; ▥ , Pre flowering; □ , flowering; ▨ , seedling.

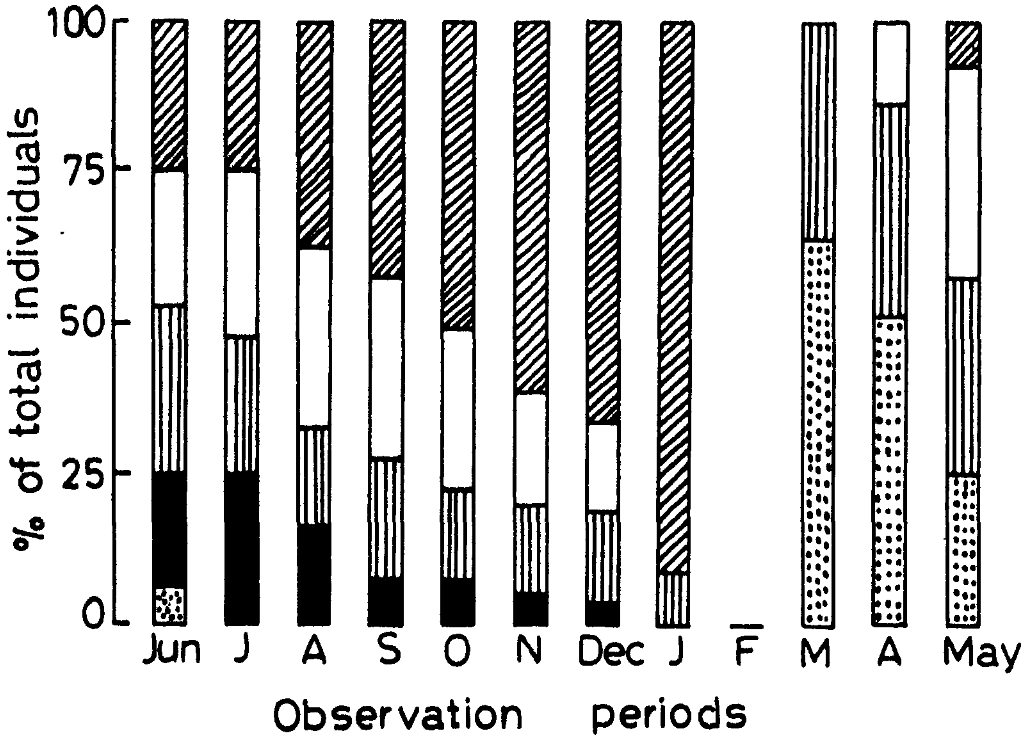

100
75
50
25
0
% of total individuals
Jun
J
A
S
O
N
Dec
J
F
M
A
May
Observation periods

Fig. 3·6

Fig. 3.7. Monthly changes in the leaf area and biomass per plant of *C. asiatica* as related to climatic conditions of Shillong.

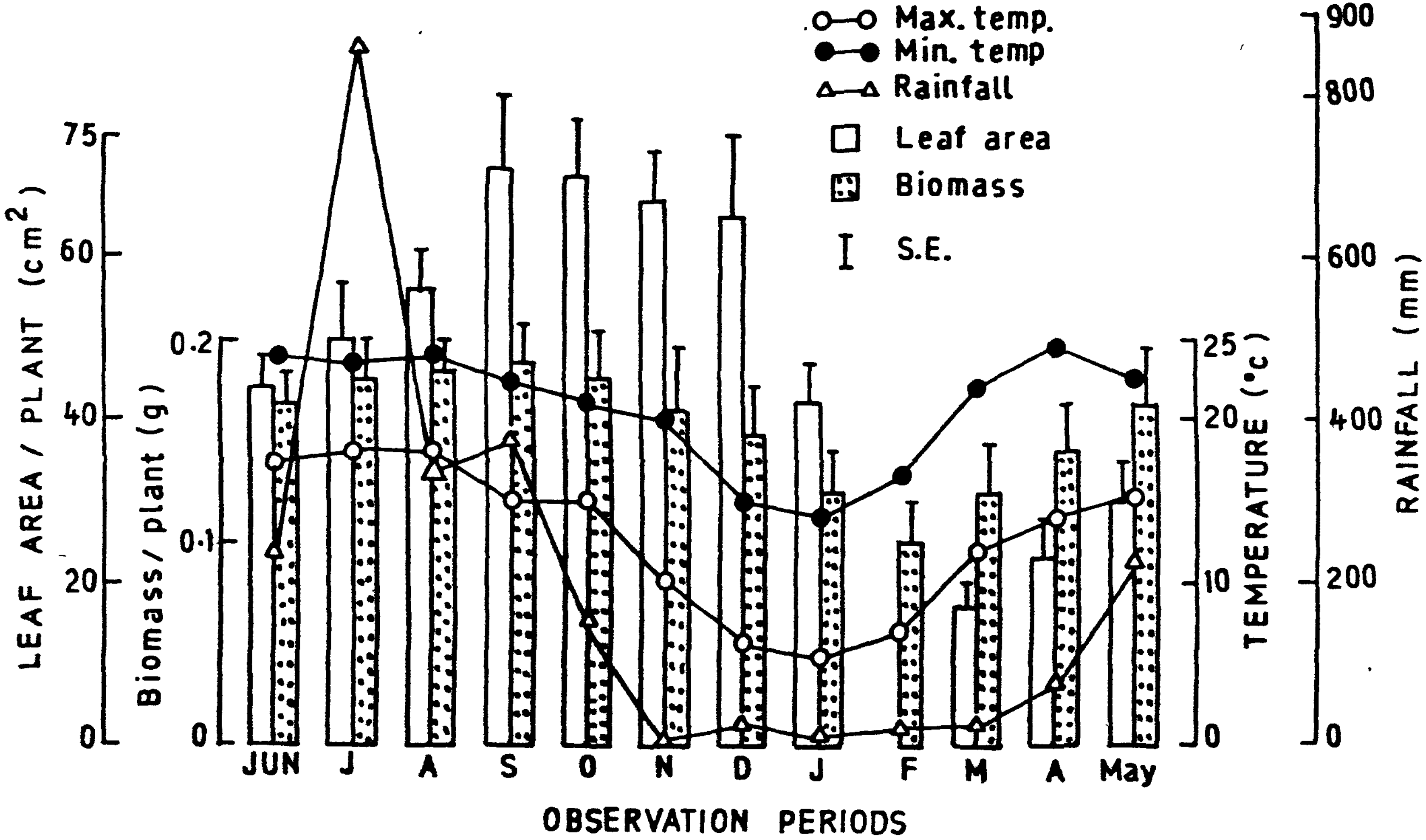
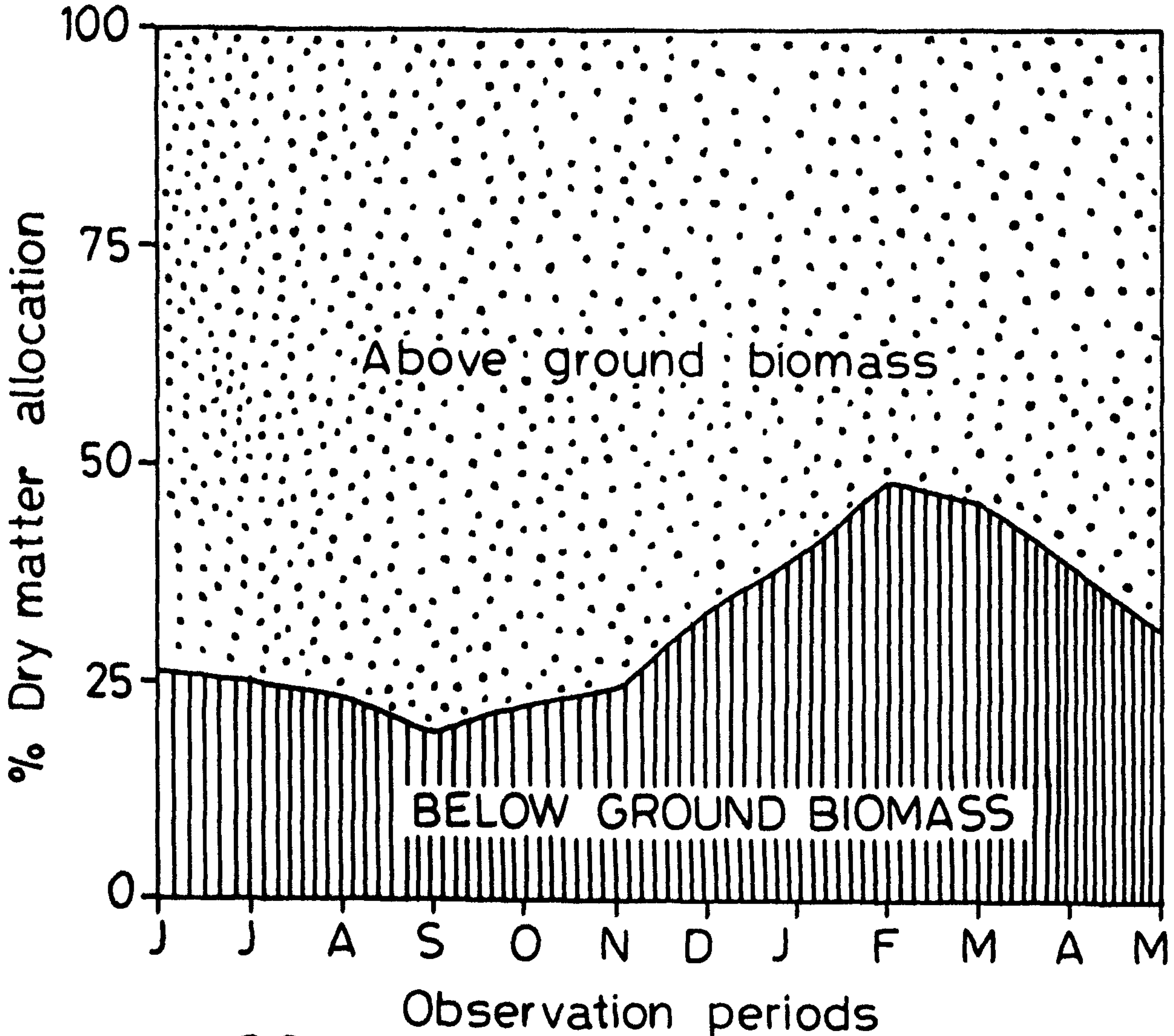

Max. temp.
Min. temp
Rainfall
Leaf area
Biomass
S.E.
LEAF AREA / PLANT (cm^2)
75
60
40
20
0
Biomass/ plant (g)
0.2
0.1
0
TEMPERATURE (°c)
25
20
10
0
RAINFALL (mm)
900
800
600
400
200
0
JUN
J
A
S
O
N
D
J
F
M
A
May
OBSERVATION PERIODS

Fig. 3.7

Fig. 3.8. Seasonal changes in biomass allocation to the above and below ground parts of C. asiatica.



% Dry matter allocation
100
75
50
25
0
Above ground biomass
BELOW GROUND BIOMASS
J
J
A
S
O
N
D
J
F
M
A
M
Observation periods

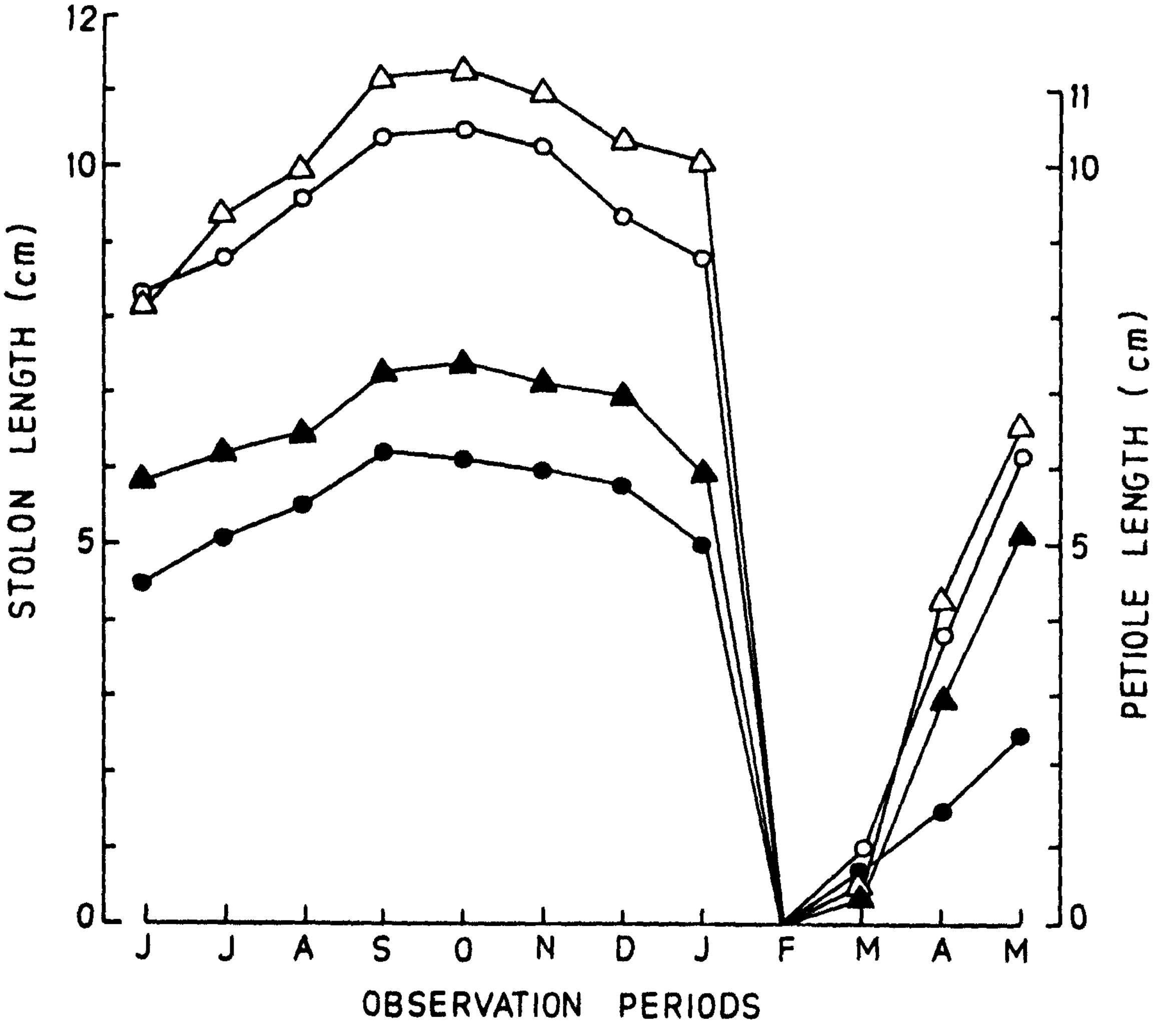
Fig. 3·8

the associated vegetation was not removed (Fig.3,9,3.10 & Table 3.6). The values for all the parameters increased steadily from March to October and declined afterwards, attaining the minima of zero in February. On the other hand, density of _C. asiatica_ was more in the plots where the associated species were not allowed to grow (Table 3.7). There was greater allocation of dry matter to the leaves and roots than to other plant parts in both the treatments (Fig.3.11). Although the allocation towards stem was almost same in both treatments, the reproductive allocation was more in the plot where _C. asiatica_ grew without any competition from other plant species.

DISCUSSION

The sprouting of plants that had dried-up during winter season coincided with rise in temperature in March. The vegetative and reproductive growth were also correlated with temperature as well as precipitation (Table 3.5). Maximum temperature accompanied with heavy rainfall appears to be conducive for the plant growth. The plant is sensitive to low temperature and moisture stress, and from October onward, the plant growth declines attaining minima in February. Such a study of various phases in time sequence reveals a phenological calender which begins with the rise

Fig. 3.9. Length of petiole and stolon of C. asiatica as affected by the associated species. Circles for petiole length and triangles for stolon length. Open symbols - with associates, filled symbols - without associates.



STOLON LENGTH (cm)
PETIOLE LENGTH (cm)
OBSERVATION PERIODS
12
10
5
0
11
10
5
0
J
J
A
S
O
N
D
J
F
M
A
M

Fig. 3·9

Fig. 3.10. Leaf area per plant of *C. asiatica* as affected by the associated species. □ , without associates; ▦ , with associates.

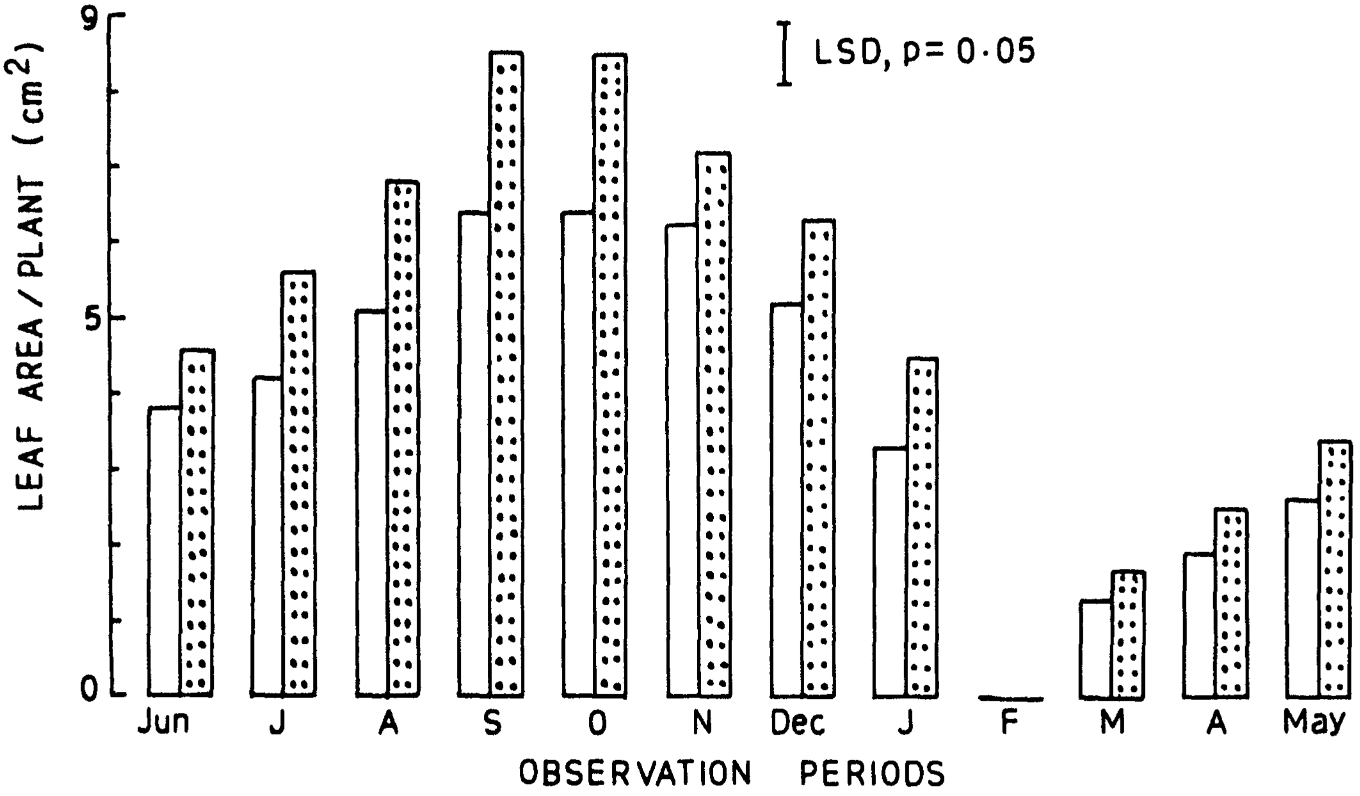

LEAF AREA / PLANT (cm^2)
9
5
0
LSD, p= 0·05
Jun
J
A
S
O
N
Dec
J
F
M
A
May
OBSERVATION PERIODS

Fig. 3·10

Table 3.6. Dry matter yield per plant (g) of C. asiatica as affected by the associated species.

	With associates	Without associates
June	0.177 ± 0.029*	0.135 ± 0.022
September	0.219 ± 0.036	0.154 ± 0.025
December	0.157 ± 0.025	0.122 ± 0.020
March	0.118 ± 0.019	0.087 ± 0.014

* ± S.E.

Table 3.7. Periodic change in density m^{-2} of C. asiatica as affected by the associated species.

Months	With associates	without associates
June	24 ± 3.2*	29 ± 3.4
July	29 ± 3.7	37 ± 4.5
August	35 ± 5.5	45 ± 5.6
September	43 ± 5.8	54 ± 7.6
October	47 ± 6.3	63 ± 8.5
November	51 ± 6.8	72 ±10.5
December	54 ± 7.2	70 ±10.5
January	26 ± 3.7	21 ± 5.8
February	0	0
March	22 ± 2.9	18 ± 2.3
April	25 ± 3.6	24 ± 3.3
May	29 ± 3.5	31 ± 4.2

* ± S.E.

Fig. 3.11. Dry matter allocation to different parts as affected by the associated species. ▥ ,Root; ▦ , stolon; □ , leaves; ░ , flowers and fruits.

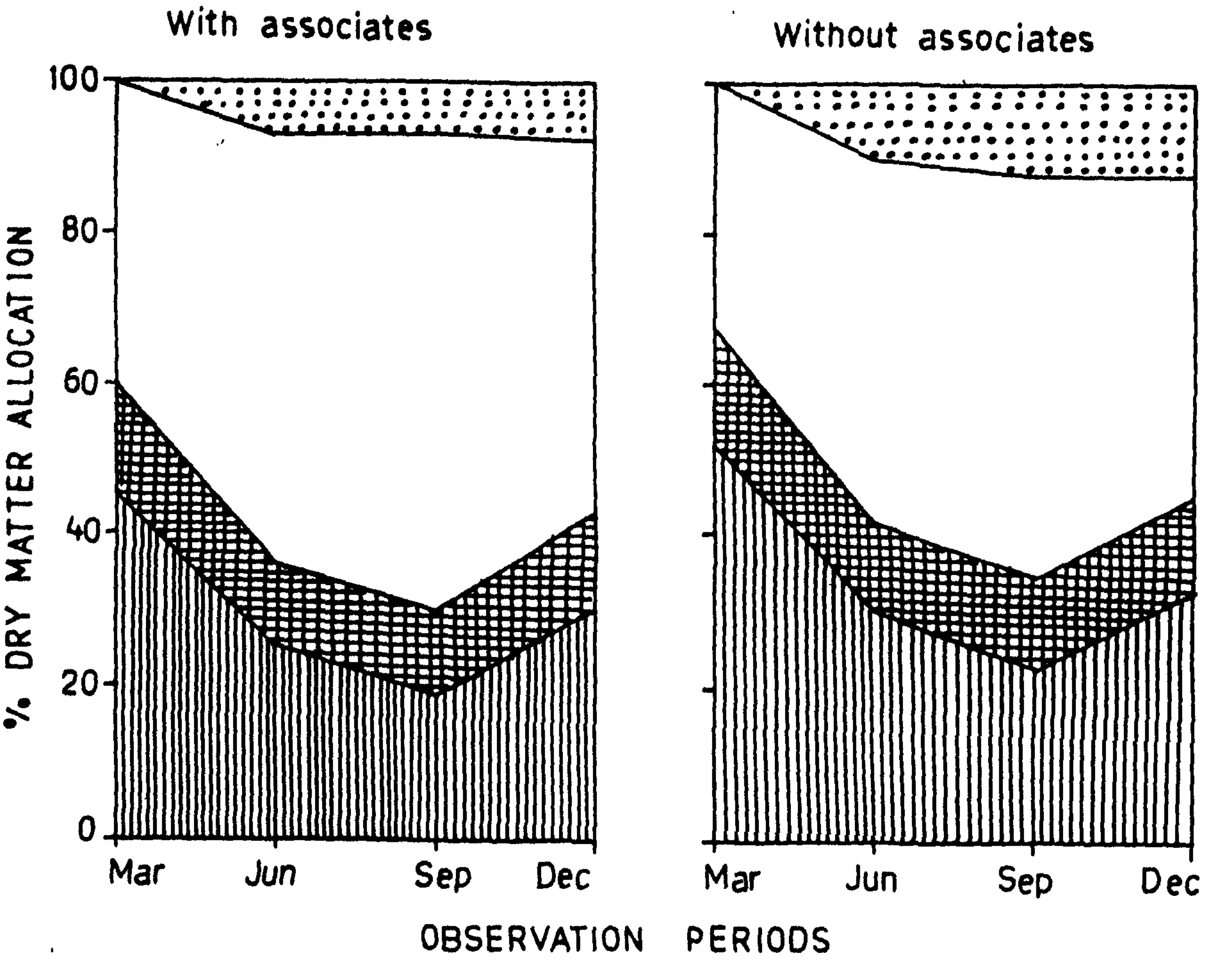

With associates
Without associates
% DRY MATTER ALLOCATION
100
80
60
40
20
0
Mar
Jun
Sep
Dec
Mar
Jun
Sep
Dec
OBSERVATION PERIODS

Fig. 3·11

in temperature.Observed similarity in phenology amongst the populations of *C. asiatica* at the three altitudes indicates that local environmental variations do not affect phenological events significantly.

Seasonal variation in growth of *C. asiatica* may be ascribed to the change in climatic conditions (Kozlowski 1971). Poor growth of C. asiatica in winter may be linked with the prevailing soil moisture stress and low temperature, and the best growth in summer may be attributed to the favourable temperature and soil moisture. Better growth during the rainy season has also been observed by Shahi *et al.* (1981) in Jammu lemon grass, Shahi & Singh (1983) in Jamrosa grass and Misra & Misra (1984) in other grasses. Greater allocation towards the belowground parts in winter months (Fig.3.8) reflects the perennial habit and adaptive response of the plant to prevailing moisture stress and low temperature.

Better growth of the plants at low altitude agrees with the observations of Kira & Shidei (1967), Yoda (1968), Maruyama (1971), Todaria & Purohit (1979) and Jolls (1980) in other plant species. This could be attributed to the warmer climate at low altitude (Table 3.1).Woodward & Pigott(1975) reported that the differences in the growth of *Sedum telephium* at different altitudes are probably due to small changes in air temperature and irradiance. The decrease in per plant biomass at higher densities may result from increased competition for limited resources (Culver & Beattie 1973, Holler & Abrahamson 1977, Tripathi & Gupta 1980, Thompson & Beattie 1981). Seed output per plant was more at higher altitude while, seed weight per hundred seeds was more at lower altitude (Table 3.2). Clausen & Hiesey (1958) also observed that higher altitude plants tend to have smaller seeds. Greater allocation of dry matter towards the roots and leaves and highly reduced allocation to seed production indicates that C. asiatica lays greater emphasis on competitive function than on sexual reproduction. An increased allocation to seed with increase in elevation as observed in the present study has also been reported in Heloniopsis orientalis (Kawano & Masuda 1980) and in Mimulus primuloides (Douglas 1981).

In the presence of associated vegetation C. asiatica produced longer petiole and stolon and larger leaf area but few daughter rosettes. On the contrary, it produced larger number of daughter rosettes when it grew without competition from the associated vegetation. This is in agreement with the findings of Titus & Stephen (1983) in Vallisneria americana. Fenner (1978) discussed that the ability of Achillea millefolium to escape from shade by an increase in leaf length could influence the optimum height required for a competitor to reduce the other plant's growth rate. Such morphological adaptability allows some avoidance of shade in *A.millefolium*.Schmid (1985a) observed that rosette density in *Bellis perennis* was stable with time and little affected by the removal of either grasses or dicotyledonous species,whereas in *Prunella vulgaris*, the module density changed clearly with time and was influenced by the presence of other dicotyledonous species in the sward. *C. asiatica* responded to competition from the associates by increase in leaf area, petiole length and stolon length which may be viewed as a competitive strategy to maximise capture of resources under increased intensity of competition. Many workers(e.g. Putwain & Harper 1970, Sagar & Harper 1970, Tripathi & Dwivedi 1978, Dwivedi & Tripathi 1980, Yadav & Tripathi, 1984) reported the adverse effect of the associated species especially grasses on vegetative and reproductive growth of some plant species. Though grasses dominate the study site in the present study (Table 3.3) they did not cause any reduction in plant growth except stolon and rosette production. This unique character of *C. asiatica* to grow successfully in presence of grasses confers on it an additional advantage in its natural habitat. More stolon production by the plant in the absence of associates may be interpreted as a response to the availability of more space for spread as also emphasised by Titus & Stephen (1983) in Vallisneria americana and Liddle et al. (1982) in Festuca rubra.

The allocation pattern of biomass indicates that the plant lays more emphasis on vegetative growth than seed production. On the whole, it seems that C. asiatica devotes more energy to vertical extension in the presence of associates and to horizontal extension in the absence of the associates.Pickett & Kempf (1980) commented that the clonal form of some shrubs permits exploitation of a broad horizontal area relatively cheaply. Stolon production is viewed as a competitive growth form adapted to resource gathering so that a clone may horizontally exploit the habitat more effectively (Thompson & Beattie 1981).

CHAPTER IV

Population dynamics of *Centella asiatica* in a 2-year and 6-year old fallow

INTRODUCTION

One of the most widespread forms of asexual reproduction in plants is clonal growth habit (Cook 1983, Hartnett & Bazzaz 1983). Study on the population dynamics of perennial clonal plants is an attractive but elusive goal for population geneticists and ecologists (Noble *et al.* 1979). This is largely because of the intractable problems associated with research into such plants, for example, the occurrence of overlapping generations (Sagar & Mortimer 1976), the difficulty of defining an individual plant (Jansen 1977) and the existence of both vegetative and seed reproduction (Thomas & Dale 1975). The variability in the magnitude and direction of changes in the number of shoots from site to site highlights a major problem in demographic analysis as indicated by Barkham (1980). Acquiring ramet data from natural populations of cloning plants is difficult because the ramet connections are mostly underground making it difficult to establish the genet's boundaries and the ramet connections usually decay in a relatively short time (Dickerman & Wetzel 1985). In recent years demographic analysis including dynamics of many perennial plants growing in natural habitat was made by a number of workers (e.g. Sarukhan & Harper 1973, Noble *et al.* 1979, Barkham 1980, Solbrig *et al.* 1980, Lovett Doust 1981a,b,c, Newell *et al.* 1981, Yadav & Tripathi 1981, 1982, Kushwaha *et al.* 1981, Kushwaha et al. 1983 b, Schellner et al. 1982, Cook 1983). However, little work has focussed on the effect of soil disturbances on the population dynamics of perennial plants (Froud-Williams et al. 1984, Miyanishi & Cavers 1981).

C. asiatica grows well in disturbed and undisturbed habitats. It is also an early colonizer in abandoned jhum fallows in the hilly terrain of north-east India. The present study investigates the effect of soil disturbance on population dynamics of C.asiatica in a 2-year and 6-year old jhum fallows.

MATERIALS AND METHODS

Study area :

Two jhum fallows of different ages, 2-year and 6-year old, were selected in Upper Shillong. Physical and chemical properties of the top 10 cm soil of both the fallows are given in Table 4.1. Further, in each fallow disturbed and undisturbed plots were marked. The disturbed plots were created by hoeing the soil with spade as is usually practiced in cultivated fields.This was done in the month of February 1984 before the onset of sprouting from the plants that remained dried up during the winter season. The same process was repeated in February 1985. The densities of the associates of C. asiatica present in the disturbed and undisturbed permanent quadrats on the two sites

Table 4.1. Physical and Chemical characteristics of the soil on the 2-year and 6-year old fallow.

Soil character	2-year old fallow	6-year old fallow
Porosity (%)	38.5	18.9
Sand (%)	54.3	49.0
Silt (%)	29.4	33.2
Clay (%)	16.3	17.8
Organic matter (%)	6.2	3.9
p^H	6.2	5.5

were recorded in the month of August 1984, 1985 (Table4.2), and the data were averaged for two years.

Method :

Five permanent quadrats of $1m^2$ were marked in disturbed and undisturbed plots of each fallow. The population dynamics of adult plants or ramets was followed from March, 1984 over a 2-year period. Each node with a rosette of leaves and root system was considered as an individual plant. Since germination of the seeds commences from July, for the study of population dynamics of the genets, a cohort of seedlings was marked in each of the five permanent quadrats in July 1984, 1985 which represent the peak germination period. Individuals arising from stolons and seeds were marked with paint of different colours. The survival of adults was recorded at monthly intervals and that of seedlings at fortnightly intervals. The study was carried out over a 2-year period from March, 1984 to February, 1986.

For estimating seed population in soil, ten soil samples representing 25 cm^2 area and 2 cm depth were collected from each of the two fallows. Soil samples were air dried, seeds were sorted manually and tested for viability and germination.

Table 4.2. Density m^{-2} of the associates of *C. asiatica* in the disturbed and undisturbed permanent quadrats of the 2-year and 6-year old fallow.

Plant species	2-year old fallow		6-year old fallow	
	Disturbed	Undisturbed	Disturbed	undisturbed
Ageratum conyzoides Linn.	1.6 ± 0.2	3.2 ± 0.4	-	-
Artemisia nilagirica (Cl.) Pamp.	-	-	-	0.4 ± 0.05
Bidens pilosa Linn.	0.9 ± 0.1	0.3 ± 0.04	1.4 ± 0.3	0.9 ± 0.18
Commelina paludosa Bl.	-	-	-	1.5 ± 0.25
Cynodon dactylon Pers.	4.1 ± 0.5	6.2 ± 0.9	14.2 ± 1.6	18.3 ± 2.3
Eupatorium adenophorum Spreng.	-	-	-	2.1 ± 0.4
Galinsoga ciliata (Raf.) Blake	25.4 ± 3.6	28.4 ± 4.1	-	-
Galinsoga parviflora Cav.	23.6 ± 2.9	23.0 ± 2.9	-	-
Hypochaeris radicata Linn.	-	3.4 ± 0.5	-	-
Imperata cylindrica Beauv.	-	4.3 ± 0.5	16.3 ± 2.0	23.3 ± 3.3
Oxalis latifolia HBK.	18.1 ± 2.3	15.6 ± 1.9	0.9 ± 0.2	4.6 ± 0.6
Oxalis corniculata Linn.	1.4 ± 0.2	4.3 ± 0.5	9.7 ± 1.2	2.4 ± 0.3
Panicum indicum Linn.	2.6 ± 0.3	4.3 ± 0.5	20.2 ± 2.5	24.0 ± 3.2
Paspalum dilatatum Poir.	-	-	19.0 ± 2.7	24.2 ± 3.0
Pennisetum clandestinum Hochst. ex Choir	-	3.4 ± 0.4	8.8 ± 1.5	12.4 ± 1.4
Plantago major Linn.	4.5 ± 0.5	4.1 ± 0.5	0.5 ± 0.06	2.0 ± 0.2

RESULTS

Adults of C.asiatica were consistently more numerous in the 6-year fallow than in the 2-year fallow. Further, the density of adults or ramets was greater on the undisturbed than on the disturbed plots (Fig.4.1a). In general, density increased rapidly from March to November, and then declined with the onset of winter season. Maintenance of population size was mainly by vegetative means or clonal growth (Fig.4.1b). No mortality occurred during the growing period (i.e. March to November) which indicates that once the plants had sprouted and established in March the chances of their survival are pretty high. Death of the aboveground shoots occurred during winter. The stolons connecting the rosettes also dried up. Well established rosettes with larger root system remained alive during cold months although in a dried state, and sprouted in spring (i.e. March), while rosettes which were not fully established failed to sprout and thus were lost from the population.

Recruitment of the seedlings was greater in the 6 year old fallow as compared to 2-year old fallow. Again, number of seedlings that appeared on the disturbed plots was approximately double the number of seedlings that appeared on the undisturbed plots. The data on the survival of seedlings (Fig.4.2) suggested that the mortality was more

Fig. 4.1. Adult population density (Fig.4.1a) and percentage vegetative recruitment of adults (Fig.4.1b) of C. asiatica on disturbed and undisturbed sites of a 2-year and 6-year old fallow during Mar. 1984 - Feb. 1986.

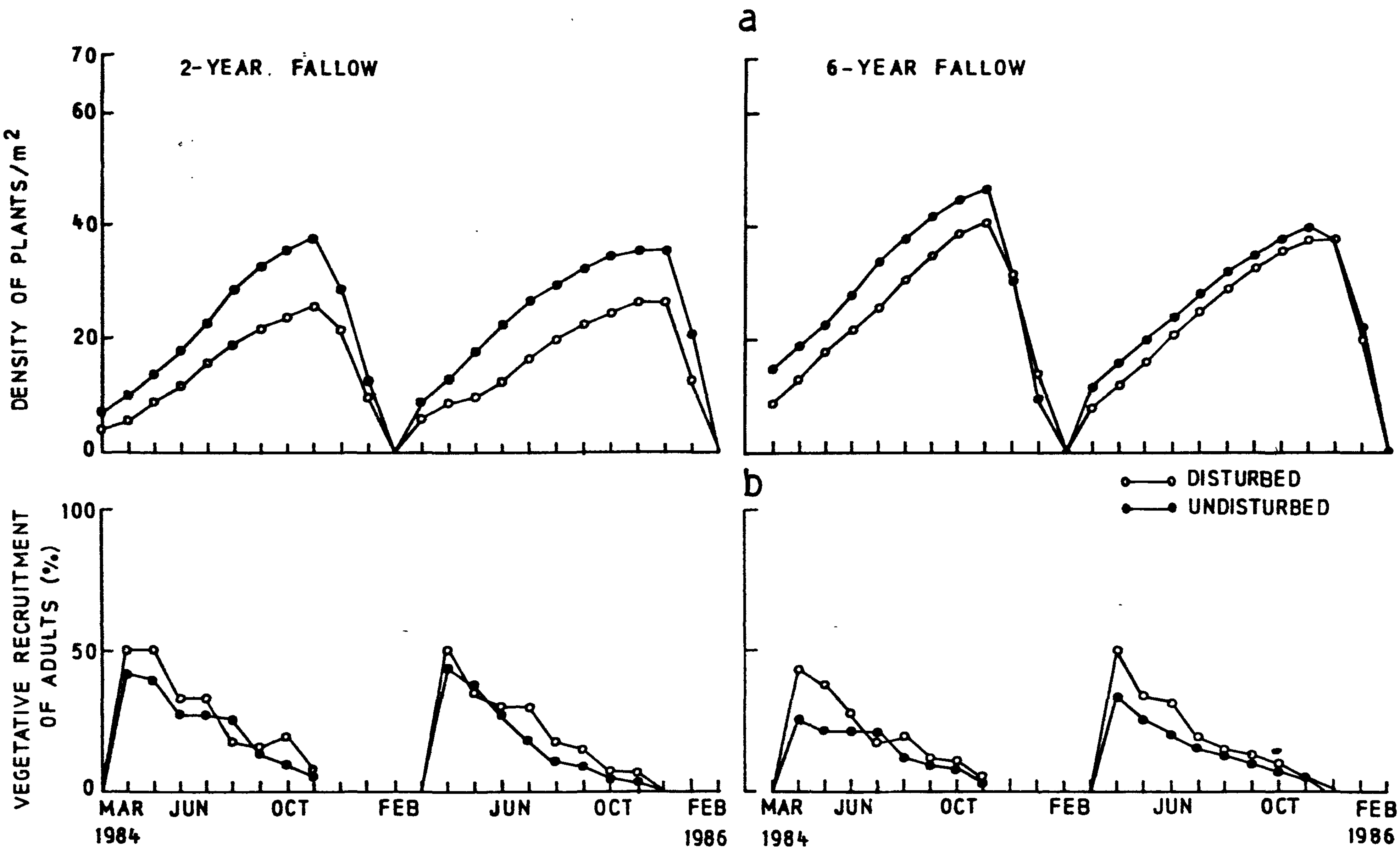

a
2-YEAR FALLOW
6-YEAR FALLOW
70
60
40
20
0
DENSITY OF PLANTS/m2
b
DISTURBED
UNDISTURBED
100
50
0
VEGETATIVE RECRUITMENT OF ADULTS (%)
MAR 1984
JUN
OCT
FEB
JUN
OCT
FEB 1986
MAR 1984
JUN
OCT
FEB
JUN
OCT
FEB 1986

Fig. 4·1

Fig. 4.2. Survivorship of seedlings of C. *asiatica* on disturbed and undisturbed sites of a 2-year and 6-year old fallow during Mar., 1984 - Feb., 1986.

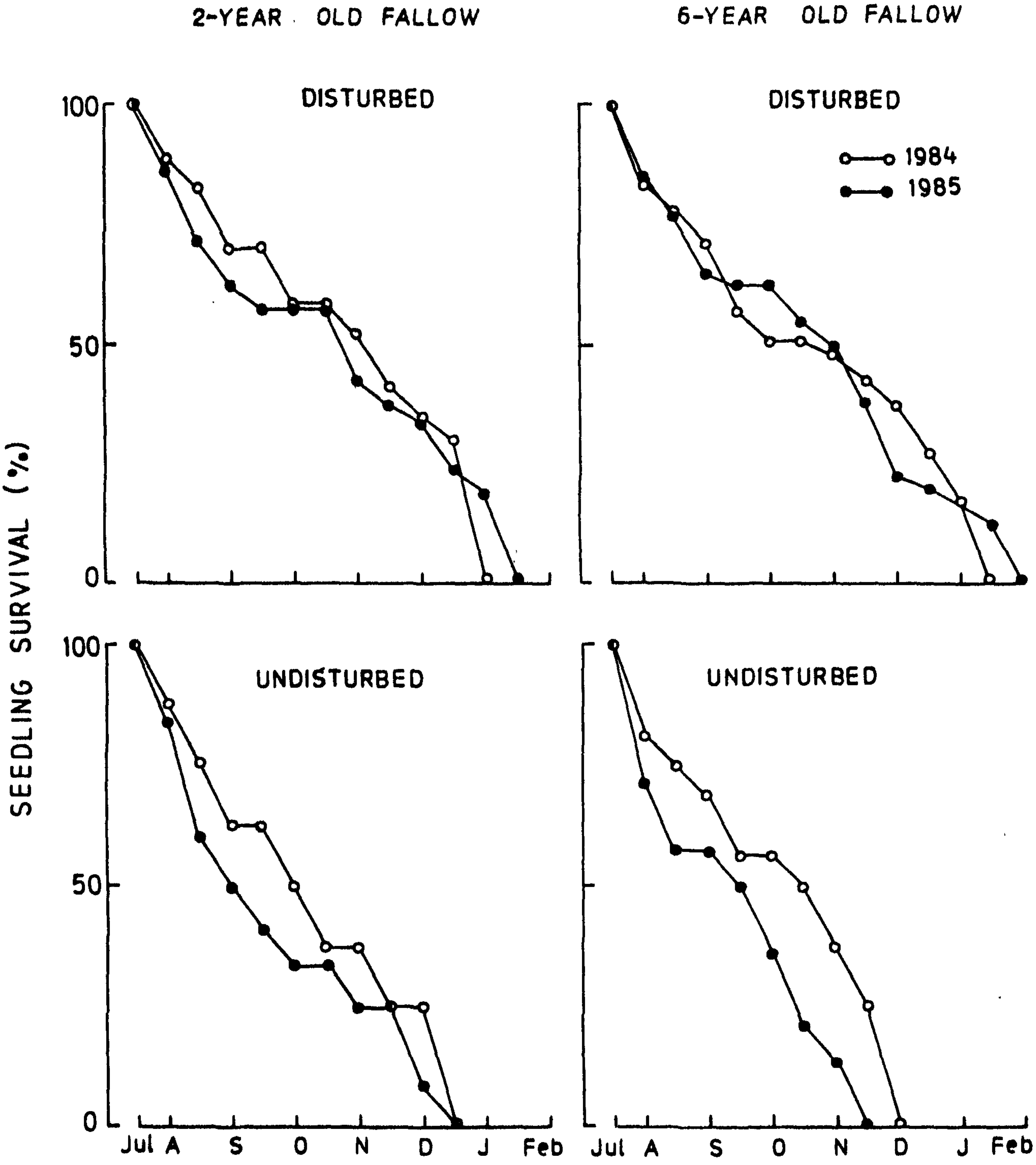

2-YEAR OLD FALLOW
6-YEAR OLD FALLOW
DISTURBED
DISTURBED
1984
1985
UNDISTURBED
UNDISTURBED
SEEDLING SURVIVAL (%)
100
50
0
100
50
0
Jul
A
S
O
N
D
J
Feb
Jul
A
S
O
N
D
J
Feb

Fig. 4·2

severe in the early life stages and this became gradually less with increasing age, but in winter all the plants died due to low temperature and high soil moisture stress. The loss of seedlings was always greater in the undisturbed plots than in disturbed plots. In the undisturbed plots, the seedlings disappeared by December. Seedling mortality was heavier in 6-year old fallow compared to the 2-year old fallow. None of the individuals resulting from the seedlings reached the flowering stage in any of the populations that were studied.

Seed number m^{-2} in the soil was more in 6-year fallow than in 2-year fallow. However, laboratory tests indicated that viability and germination of the seeds collected from the 2-year fallow was better (Table4.3).

Table 4.3. Soil seed population m^{-2}, seed viability and germination of C. asiatica.

	2-year old fallow	6-year old fallow
Seed population	1392 ± 231.5	2160 ± 359.1
Viability (%)	70.5 ± 11.4	69.0 ± 11.0
Germination (%)	80.0 ± 13.3	60.6 ± 9.6

± S.E.

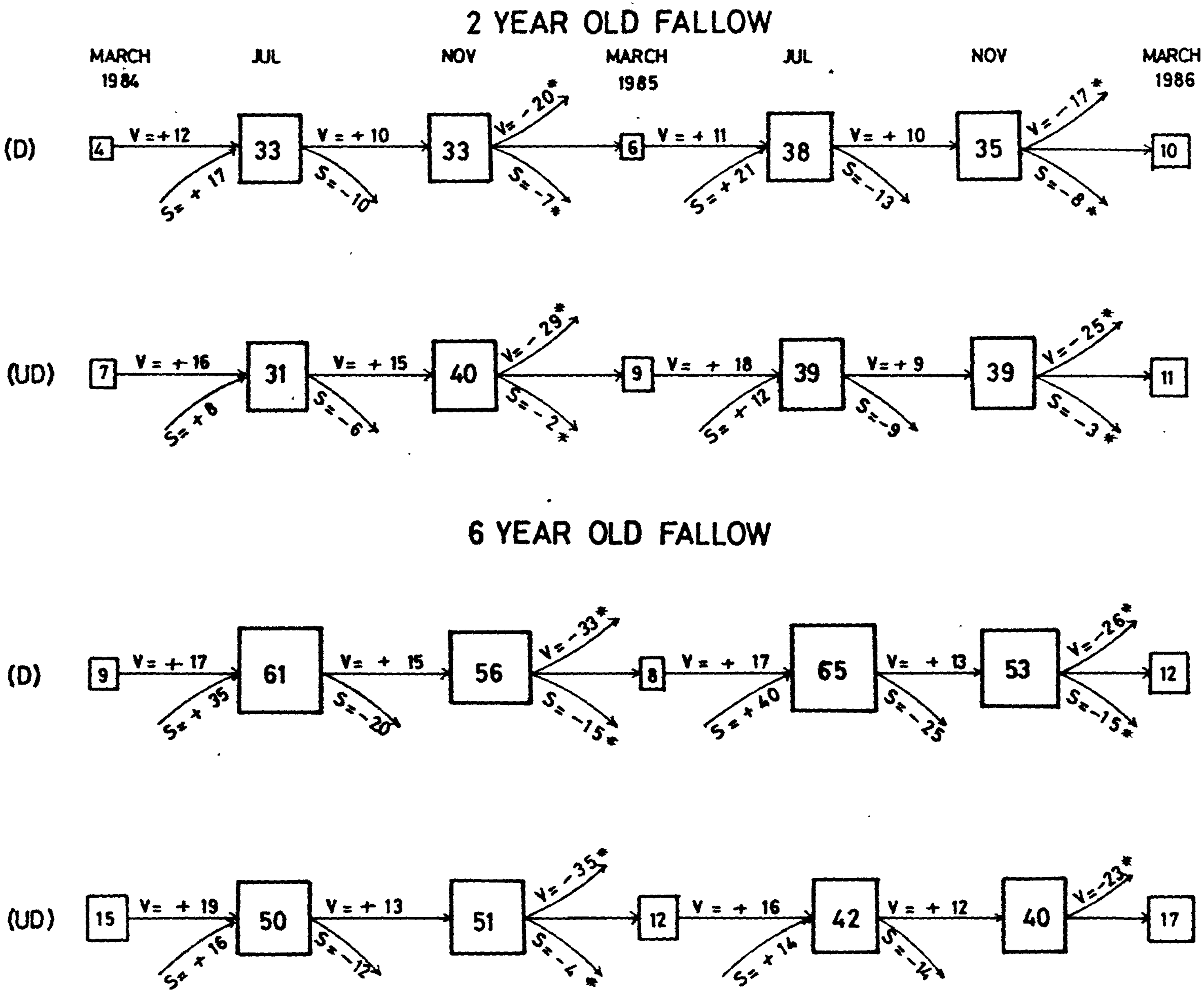
A schematic summary of the population flux of C. asiatica is given in Fig. 4.3. Although there was loss of individuals from the populations of the 6-year fallow in the first year, the net population after 2-year period was greater than the initial population showing that there was a net gain of individuals on both fallows. Maximum increase was observed on the disturbed site of the 2-year fallow and minimum on the undisturbed site of the 6-year fallow.

DISCUSSION

In the disturbed plots, C. asiatica regenerated from the plants that got buried during hoeing. The severed ones and those which came on the soil surface as a result of hoeing, either dried up or decomposed in course of time. Thus, the initial population of C. asiatica was larger in the undisturbed than in disturbed plots. Seedling population that came up in July further contributes to the population.

The greater population size on the disturbed plots compared to the undisturbed ones is because of rapid clonal growth in the former. The result is in agreement with the findings of Jurik (1985), who reported that wild strawberry produces higher number of stolons on recently disturbed habitat as compared to undisturbed habitat. Solbrig et al. (1980) studied the population biology of Viola sororia and observed that in cultivation when plants are supplied with ample

Fig. 4.3. Schematic summary of the population flux of *C. asiatica* on disturbed (D) and undisturbed (UD) sites of a 2-year and 6-year old fallow during Mar., 1984 - Mar., 1986. Numbers in boxes refer to the population m^{-2}. Numbers along the arrows refer to the population recruited vegetatively (V) and through seedlings (S). +, gain; -, loss.



*— SHOOTS THAT DRIED UP DURING WINTER

Fig. 4.3

water and light and are freed from competition, they grow at a much faster pace than in the field. Ashmun & Pitelka (1984)reported that patches of Aster acuminatus flourish in disturbed areas of high light intensity, though it may also manage in low light undisturbed locations. Reader (1985) observed that with increase in population density recruitment in Hieracium floribundum usually decreased with increase in population density and it was better at high soil moisture regime. It may be mentioned that density of the associated species was more in the undisturbed plots of both the fallows(Table 4.2),and these associates could have affected the abundance of C.asiatica as observed by Putwain & Harper (1970), Raynal & Bazzaz (1975) and Tripathi & Dwivedi (1978) in other species.

Greater seedling recruitment in the disturbed plots is in agreement with the findings of Froud - William et al. (1984), who observed that soil disturbances promoted the seedling emergence in many species.In undisturbed soil less germination occurs because the conditions are not conducive to germination and seeds may remain ungerminated solely because they are buried even if their innate dormancy was overcome (Chancellor 1964,Roberts & Dawkins 1967, Chancellor 1986). Roberts (1986) suggested that cultivations frequently stimulated germination by exposing the seeds to light. It may be argued that repeated and widespread disturbances caused by man's activities tend to favour seedling recruitment and growth of C. asiatica.

Most of the seedlings of C. asiatica that appear in nature do not survive to maturity. In other species, Harper (1977) and Noble et al.(1979) observed that recruitment of new genet is often rare and the dynamics of the populations is dominated by the birth and death of the clonal modules. Clonal growth is obviously advantageous where horizontal spread is favoured over vertical growth. Beyond that, it appears to have been favoured in environments where seed and seedling mortality are high (Abrahamson 1980). Ginzo & Lovell (1977a,b) suggested that the small size of a seedling and the risks involved in changing from heterotrophic nutrition to autotrophic life make this stage hazardous, while the ramets develop with a continuous supply of resource from the parent plant. Schellner et al.(1982) observed that ramets of violet can exchange carbon through the stolons and their survival are therefore, not necessarily dependent on the availability of local resources as is the case with seedlings. Dependence on parental resources during establishment has been shown to increase survivorship of new offspring in natural populations of Rubus vesticus and Solidago canadensis (Kirby 1980, Hartnett & Bazzaz 1983). One possible explanation for the unusual mortality pattern is the physiological integration of clones as observed by Pitelka et al.(1984) in Clintonia borealis. A major advantage of clonal habit appears to be the potential for physiological integration of connected ramets via translocation of resources such as water, minerals and photosynthate (Hartnett & Bazzaz 1983, Noble & Marshall 1983, Callaghan 1984, Pitelka & Ashmun 1985, 1986, Salzman & Parker 1985, Alpert & Mooney 1986). Many workers (e.g. Harper & White 1974, Harper 1977, Harper & Bell 1979, Bell et al. 1979, Bell & Tomlinson 1980) emphasised that vegetative spread is more economical than seed production in removing the daughter plant from the competitive influence of its parent.This probably explains the better survival of the new ramets compared to that of seedlings and why the ramets are less affected by density than are seedlings. The greater contribution of clonal growth to adult population has also been observed by many workers (Tamm 1972, Anderson & Loucks 1973, Whigham 1974, Raynal 1979, Barkham 1980, Pitelka et al. 1984).

In adults no mortality occured during the period of study except in winter,which indicates that once a plant reached the rosette stage, the survival was consistently high. Ramet mortality is independent of density while seedling mortality is density-dependent. Mortality rate of the seedlings declined with age as also reported by Sharitz &

McCormick (1973) and Sarukhan & Harper (1973). The negative effect of ramet density on seedling survival is most likely brought about through competition for resources as pointed out by Schellner *et al*. (1982). Some workers (Hawthorn & Cavers 1976, Surakhan & Harper 1973, Rai & Tripathi 1984) have suggested that competition for limited resources was the major factor causing seedling death in certain species and that climatic variations were relatively less important. Generally, the seedlings of *C. asiatica* died before pre-flowering stage, which is in agreement with the observations reported for other herbaceous perennials (e.g. Thomas & Dale 1975, Hawthorn & Cavers 1976, Bishop *et al*. 1978).

✓ Though the seed population in soil was higher in the 6-year old fallow than in the 2-year fallow, the seedling population was rather low in the former (Table 4.3). The low seedling population of *C. asiatica* in the undisturbed plots of both fallows was not due to low seed bank in soil but due to conditions that prevented the buried seeds to germinate. Rai & Tripathi (1984) found that seed germination and seedling establishment in *Galinsoga* spp. were quite low on the habitats having dense vegetation, although a large population of seeds is present in the soil. Lovett Doust (1981 a) observed that shortage of *Ranunculus repens* seedlings in the grassland was due to conditions in the sward that apparently kept the greater part of the seed bank in a dormant state.Besides, the seedling mortality was also comparatively high in the 6-year old fallow,which may be attributed to the competition offered by the established plant community. Kushwaha *et al.* (1981) observed that population of *Eupatorium odoratum* experienced more severe mortality in older fallows than in newer fallows.

CHAPTER V

Competitive interaction between individuals raised from seeds and cuttings

INTRODUCTION

Many perennial herbs rely almost exclusively on clonal multiplication once they have colonized a site, the seedlings if present, rarely survive to adulthood (Sarukhan & Harper 1973, Bernard 1975, Turkington *et al.* 1979, Schmid 1980, 1984, Hartnett & Bazzaz 1985 a). In these plants the genetic changes within a population are largely due to the changes in the abundance and distribution of genets which get established during the initial colonization phase (Schmid 1985 b). The few studies on conspecific populations show considerable competitive differentials between plants (Snaydon 1971, Ford 1981, Bazzaz *et al.* 1982, Heywood & Levin 1984, Clay & Levin 1986, Lee *et al.* 1986). Studies on competition between the populations of *Agropyron repens* and *A. canicum* raised from seeds and from tillers, and between populations of *Imperata cylindrica* produced from seeds and rhizomes have been respectively made by Tripathi & Harper (1973) and Kushwaha *et al.* (1983 a). Such a study may add to our understanding of natural co-existence of the two categories of plants and their ultimate contribution to the population maintenance. This type of study could be of great significance under the situations where a particular species reproduces sexually as well as asexually. *C. asiatica* falls in this category. It had been observed that the seedlings have rare chance of survival in nature. The failure of individuals to survive in nature may be,in part, a function of the competitive interaction between established and establishing individuals of the species, which can be conveniently studied by growing them in mixtures and in monocultures. The success of genets would also depend upon the'stress'created by its own asexually produced allies and the other associated plant species.Therefore, an experiment was planned to analyse the growth of the populations raised from seeds and from stem cuttings in pure and mixed stands.

MATERIALS AND METHODS

The experiment was performed in a polythene-covered net house. The stem cuttings of uniform size and weight (0.020 - 0.030 g) and seedlings having 2-3 leaves (0.010-0.015 g) were collected from the natural population. Keeping the over-all density constant (4 plants/pot), the stem cuttings and seedlings were grown in the pots (21 cm diameter,19 cm depth with a basal drainage hole)filled with garden soil in the ratios of 100:0,75 : 25,50 : 50, 25 : 75 and 0 : 100, so as to give a 'replacement series' (De wit 1960). Thus pure and mixed populations of individuals raised from the stem cuttings and seedlings were maintained in the pots with the following density combinations :

(i) Pure population raised from the stem cutting (4 plants/pot).

(ii) 3 plants from the stem cutting + 1 plant from the seedling.

(iii) 2 plants from the stem cutting +2 plants from the seedling.

(iv) 1 plant from the stem cutting + 3 plants from the seedling.

(v) Pure populations raised from the seedlings (4 plants/pot).

The planting density of the stem cuttings and seedlings was three times that of the population density of each type of individuals desired to be maintained in the experimental pots.After the cuttings sprouted and the seedlings established, the population was thinned down to the desired density of 4 plants per pot for both pure and mixed stands.

The experiment started on September 4, 1985 and terminated on May 10, 1986. The plants were harvested at 3 months interval after planting. At each harvest, stolon production, leaf area and dry matter yield were determined. Relative yield (RY),relative yield ratio (RYR) and relative yield total (RYT) (De wit and van den Bergh 1965) were computed from the yield data. For the sake of convenience, plants raised from the stem cuttings and seedlings were designated as 'C_c' and 'C_s' respectively.

RESULTS

The two categories of plants showed small but significant differences in growth performances. **After 3** months growth, no stolon was produced either by 'C_C' or 'C_S', however, after 6 months growth the stolon production increased sharply. The production of stolons by 'C_C' or 'C_S' was almost similar when they were grown in pure or mixtures. In general the number of stolons produced by 'C_C' was greater as compared to that by 'C_S' (Table 5.1).

Table 5.1. Number of stolons produced per plant of the stem cuttings and seedlings of C. *asiatica* grown in pure and mixed stands at the 2nd and 3rd harvests.

Nature of stands	H_2	H_3
Stem cuttings (Pure stand)	3.6	6.6
Stem cuttings grown with seedling (3:1 mixture)	4.1	6.7
Seedling grown with stem cuttings (1:3 mixture)	1.8	4.2
Stem cuttings grown with seedlings (2:2 mixture)	3.6	6.4
Seedlings grown with stem cuttings (2:2 mixture)	2.0	4.5
Stem cutting grown with seedlings (1:3 mixture)	3.2	7.0
Seedlings grown with stem cutting (3:1 mixture)	2.4	4.8
Seedlings (Pure stand)	2.1	4.4

The total leaf area and yield of the plants raised from the stem cuttings were greater in monoculture than in mixtures, while the reverse was true with the plants developing from the seedlings (Fig. 5.1 & 5.2). Seed output of plants developing from the cuttings was more compared to those raised from the seedlings (Table 5.2).

Table 5.2. Number of seeds per plant produced from the stem cuttings and seedlings of _C. asiatica_ in pure and mixed stands at 2nd and 3rd harvests.

Nature of stands	H_2	H_3
Stem cuttings (Pure stand)	17.2	61.9
Stem cuttings grown with seedling(3:1 mixture)	20.5	62.3
Seedling grown with stem cuttings(1:3 mixture)	5.9	25.2
Stem cuttings grown with seedlings(2:2 mixture)	18.7	61.4
Seedlings grown with stem cuttings(2:2 mixture)	6.6	27.9
Stem cutting grown with seedlings(1:3 mixture)	16.6	67.2
Seedlings grown with stem cutting(3:1 mixture)	8.1	29.7
Seedlings (Pure stand)	6.7	26.4

Relative yield of 'C_c' was greater than that of 'C_s' (Table 5.3 a). The RYR values were always greater than one except in the ratio 1 C_c : 3 C_s of the second harvest (Fig. 5.3), which indicates that 'C_c' is more competitive

Fig. 5.1. Replacement series diagram based on total leaf area/pot (Cm^2) of the two populations of *C. asiatica* at three harvests. —●—, yield of pure population raised from the stem cutting (C_c); —○—, yield of pure population raised from the seedling (C_s); ---△---, yield of the mixed population.

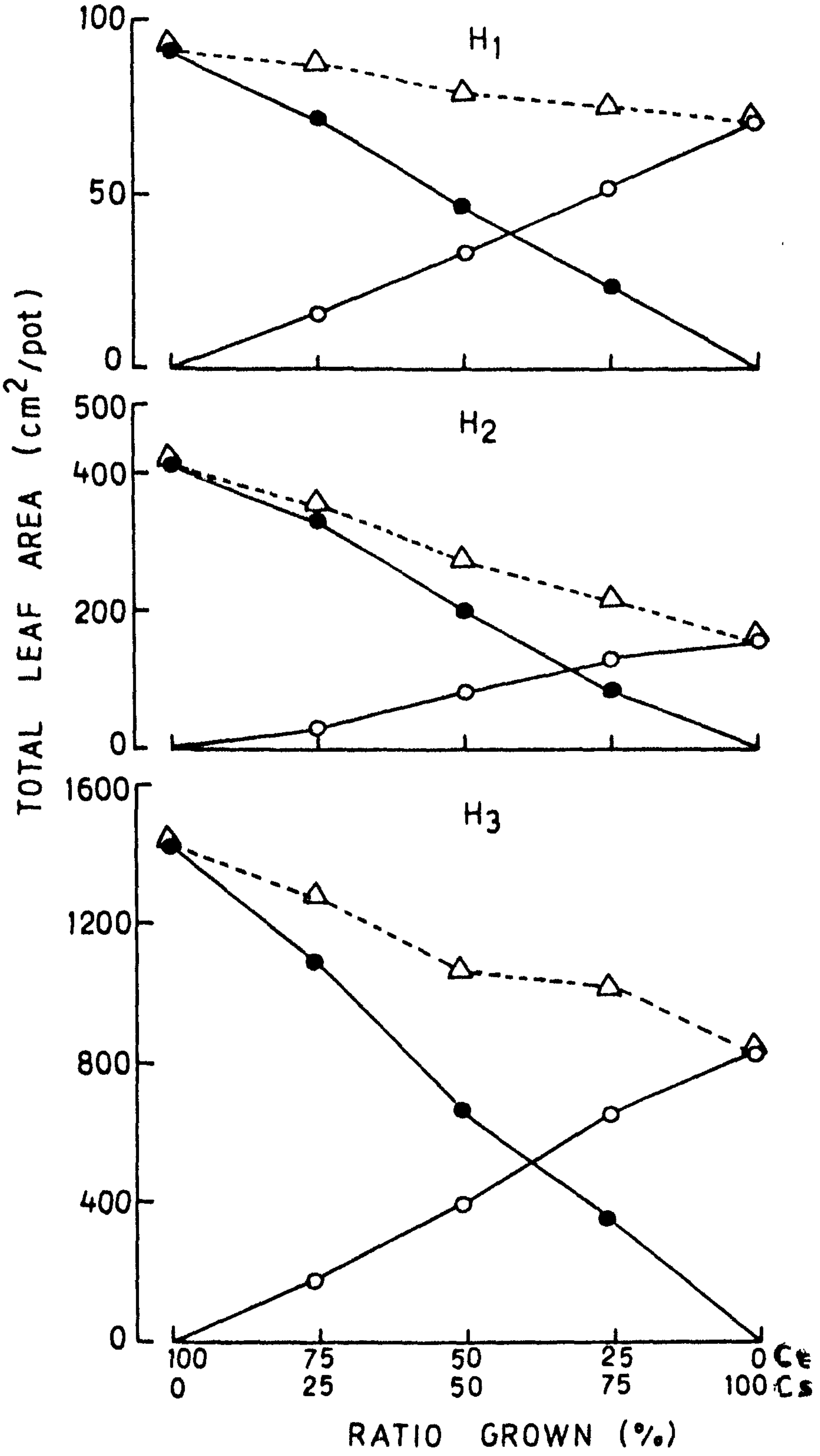

H1
H2
H3
TOTAL LEAF AREA (cm2/pot)
100
50
0
500
400
200
0
1600
1200
800
400
0
100 75 50 25 0 Ce
0 25 50 75 100 Cs
RATIO GROWN (%)

Fig. 5·1

Fig. 5.2. Replacement series diagram based on total biomass of the two populations of *C. asiatica* at three harvests. Symbols as in Fig. 5.1.

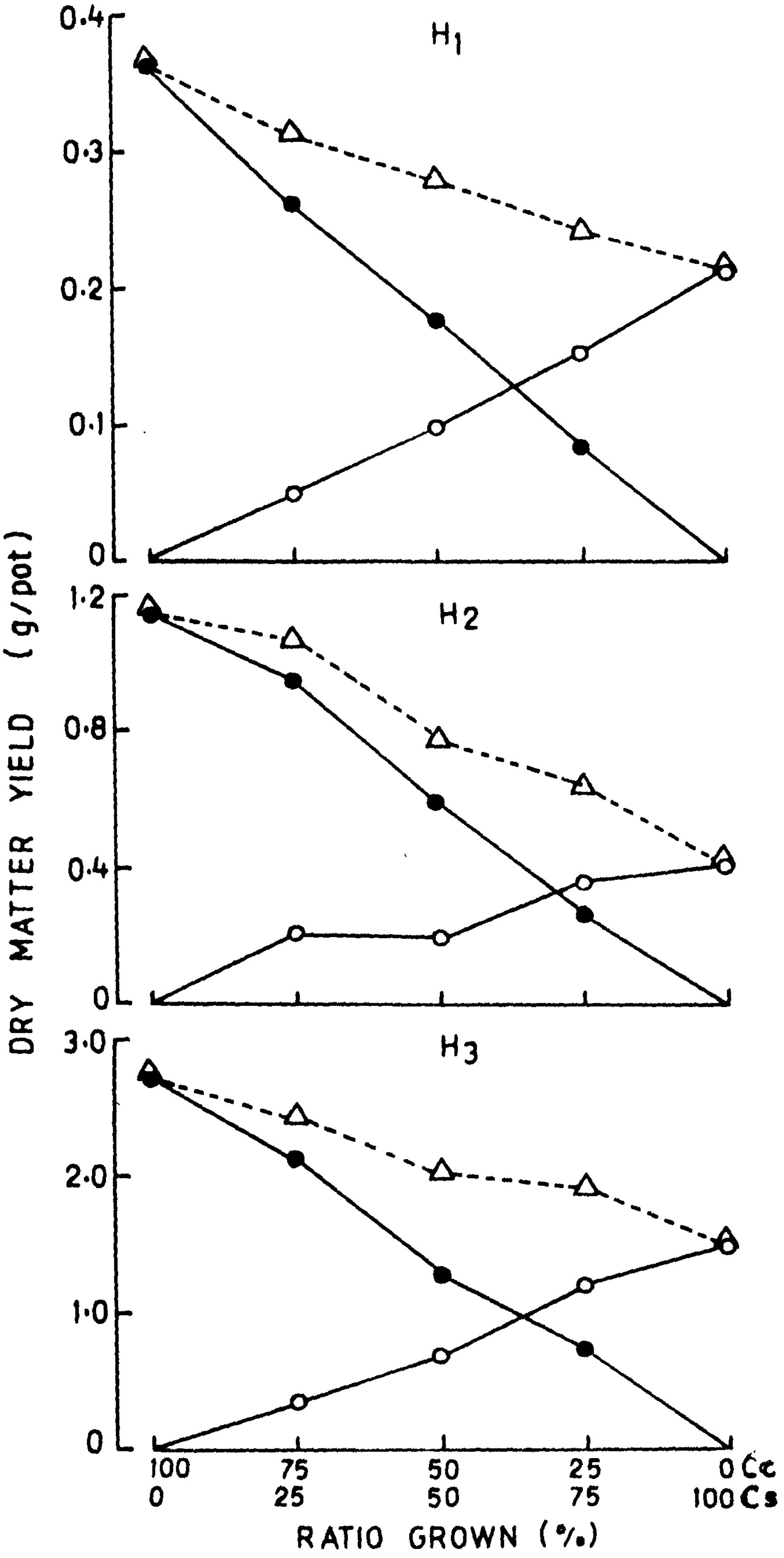

H1
H2
H3
DRY MATTER YIELD (g/pot)
0.4
0.3
0.2
0.1
0
1.2
0.8
0.4
0
3.0
2.0
1.0
0
100
0
75
25
50
50
25
75
0 Cc
100 Cs
RATIO GROWN (%)

Fig. 5.2

Fig. 5.3. Relative yield ratio of the population raised from stem cutting (C_c) to that from seedling (C_s) —○—, 75% C_c + 25% C_s; —●—, 50 C_c + 50 C_s; —△—, 25 C_c + 75 C_s; at three harvests.

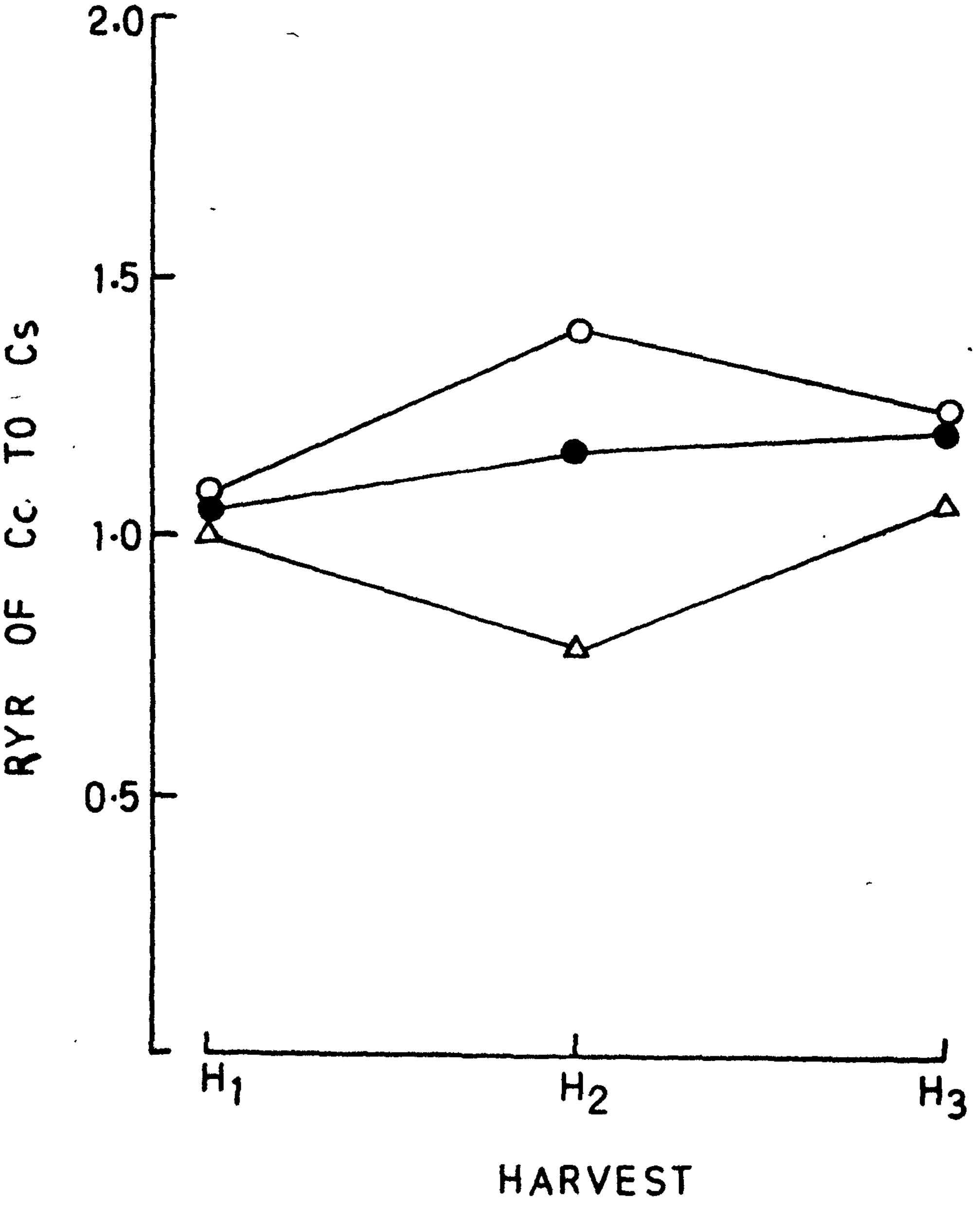


Fig. 5.3

than 'C_S'. The RYT worked out to be more than one at all harvests (Table 5.3 b).

Table 5.3. Relative yield (Table 5.3 a) and relative yield total (Table 5.3 b) of C. asiatica in different replacement series at three harvests.

Table 5.3 a.

Nature of the stand	Relative yield H_1	 H_2	 H_3
Stem cuttings grown with seedling (3 : 1 mixture)	0.97	1.06	1.07
Seedling grown with stem cuttings (1 : 3 mixture)	0.90	0.76	0.86
Stem cuttings grown with seedlings (2 : 2 mixture)	0.98	1.04	1.14
Seedlings grown with stem cuttings (2 : 2 mixtures)	0.92	0.89	0.95
Stem cutting grown with seedlings (1 : 3 mixture)	0.97	0.89	1.13
Seedlings grown with stem cutting (3 : 1 mixture)	0.96	1.12	1.06

Table 5.3 b.

Nature of the stand	Relative yield total H_1	 H_2	 H_3
Stem cuttings grown with seedling (3 : 1 mixture)	1.87	1.82	1.93
Stem cuttings grown with seedlings (2 : 2 mixture)	1.90	1.93	2.03
Stem cutting grown with seedlings (1 : 3 mixture)	1.93	2.01	2.19

DISCUSSION

The differences between the growth of plants raised from the cuttings and the seedlings could be related to differences in initial weight of 'C_c' and 'C_s'. The result is in agreement with the findings of Tripathi & Harper (1973) and Kushwaha et al. (1983 a). The large differences in survival and growth between seedlings and transplants of Trifolium repens in permanent grasslands probably reflect the initial differences in plant size between seedlings and ramets (Turkington et al. 1979). Abrahamson (1980) **discussed that where both vegetative** and sexual reproduction occur simultaneously, the vegetative offspring will develop immediately and quickly become an adult due to larger food supply in the initial stage of growth. Zangerl & Bazzaz (1983) reported that larger food reserves in the rhizomes of Polygonum compared to its seeds permit the plants of rhizomatous origin to persist in resource limited environments where plants derived from seeds do not succeed.

With the passage of time, it was observed that the growth and production of stolons in the plants developing from the seedlings were more or less same as that in the plants produced from the stem cuttings, which indicates that if ample space is available, even the seedlings can successfully grow into adult plants in nature. Antovonics &

Primack (1982) and Schmid (1985 b) suggested that the very rare event of the seedlings of Plantago lanceolata and Prunella vulgaris surviving to adulthood in field conditions may depend rather on "the coincidental absence of lethal conditions" than on its own particular genotype. Howe & Snaydon (1986) reported that under most suitable garden conditions nearly 14% of Festuca rubra and 20% of Poa trivialis seedlings survived after 18 months. Many workers (e.g. Sagar & Harper 1960, Cavers & Harper 1967, Putwain et al. 1970, Rai & Tripathi 1984) reported that in many dicotyledonous species, there is little establishment and survival of seedlings in closed vegetation.

As observed earlier (Chapter IV Table 4.3) there is relatively less number of seeds of C. asiatica in the soil, and the seedlings that come up may not be very competitive.The rapid spread of C. asiatica in nature is because of its vegetative reproduction.Howe & Chancellor (1983) observed that seedlings of Agrostis stolonifera were not very competitive, nor there is much seed in the soil, and Grime (1979) suggested that its ability to dominate the older swards is largely due to its ability to spread vegetatively.

The relative competitive superiority in terms of total leaf area and dry matter production by the plants in mixture was sufficiently greater for 'C_c' compared to 'C_s'. The higher RY and RYR values for'C_c' depict that it is more competitive than the 'C_s'. This result agrees with the findings of Tripathi & Harper (1973) and Kushwaha _et al._ (1983 a). The unit RYT which is greater than one suggests facilitation as reported by Clay & Levin (1986), which indicates that the two populations can co-exist provided there was no crowding. It may be argued that in nature the small number of seedlings of _C. asiatica_ that appeared may be the result of not only a small seed bank, but of the unmeasured effects of competition from the associated plants including the adults. The rosettes are however, able to tolerate the dense conditions better perhaps by depending on the parents.

CHAPTER VI

Effect of light regimes and NPK levels on the growth of *Centella asiatica*

INTRODUCTION

C. asiatica forms localized patches in a wide variety of ecological habitats in nature. It was observed that in low illuminated areas, the growth of *C. asiatica* is very poor and it does not form dense patches as observed in open situations. Therefore, an investigation into the response of *C. asiatica* to varying light intensity was undertaken. Since light and nutrients often interact in determining the growth of plants, it was thought worthwhile to study the interactive influence of these two factors under controlled conditions.

Several studies have been made to analyse the effect of light (Zimmerman 1976, Pandey & Sinha 1977, Patterson *et al.* 1978, Teramura 1983, Longstreth & Mason 1984) and nutrients (Sims & Atkinson 1973, Rajeshwara Rao *et al.* 1983, Roberts *et al.*1984, McGraw 1985, Austin *et al.* 1985) on the growth and reproduction of many plant species. Comparatively few experiments have, however, been conducted to investigate the interacting influence of varying levels of light intensity and nutrients on plant growth (Peace & Grubb 1982, Tripathi & Yadav 1982, Jurik *et al.*1982, McGraw 1985).

MATERIALS AND METHODS

The experiment was conducted in a polythene covered net house which was divided into two compartments with the help of a partition made of bamboo. .In one compartment the four sides of the net house were covered with a white muslin cloth upto a height of 140 cm from the ground level which represented two third of the total height of the net house and the top (i.e. below the polythene roof) was covered with a black muslin cloth. The covered compartment representing the low light regime received 50%(25400 lux) of the light (50800 lux) that was available in the uncovered compartment of the net house, which represented the high light regime. The experimental plan consisted of 2 NPK levels x 2 light regimes x 3 harvests x 5 replicates = 60 pots.Four stem cuttings having 4.5-5.0 mm diameter and 4.5-5.2 cm length were planted in each of the plastic pots (21 cm diameter and 19 cm depth provided with a basal drainage hole). 30 pots filled with garden soil received no supplemented nitrogen,phosphorus and potassium and this was referred to as 'low NPK level'. For 'high NPK level' additional amounts of ammonium nitrate (8.57 g),super phosphate (53 mg) and potassium sulphate (440 mg) were added to each of the remaining 30 pots. Equal number of pots were placed in high light as well as in low light condition.The nitrogen, phosphorus and potassium contents of both the sets are given in Table 6.1. The fertilizer doses were determined on the basis of the soil fertility status of different habitats of C. asiatica in nature. The N,P & K contents were analysed following the procedures given by Allen (1974). Total nitrogen was determined by Kjeldahl method, potassium by flame photometer and available phosphorus was measured by the molybdenum - blue method colorimetrically. The light intensity was measured by a lux meter.

Three harvests, H_1, H_2 and H_3, were taken after 4,8 and 12 months from planting.At each harvest,the numbers of stolons, leaves, flowers and fruits were counted.Petiole length and leaf area were also measured. The roots were thoroughly washed to remove the adhering soil particles and the component plant parts were then separated,oven dried at 60°C to a constant weight and weighed. The leaf area ratio was calculated by the formula given by Evans (1972).

At the final harvest,as majority of the seeds had fallen off, the computation of the total seed number per plant for a given treatment was done by multiplying the average number of seeds per fruit with the average number of fruits per plant.

Table 6.1. Nitrogen, phosphorus and potassium contents (%) in the low and high NPK level treatments.

	Low NPK level	High NPK level
Nitrogen	0.15	0.21
Phosphorus	0.0018	0.013
Potassium	0.05	0.11

RESULTS

Plants grown under low light regime and at high NPK level could not survive and all decomposed. Leaves of the plants grown under low light regime and at low NPK level produced longer petiole than those grown under high light regime (Fig. 6.1). On the other hand, leaf area and leaf area ratio were greater under high light than under low light (Fig. 6.2 a & 6.2 b).Length of petiole as well as leaf area and leaf area ratio did not differ much at two levels of NPK.

There were great differences in the production of leaves, fruits, seeds and stolons under high light and low light regimes (Table 6.2). The production of seeds and stolons of *C. asiatica* was drastically reduced under low light, while maximum values were observed under high light regime at low NPK level. Dry matter yield of the plants grown under high light regime was much greater as compared to those grown under low light regime (Table 6.3).Dry matter yield was highest at low NPK level under high light regime.

Under low light regime few plants flowered and only some of them produced clonal offspring and most plants simply managed to maintain themselves. In contrast to this, plants under high light regime produced flowers and nume-

Fig. 6.1. Length of petiole of *C. asiatica* under two light regimes and two NPK levels. □ , low NPK; ⠿ , high NPK. H_1, H_2 and H_3 represent harvests taken after 4, 8 and 12 months from planting.

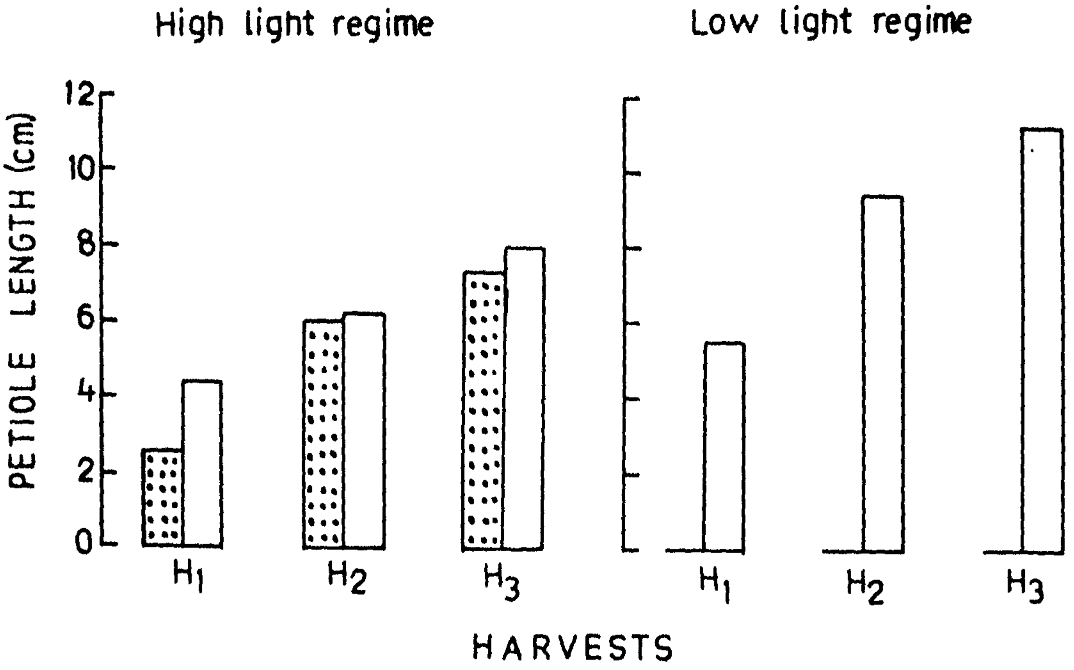

High light regime
Low light regime
PETIOLE LENGTH (cm)
0
2
4
6
8
10
12
H1
H2
H3
H1
H2
H3
HARVESTS

Fig. 6·1

Fig. 6.2 a. Total leaf area per plant of *C. asiatica* raised from stem cutting under two light regimes and two NPK levels. Symbols as in Fig. 6.1.

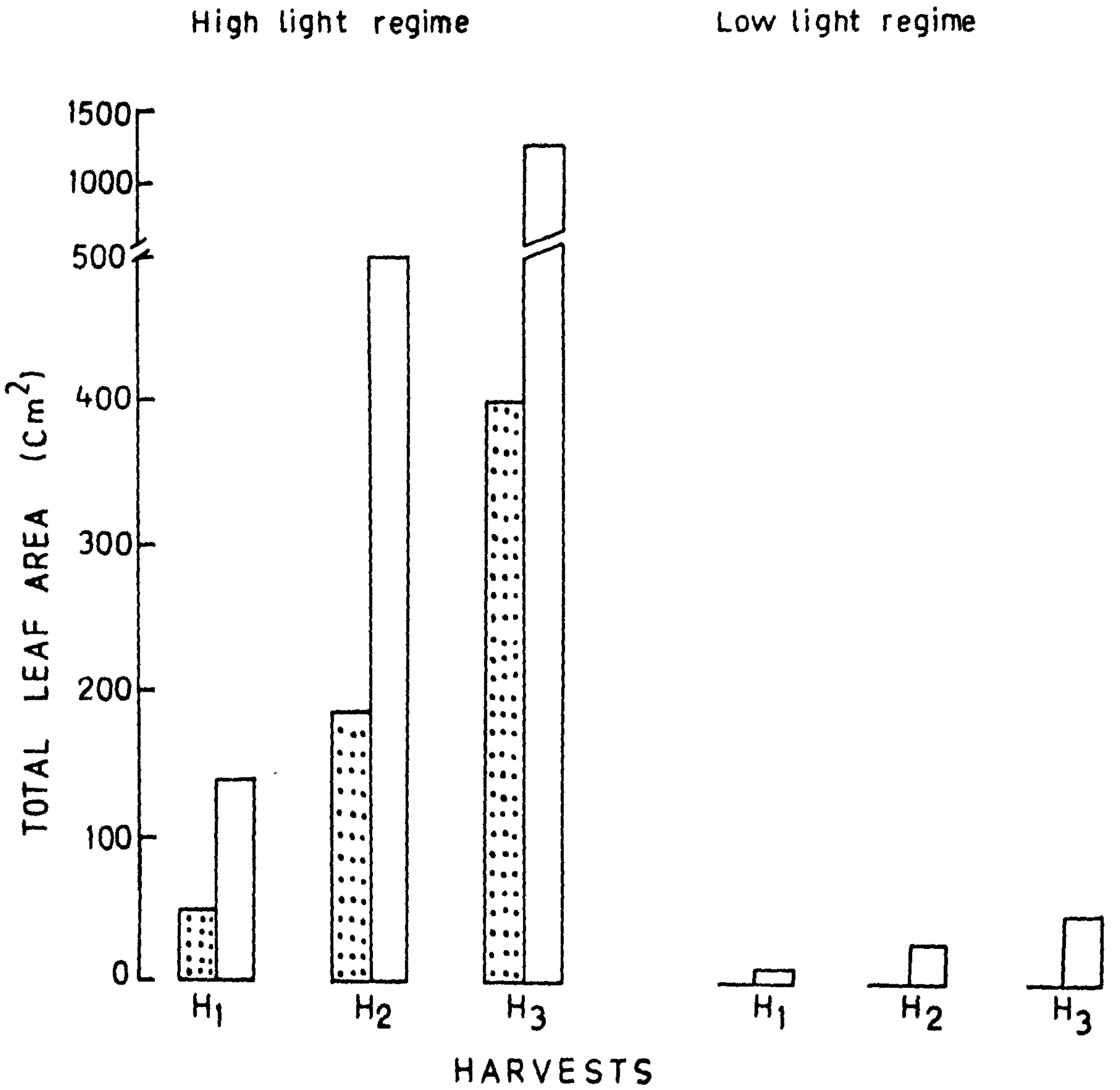

High light regime
Low light regime
TOTAL LEAF AREA (Cm^2)
1500
1000
500
400
300
200
100
0
H1
H2
H3
H1
H2
H3
HARVESTS

Fig. 6·2 a

Fig. 6.2 b. Leaf area ratio of C. *asiatica* under two light regimes and two NPK levels. Symbols as in Fig. 6.1.

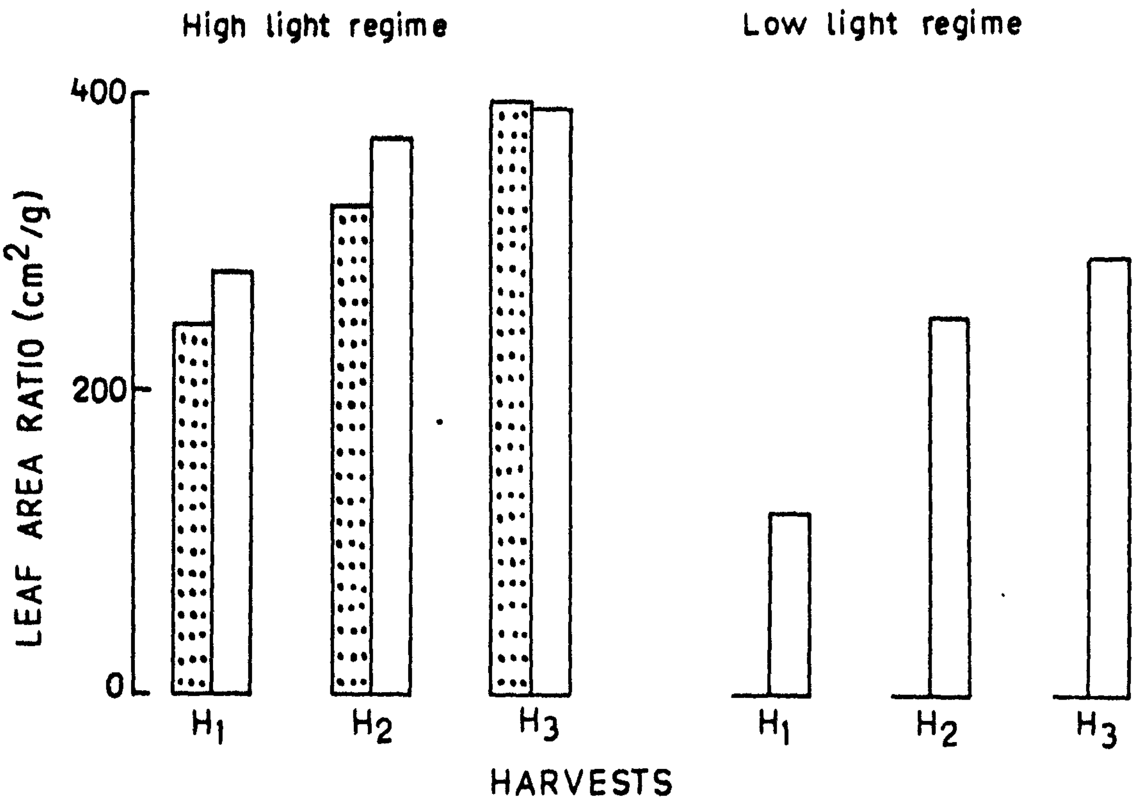

High light regime
Low light regime
LEAF AREA RATIO (cm²/g)
400
200
0
H1
H2
H3
H1
H2
H3
HARVESTS

Fig. 6·2 b

Table 6.2. Average number (± S.E.) of leaves, fruits, seeds and stolons per plant of *C. asiatica* under two light regimes and two NPK levels.

	High light regime		Low light regime	
	High NPK	Low NPK	*High NPK	Low NPK
Leaf number	66.4 ±5.53	153.0 ±7.65		7.0 ±0.28
Fruit number	11.6 ±0.61	39.0 ±1.63		1.6 ±0.08
Seed number	69.7 ±3.87	200.6 ±10.03		6.4 ±0.36
Stolon number	8.3 ±0.51	17.0 ±0.89		1.3 ±0.087

* The individuals failed to survive.

Table 6.3. Dry matter yield (g) per plant of *C. asiatica* under two light regimes and two NPK levels.

Harvest	High light regime		Low light regime	
	High NPK	Low NPK	*High NPK	Low NPK
H_1	0.202 ± 0.02	0.492 ± 0.045		0.078 ± 0.007
H_2	0.565 ± 0.07	1.398 ± 0.14		0.108 ± 0.012
H_3	1.008 ± 0.12	3.247 ± 0.36		0.157 ± 0.014

*The individuals failed to survive.

± S.E.

rous clonal offsprings. Percentage allocation towards clonal growth (i.e. allocation to daughter rosettes + allocation to stolons) was more under high light regime irrespective of NPK levels. However, allocation to mother rosette was more under low light regime. In all **treatments the** allocation toward seed production was comparatively less (Table 6.4).

DISCUSSION

Low light regime and fertilizer treatment had a strong negative effect on the growth and development of C. asiatica. The differences in yield due to soil NPK treatment were, however, not much under the same light condition, while, light affected the growth significantly irrespective of NPK level. Blackman and Templeman (1938) also found a reduction in the growth of Agrostis tenuis and Festuca rubra at ca. 40% daylight when ammonia or nitrate were added to the soil. Recently McGraw (1985) observed that ecotypes of Dryas octopetala showed a negative response to shade and nutrient treatment. Conversely , Peace & Grubb (1982) and Jurik et al. (1982) reported that high light and high nutrient favoured the growth of Alternanthera philoxiroides and Fragaria virginiana.

Petiole length and leaf area in this experiment were strongly influenced by light regime (Fig. 6.1 & 6.2a). Largest leaves were produced by the plants grown under high

Table 6.4. Total dry weight per plant and biomass allocation of C. asiatica to mother rosette, clonal growth and seed production under two light regimes and two NPK levels.

	High light regime		Low light regime	
	High NPK	Low NPK	*High NPK	Low NPK
Total dry weight per plant (g)	1.008 ±0.053	3.247 ±0.216		0.157 ±0.012
Biomass allocation (%) to mother rosette	28.67 ±1.91	14.75 ±1.14		62.43 ±5.20
Biomass allocation (%) to daughter rosette	52.48 ±4.37	68.49 ±5.27		22.93 ±1.76
Biomass allocation (%) to stolons	13.10 ±0.87	11.52 ±0.77		11.46 ±0.95
Biomass allocation (%) to clonal growth	65.58 ±4.37	80.01 ±6.67		34.39 ±2.65
Biomass allocation (%) to seeds	5.75 ±0.44	5.24 ±0.35		3.18 ±0.27

*Plants could not survive.

± S.E.

light, while longer petiole by the plants grown under low light. Increased stem length at reduced light was also reported by William (1970). Skuterud (1984) found that though Elymus repens and Agrostis gigantia produced longer stem, the number of aerial shoots was reduced under low light condition.

Low light regime had an adverse effect on the growth of the plant causing drastic reduction in leaf area and dry matter yield. This conforms with the findings of Benneth & Rao (1968), Cruttwell (1968), Shamsi & whitehead (1974), Zimmerman (1976), and Teramura (1983). Longstreth and Mason (1984) observed that at highest PPFD (photosynthetic photon flux density) average dry weight of Alternanthera philoxiroides was nine fold that of lowest PPFD.

The plant growth was also affected by the NPK level. The result indicates that the growth of C. asiatica was far better at low NPK level. This tactical response for better growth at low NPK level serves to maintain and favour the clonal growth of C. asiatica in an area which is unfavourable to tall competitors. High NPK level particularly under low light regime, hampered the growth of C. asiatica to such an extent that none of the plants could survive. The use of a large amount of nitrogen fertilizer increased soil acidity which influenced the availability of nutrients and depressed accumulation of dry matter in burley tobacco (Sims & Atkinson 1973). In the present study too, the supressed growth of *C. asiatica* at high NPK level may be linked with the increased soil acidity brought about by the addition of nitrogen fertilizer. Austin *et al* (1985) also reported a better yield of *Carthamus* at low soil nutrient level. Further research is, however, required to find out the cause of the failure of the plants to survive under low light at high NPK level. Increased fertility was also observed to reduce rhizome growth in *Tussilago farfara* (Ogden 1974).

Seed and stolon production was highly influenced by light (Table 6.2). Zimmerman (1976) found that the capsule numbers in purslane were positively correlated with the amount of light received. Pitelka *et al*. (1985) observed that periods of high light increased ramet height, yield, rhizome production and flowering in *Aster acuminatus*, while reduced light limited the growth and reproduction (Pitelka *et al*. 1980, Ashmun & Pitelka 1984).

The investment of *C. asiatica* into clonal growth is > 60% at high light regime irrespective of NPK level , while it was only ca. 30% at low light regime. Turkington & Cavers (1978) found that in *Trifolium repens* clonal growth accounted for 12% of the biomass allocation after 10 weeks and Ericksson (1985) found that at any given density $>$ 60% biomass is invested to clonal growth in Potentilla anserina. In terms of numbers Tripathi & Harper (1973) found that Agropyron repens produced only 30 seeds and the number of buds produced along an extensive rhizome system was 215 which shows that energy spent for clonal growth is much greater as compared to seed production. Hawthorn & Cavers (1978) argued that the energy input into clonal growth might represent two ends i.e., rapid means of producing potentially self supporting offspring and a means of sampling the immediate environment more effectively. Debate continues over whether clonal growth represents reproduction or only vegetative growth. Although genetic recombination does not occur in the production of new ramets, new variants arise from somatic mutations in meristems, and clonal growth does serve many of the same functions as sexual reproduction (Bazzaz *et al.* 1987). Less allocation to sexual and clonal growth at low light regime is consistent with the observations of Ashmun & Pitelka (1984) in Aster acuminatus. They found that in low light garden few ramets flower and less amount is devoted to clonal growth, on the other hand, plants at high light condition produced many flower buds and numerous clonal offsprings. It may be concluded that appropriate light condition is more important for the growth of C. asiatica than fertilizer application.

CHAPTER VII

Effect of soil types, light regimes, and moisture on the growth of *Centella asiatica* raised from the stem cuttings of different sizes

INTRODUCTION

Environmental factors such as moisture availability and soil texture account for much of the variation with respect to the growth and dry matter allocation in plants (Humes & Cavers 1983). Considerable amount of work has been done on the effect of moisture (Engin & Spernt 1973, Foulds 1978, Rahman & Rutter 1980, Yadav & Tripathi 1985, Stevenson & Laidlaw 1985) and soil texture (Snaydon & Bradshaw 1959, Bishop et al. 1978, Gulmon & Turner 1978, Humes & Cavers 1982) on plants. Studies pertaining to the combined effect of soil moisture and soil texture have also been made by some workers (Muller-Dombois & Sims 1966, Trivedi & Tripathi 1982 b, Rai & Tripathi 1983 etc.). In addition to soil moisture and soil texture, light has been cited as an important factor affecting growth and reproduction in many forest herbs (Anderson et al. 1969, Halls 1973, Whigham 1974, Hall & Sibley 1976, Thompson & Willson 1978).

The relationship between the variation in light intensity, ramet size and sexual reproduction in natural and experimental populations of Aster was studied by Pitelka et al. (1985). Components of fitness such as fertility and survivorship may be closely related to size (weight) rather than age (Werner & Caswell 1977, Harper 1977, Leverich & Levins 1979). Fecundity of individual plant is usually a function of size (Harper 1977, Harper & White

1979).Plant or ramet size has been shown to be an important component of fitness in many plants (Cook 1980, Pitelka *et al*.1980, Bradbury 1981, Solbrig 1981, Thompson & Beattie 1981, Ashmun & Pitelka 1985).

MATERIALS AND METHODS

Stem cuttings of *C. asiatica* were obtained from naturally growing plants at Upper Shillong. The stem pieces of three different sizes(4.0-4.3 mm, 4.9-5.2 mm, 5.5-6.0 mm diameter and 3.5-4.0 mm, 4.5-5.0 cm and 5.5-6.0 cm length) were cut in such a manner that each piece contained a node and these were used for the experiment. Samples of the stem cuttings were weighed to provide a quantitative comparison of the small,medium and large categories. The dry weight of the cuttings ranged from 0.025-0.035 g, 0.050-0.065 g and 0.080-0.095 g for small, medium and large cuttings respectively. Four cuttings of each size were planted in the experimental pots (21 cm diameter and 19 cm depth with a basal drainage hole) on 4th July 1985.

The experiment was conducted in an unheated net house provided with a polythene sheet roofing. The four sides of the net house were also covered with a polythene sheet up to a height of 70 cm from the ground level which represented one third of the total height so as to provide protection from the splashing rain water. For the light regimes, the two compartments were maintained in the net house as described in Chapter VI. The experiment consisted of 2 light regimes x 2 soil types x 2 moisture regimes x 3 harvests x 3 replicates x 3 cutting sizes, thus involving in all 216 pots. Of these 108 pots were filled with clay loam soil and 108 pots with sandy loam soil.Equal number of pots filled with clay loam soil and sandy loam soil were placed under high light and low light regime respectively. The percentage of sand, silt, clay and nitrogen and organic matter contents of both the soil types are given in Table 7.1. Soil texture was determined by pipette method as described by Piper (1947). Nitrogen was estimated by Kjeldahl method (Allen 1974) and organic matter by rapid titration method (Walkley & Black 1934). Two moisture regimes, high and low were maintained by watering the pots on alternate day and at weekly intervals respectively, by supplying them with equal quantity (250 ml) of water.

Table 7.1. Percentages of sand, silt, clay and nitrogen and organic matter contents in the two soil types.

	Sandy loam soil	Clay loam soil
Sand	76	50
Silt	8	20
Clay	16	30
Nitrogen	0.10	0.17
Organic matter	2.8	3.1

Sprouting of the stem cuttings was recorded at weekly intervals. The three harvests were taken after 75 days, 150 days and 225 days from planting. At each harvest, data concerning number of leaves, number of stolons, leaf area, length of petiole and dry matter yield per plant were recorded as described in Chapter VI.

RESULTS

Most cuttings sprouted within two weeks from planting. Sprouting of the stem cuttings was not much affected by soil types and light regimes. The cuttings sprouted much earlier in the pots watered on alternate day than those watered at weekly intervals (Table 7.2).

The overall result showed that the growth and development of individual plant were highly size-dependent. Larger cuttings emerged earlier and showed a higher sprouting percentage and produced larger number of stolons than the smaller cuttings (Table 7.3) under high light regime, while such differences were not shown by the plants grown under low light regime. At the final harvest, most of the plants under high light produced flowers, while only a few plants flowered under low light. Leaf number and leaf area per plant were greater under high light than under low light (Fig. 7.1 & Table 7.4). The values for these parameters were greater in sandy loam soil than in clay loam

Table 7.2. Sprouting (%) of stem cutting of *C. asiatica* in relation to light regimes, soil texture and soil moisture regimes.

Size of the stem cutting	Weeks after planting	High light regime				Low light regime			
		Sandy loam soil		Clay loam soil		Sandy loam soil		Clay loam soil	
		Low moisture	High moisture	Low moisture	High moisture	Low moisture	High moisture	Low moisture	High moisture
Small	1	36.6 ±2.4	50.0 ±3.6	30.0 ±2.1	41.6 ±2.6	40.3 ±2.5	50.0 ±3.2	40.3 ±3.2	46.0 ±3.2
	2	83.2 ±5.9	88.0 ±5.5	76.0 ±5.0	86.6 ±6.2	86.6 ±6.3	95.0 ±7.7	81.3 ±5.6	92.0 ±6.8
	3	90.8 ±5.7	91.3 ±5.7	84.3 ±6.2	96.6 ±5.4	99.9 ±7.9	-	97.9 ±7.8	-
Medium	1	50.0 ±3.3	70.0 ±4.7	45.0 ±2.8	63.0 ±4.5	58.3 ±3.3	73.3 ±5.5	50.0 ±3.4	66.6 ±5.3
	2	91.6 ±5.7	100.0 ±7.7	90.0 ±5.6	99.6 ±6.3	99.9 ±6.5	99.9 ±8.3	91.6 ±6.8	99.9 ±9.3
	3	99.9 ±5.9	-	100.0 ±5.9	-	-	-	99.6 ±7.2	-
Large	1	53.3 ±3.6	58.3 ±4.2	50.0 ±3.2	56.3 ±3.2	60.6 ±4.2	70.0 ±5.2	60.0 ±4.3	66.6 ±5.2
	2	99.9 ±6.2	99.9 ±6.2	100.0 ±6.3	99.9 ±7.3	99.9 ±7.6	100.0 ±7.3	98.0 ±8.3	33.3 ±2.3
	3	-	-	-	-	-	-	-	99.9 ±8.3

± S.E.

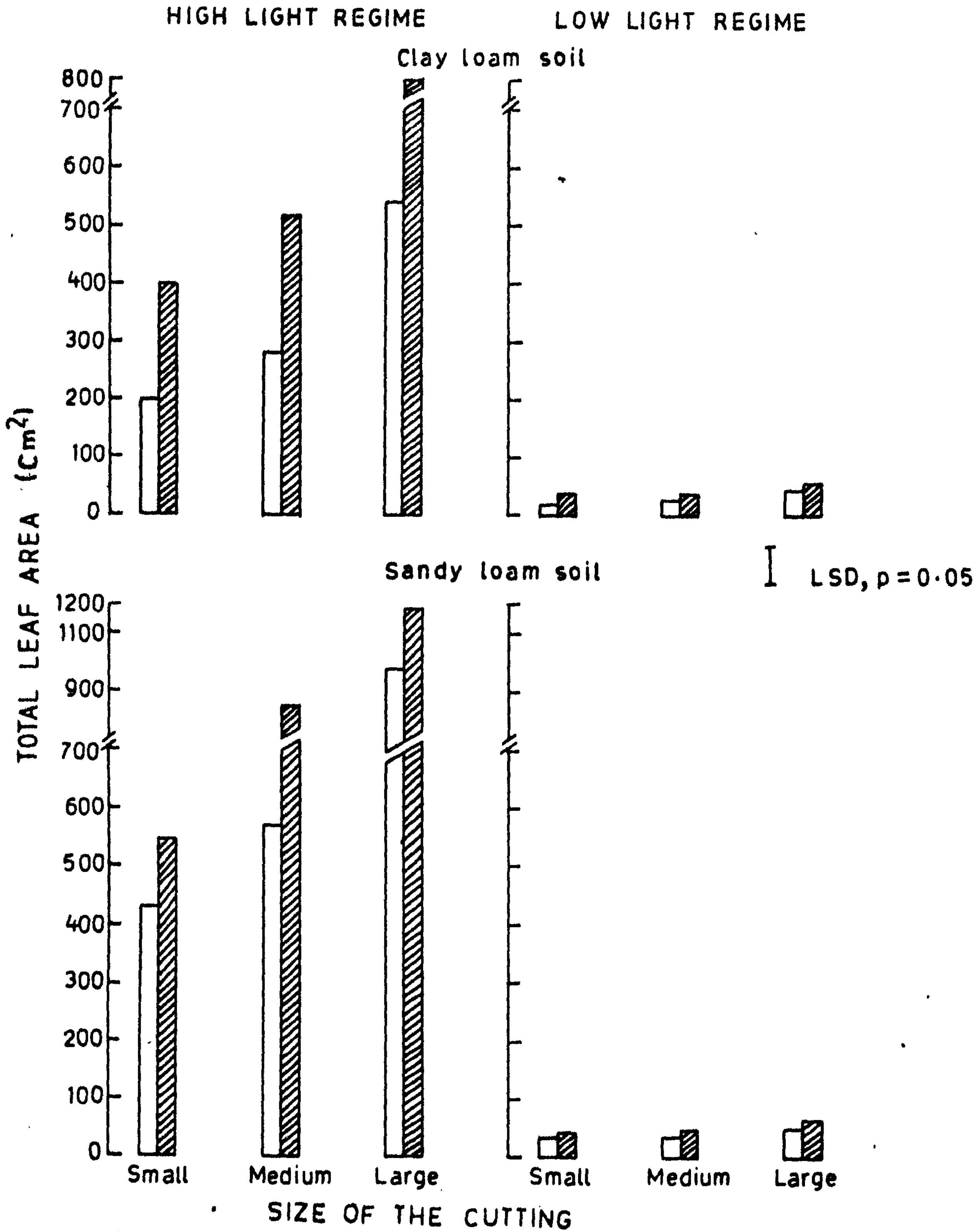
- indicates absence of sprouting.

Table 7.3. Number of stolons per plant of *C. asiatica* in relation to light regimes, soil texture, soil moisture regimes and size of stem cuttings.

Size of the stem cutting	High light regime				Low light regime			
	Sandy loam soil		Clay loam soil		Sandy loam soil		Clay loam soil	
	Low moisture	High moisture	Low moisture	High moisture	Low moisture	High moisture	Low moisture	High moisture
Small	7.3	8.2	5.4	6.6	1.6	1.8	0	1.6
Medium	9.4	12.0	6.9	9.5	1.6	1.8	1.2	1.3
Large	14.5	16.5	12.4	14.8	2.0	2.4	2.2	2.2

Source of variation	Probability
Size	<0.05
Light	<0.01
Moisture regime	Not significant
Size x light	<0.05
Size x moisture regimes	Not significant
Light x moisture regimes	Not significant
Error	Not significant

Fig. 7.1. Total leaf area per plant of *C. asiatica* raised from cutting as affected by light, soil texture, moisture and size of the stem cutting used for planting. □ , low moisture regime; ▦ , high moisture regime.


HIGH LIGHT REGIME
LOW LIGHT REGIME
Clay loam soil
800
700
600
500
400
300
200
100
0
TOTAL LEAF AREA (Cm^2)
Sandy loam soil
LSD, p = 0·05
1200
1100
900
700
600
500
400
300
200
100
0
Small
Medium
Large
Small
Medium
Large
SIZE OF THE CUTTING

Fig· 7·1

Table 7.4. Leaf number per plant of C. asiatica in relation to light regimes, soil texture, soil moisture regimes and size of the stem cutting.

Size of the stem cutting	High light regime				Low light regime			
	Sandy loam soil		Clay loam soil		Sandy loam soil		Clay loam soil	
	Low moisture	High moisture	Low moisture	High moisture	Low moisture	High moisture	Low moisture	High moisture
Small	61.32	68.88	32.40	50.16	8.0	9.0	4.6	7.7
Medium	79.9	102.0	44.16	76.0	8.3	9.7	6.2	7.0
Large	124.7	141.9	84.32	121.3	10.8	12.9	11.4	11.9

Source of variation	Probability
Size	<0.05
Light	<0.01
Moisture regime	Not significant
Size x light	<0.05
Size x moisture regimes	Not significant
Light x moisture regimes	Not significant
Error	<0.05

soil. Further, the plants watered on alternate days produced greater number of leaves and possessed greater leaf area than those watered at weekly interval.The above differences were, however, not observed in the plants grown under low light regime. Unlike leaf number and leaf area, petiole length was significantly greater under low light than under high light (Table 7.5).

The dry matter yield of the plants grown under high light was significantly greater compared to those grown under low light (Fig. 7.2). Sandy loam soil favours the growth of the plant, and the yield was more in high water regime than in low water regime in both soil types.

The partitioning of dry matter to mother rosette, clonal growth (allocation to daughter rosettes + allocation to stolons)and seed showed significant differences between plants grown under low and high light regimes (Fig. 7.3). Under high light regime maximum allocation was made towards daughter rosettes, especially in those plants which were produced from the large cuttings. In contrast, under low light regime maximum allocation was towards mother rosettes particularly in those plants that resulted from the small cuttings. Allocation towards stolons and seeds was greater under high light than under low light. On the whole, the differences in allocation pattern due to soil types, moisture regimes and size of the cuttings were small.

Table 7.5. Petiole length of *C. asiatica* in relation to light regimes, soil texture, soil moisture regimes and size of the cuttings.

Size of the stem cutting	High light regime				Low light regime			
	Sandy loam soil		Clay loam soil		Sandy loam soil		Clay loam soil	
	Low moisture	High moisture	Low moisture	High moisture	Low moisture	High moisture	Low moisture	High moisture
Small	8.0	8.0	7.6	7.7	11.0	11.4	10.8	11.0
Medium	8.2	8.6	8.2	8.2	11.8	11.8	10.2	11.0
Large	8.2	8.2	8.0	8.0	12.4	12.4	12.2	12.2

Sources of variation	Probability
Size	<0.05
Light	<0.05
Moisture regime	Not significant
Size x light	<0.05
Size x moisture regimes	Not significant
Light x moisture regimes	Not significant
Error	Not significant

Fig. 7.2. Dry matter yield per plant of *C. asiatica* raised from cutting as affected by light, soil texture, moisture and size of the stem cutting used for planting. Symbols as in Fig. 7.1.

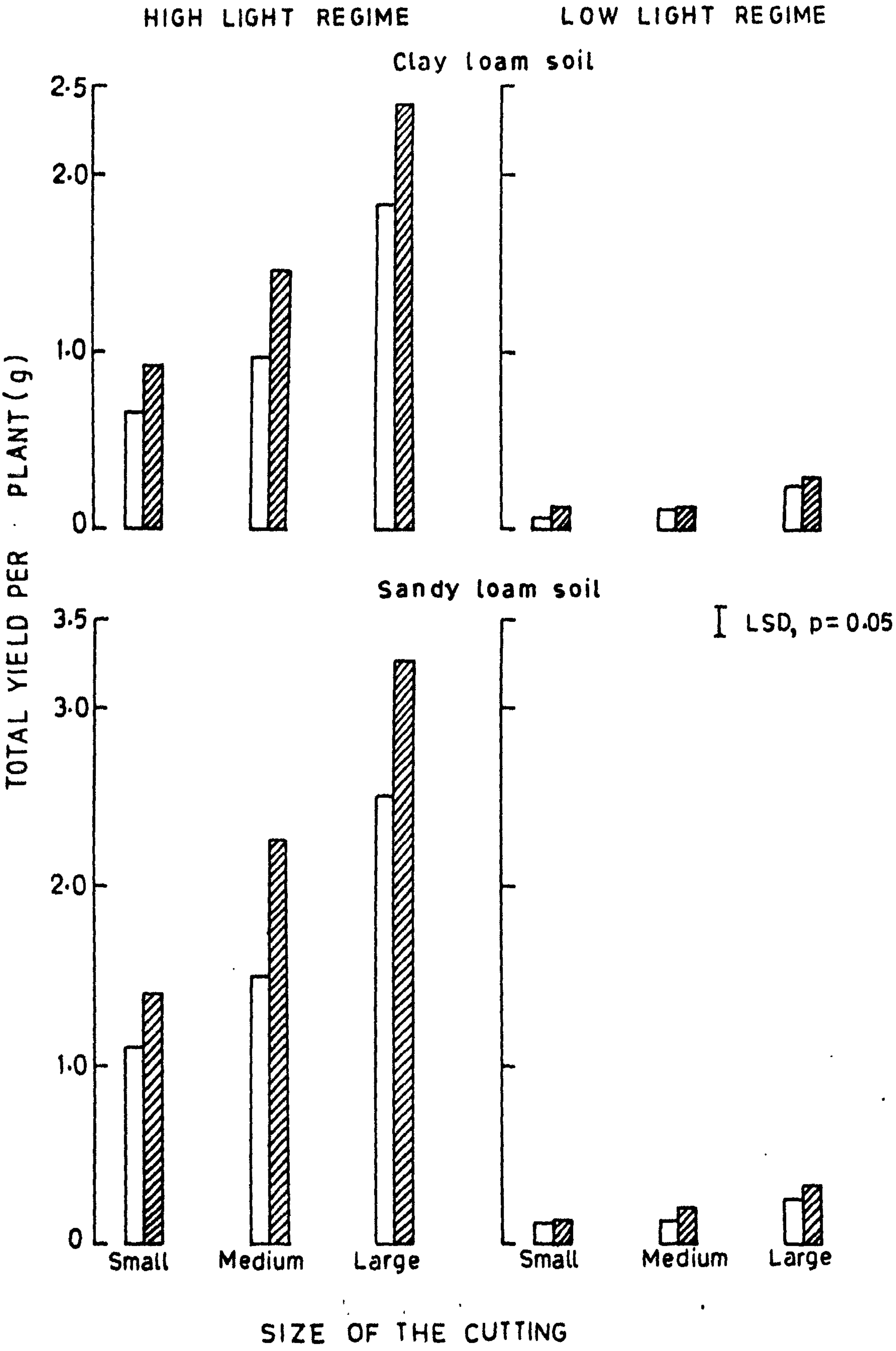

HIGH LIGHT REGIME
LOW LIGHT REGIME
Clay loam soil
2.5
2.0
1.0
0
Sandy loam soil
I LSD, p= 0.05
3.5
3.0
2.0
1.0
0
TOTAL YIELD PER PLANT (g)
Small
Medium
Large
Small
Medium
Large
SIZE OF THE CUTTING

Fig. 7.2

Fig. 7.3. Dry matter allocation towards mother rosette ▥ , daughter rosette ▒ , stolon ▤ , and fruits and seeds ■ , of *C. asiatica* as affected by light, soil texture, moisture and size of the stem cutting used for planting.

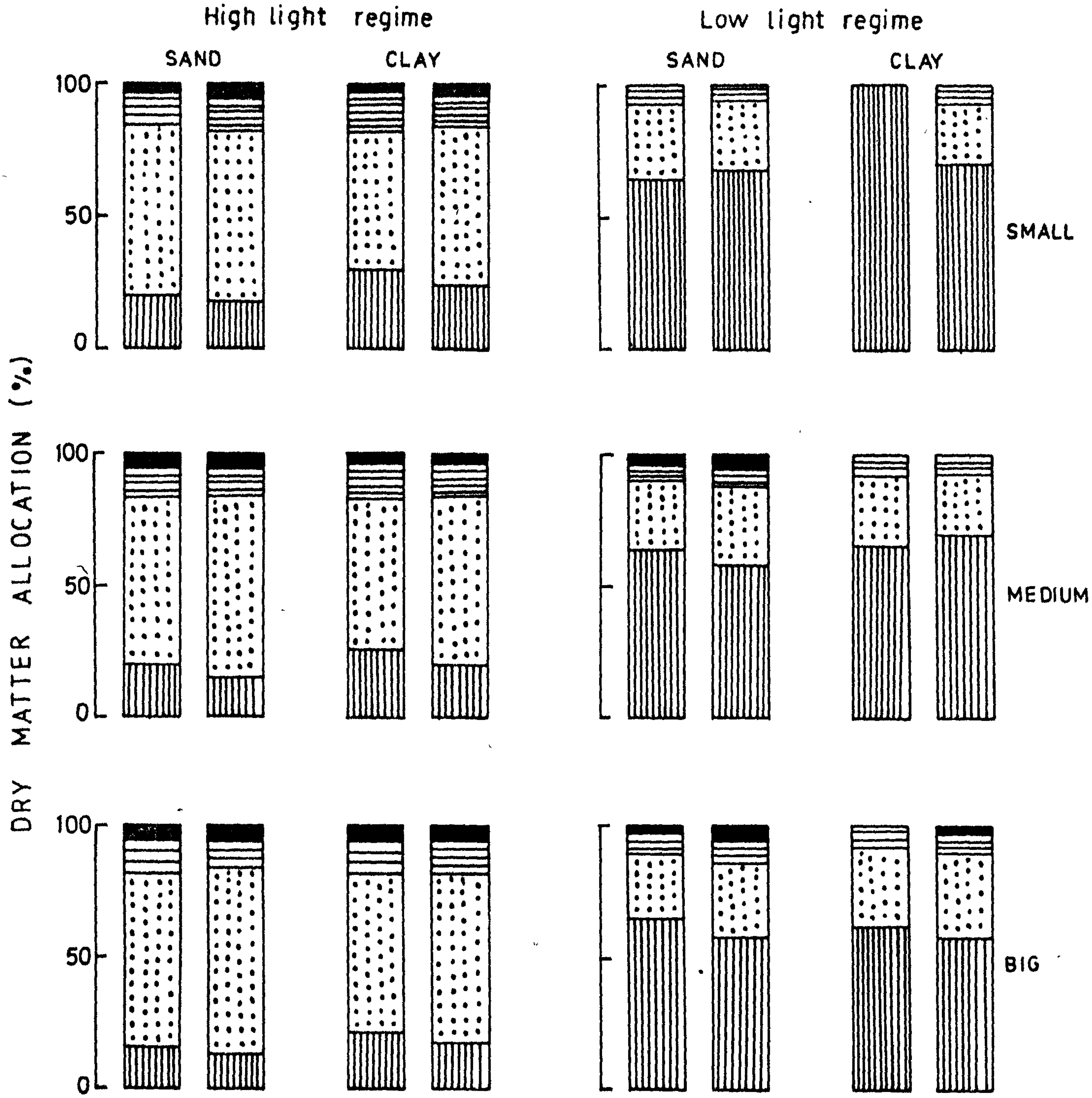

High light regime
Low light regime
SAND
CLAY
SAND
CLAY
100
50
0
DRY MATTER ALLOCATION (%)
SMALL
MEDIUM
BIG

Fig. 7·3

DISCUSSION

Early sprouting of the cuttings at high water regime may be due to the greater availability of moisture (Lane 1984). The tendency of the larger cuttings to emerge earlier conforms with the findings of Brown et al. (1985) in Aster acuminatus and Clintonia borealis. Winn & Pitelka (1981) suggested that earlier emergence of larger ramets could be ascribed to their greater storage of food reserves and the probability of dying decreases with increasing ramet size as observed by Gross (1981). The existence of seed polymorphism for example, tuberculate and non-tuberculate seeds in Caryophyllaceae or of small and large seeds in compositae is often treated as an adaptation to life as discussed by Harper (1977). Larger embryos and larger food reserves make it possible for a seedling to emerge from greater depth, survive longer and grow to a more aggressive size in an environment that is depleted of resources (Grime & Jeffrey 1965, Harper & Obeid 1967, Twamley 1967, Harper et al. 1970). Increased number of stolons with increase in ramet size has also been reported by Ashmun & Pitelka (1985), Pitelka et al. (1984) in Clintonia borealis and Kingsolver (1986) in Yucca glauca. This may be due to the greater food storage in the cuttings of larger size and ability of such cuttings to produce more than one stolon at a time. Regardless of the environmental constraints the growth of the individuals is largely dependent on size of the cuttings from which they develop as pointed out by Pitelka et al. (1980). Poor growth and reduction of stolon number in C. asiatica grown under low light agrees with Werner (1975) who found that in open condition even the smallest rosette in Dipsacus fullonum flowers, and produces stolons and seed, but in shade growth is limited. Pitelka et al. (1985) have shown that rhizomes and especially, flower stalks require substantial investment of carbon and they suggested that in shade carbon might be limiting. It seems likely that reproduction whether vegetative or sexual, largely depends on the resource availability rather than ramet size. Other workers (e.g. Pitelka et al. 1980, Ashmun & Pitelka 1984, 1985) have reported that ramet dynamics and patch characteristics in Aster acuminatus and Clintonia borealis are highly light-dependent. Undoubtedly the type of environment in which an individual is growing affects the growth of the plant irrespective of the size of the cuttings. On the whole, the plant appears to be a light demander and as such it cannot successfully inhabit areas with low light intensity.

Irrespective of light regimes, stolon production was more in sandy loam than in clay loam soil. Further, greater number of stolons were produced at high water regime. Reduction in water availability during the initiation of stolons from the cuttings may have adversely affected the supply of nutrients and water to the developing stolon. Salisbury (1942) observed that each plant produced 4 - 5 stolons in a wet season, while in a sunny dry summer only 3-4 stolons were produced. Stevenson & Laidlaw (1985) have pointed out that drought does not only reduce root growth and shoot growth but also causes reduction in stolon formation.

Better growth of *C. asiatica* at high water regime on both soil types is in agreement with the observations of Trivedi & Tripathi (1982 b) in *Spergula arvensis* and *Plantago major*, and Yadav & Tripathi (1985) in *Eupatorium* spp. As observed by Hiaso (1973) leaf expansion and growth are highly sensitive to water stress. Sobrado & Turner (1986) reported that water deficit reduced the rate of net photosynthesis, and the dry weight of leaves, stems, roots and reproductive parts in *Helianthus petiolaris* and *H. annuus*.

Growth of *C. asiatica* was better in sandy loam than in clay loam soil. Hume & Cavers (1982) and Rai & Tripathi (1983) working with *Rumex crispus* and *Galinsoga* spp. respectively, also observed that plants showed better growth in course textured soil than in fine textured soil. The differences in soil texture affects the drainage, soil aeration and ease of penetration by developing roots, which may influence the plant growth irrespective of soil nutrient status (Packham & Willis 1982). Although the root length of the plants grown in this experiment was not measured, the visual observation indicated that the root system of C. asiatica was much more extensive in sandy soil than in clay loam soil. The differences in dry weight of the plants on the two soil types could be related to differential moisture and nutrients availability. Daubenmire (1974) has pointed out that water in sandy soil percolates quickly and therefore, a larger root system would be more advantageous to plants growing on such soils. On the other hand, soils with high clay and silt content tend to retard root growth.

The effect of light on the allocation pattern has been discussed in Chapter VI. In all treatments the result indicates that the contribution towards clonal growth is much greater than to seeds (Fig.7.3). Similar findings have been reported in certain other species (Tamm 1948, 1972, Prime 1955, Anderson & Loucks 1973, Whigham 1974, Kawano & Nagai 1975, Barkham 1980). The reproductive investment in C. asiatica is constrained by the necessity of a primary investment into clonal growth as reported by Ericksson (1985) in Potentilla anserina. Kingsolver (1986) reported that the blooming rosette of Yucca glauca apparently expends a fixed effort on sexual reproduction and then allocates its remaining resources to vegetative growth.

Individual parents contained much more biomass than daughters mostly because of the accumulation of old stem tissue as observed by Alpert & Mooney (1986) in _Fragaria chiloensis_.

The relative cost of clonal growth and sexual reproduction is, to some extent, dependent on sizes of the cuttings. The plants developed from the large cuttings allocate more resources to clonal growth and seed production as compared to those developed from the small cuttings. _C. asiatica_ resembles other clonal herbs in which clonal growth rate depends on ramet size (Hutchings & Barkham 1976, Barkham 1980, Cook 1980, Pitelka _et al_. 1980, Solbrig _et al_. 1980, Solbrig 1981, Biergychudek 1982 a,b, Meagher & Antonovics 1982, Pitelka _et al_. 1984). There was, however, no evidence to suggest that variation in soil moisture and soil texture had any significant effect on the allocation pattern. The significant differences in allocation pattern due to light regimes and large effect of light on other growth parameters revealed that light is the most crucial environmental factor for _C. asiatica_.

GENERAL DISCUSSION

Centella asiatica grows successfully under a variety of ecological conditions which reveals that it has wide ecological amplitude. The effective curative action of this plant against various ailments, its chemical composition and pharmacological action presented in Chapter I reveals that it is one of the most valuable medicinal plants. Another interesting aspect of the plant is its clonal growth habit. The present study concentrates on the ecological requirements of the species under field and controlled conditions.

(i) Growth of *C. asiatica* in natural conditions :

The phenological study of *C. asiatica* starting from sprouting to seeding phase reveals a phenological calender which begins in March when the temperature rises and light showers are received and it ends with the onset of cold and soil moisture stress in winter (Chapter III). Because of clonal habit of the plant, individuals at pre-flowering, flowering and seeding phases are observed throughout the growing period. The seedlings constitute a small percentage of the total population. Warm and humid condition is conducive for the growth of the plant as revealed by maximum yield during summer season which is characterised by high temperature and heavy rainfall (Fig. 3.7).

The seasonal variation in growth of *C. asiatica* could be ascribed to the change in climatic conditions.Poor growth in winter season may be linked with the prevailing soil **moisture** stress and low temperature, and the maximum growth in summer may be attributed to the favourable temperature and moisture. Observed similarity in phenology amongst the populations of *C. asiatica* growing on different study sites(Chapter III) indicates that local environmental variation does not affect phenological events significantly. However, better growth at low altitude could be ascribed to the warmer climate. Many workers (e.g. Kira & Shidei 1967, Yoda 1968, Maruyama 1971, Todaria & Purohit 1979, Jolls 1982) found similar results in other plant species.

The reaction of *C. asiatica* to competition from the associated plant species is rather interesting(Chapter III). In the presence of associates, it produces longer petiole and stolon and larger leaf area but few daughter rosettes, while clonal growth was more in plots devoid of associates. Similar observations were reported by Titus & Stephens (1983) in *Vallisneria americana*. Fenner (1978) discussed that morphological adaptation, as for example, increase in leaf length allows some avoidance of shade in *Achillea millefolium*. Schmid (1985 a) observed **that** in *Bellis perennis*, rosette density was stable with time and little affected by the removal of either grasses or dicotyledonous species, while in *Prunella vulgaris*, the module density changed clearly with time and was influenced by the presence of other dicotyledonous species in the sward. The production of longer petiole and stolon by C. asiatica in the presence of associated species **facilitates** availability of light. The more vigorous stolon and rosette production by the plants in absence of competition from the neighbours however, may be interpreted as a response to the availability of more space for its spread as also observed by Titus & Stephen (1983) in Vallisneria americana and Liddle et al. (1982) in Festuea rubra.

(ii) Seed germination and seedling establishment :

Seeds of C. asiatica do not readily germinate although the viability is quite high (Chapter II). Germination was obtained only at alternating temperature under intermittent light. The seeds scarified with sulphuric acid gave better germination. As reported by Grime et al. (1981), chilling treatment is well known as a means of breaking dormancy in Umbelliferae, but C. asiatica though belonging to the same family exhibited different behaviour. The buried seeds showed better germination than the freshly collected seeds. The poor emergence of seedlings from freshly collected seeds indicates that a large percentage of them exhibited innate dormancy. In nature soil disturbance was found to promote the seedling emergence (Chapter IV), as also reported by Froud-William et al. (1984). Even though the soil seed bank was same in the disturbed and undisturbed plots, the seedling population was low in the latter which may be attributed to the conditions that presumably kept the greater part of the seed bank in dormant state as observed by Lovett Doust (1981a) in Ranunculus repens. Rai & Tripathi (1984) found that seed germination and establishment of the two species of Galinsoga were quite low on habitats having dense vegetation, although a large population of seeds was present in the soil. Many workers (e.g. Chancellor 1964, Roberts & Dawkins 1967, Chancellor 1986) reported that in disturbed soil less germination occurs because the conditions are not conducive for germination and seeds may thus remain ungerminated due to enforced dormancy. Roberts (1986) suggested that cultivation frequently stimulated germination by exposing the seeds to light. The light requirement for successful germination of C. asiatica seeds (Chapter II) may, to some extent, account for better germination on disturbed habitats.

Larger seeds obtained from low altitude population showed greater viability and germination (Chapter II & III). Many workers for example, Werner (1977, 1979) Rai & Tripathi (1982) and Wulf (1986), reported that an increase in seed size is positively correlated with emergence capacity.

In nature, the seedling mortality is density-dependent. The mortality rate declined with age as also reported by Sharitz & McCormick (1973), Sarukhan & Harper (1973) and Yadav & Tripathi (1981). Generally, the seedlings of C. asiatica died before making sufficient vegetative growth, which is in agreement with the observations reported for other herbaceous perennials (Thomas & Dale 1975, Hawthorn & Cavers 1976, Bishop et al. 1978). The negative effect of ramet density on seedling survival is most likely brought about through competition for limited resources as pointed out by Schellner et al.(1982). Several workers(Hawthorn & Cavers 1976, Sarukhan & Harper 1973, Rai & Tripathi 1984)have suggested that competition for limited resources is the major factor causing seedling death and that the climatic variations are relatively less important. Further, the seedlings experienced more severe mortality in older fallows than in newer fallows as also observed by Kushwaha et al. (1981) in Eupatorium odoratum. This may be attributed to the competition offered by the established plant communities on the older fallows.

(iii) Population dynamics :

The study on population dynamics of C. asiatica (Chapter IV) reveals that it produced more stolons on recently disturbed habitats than on undisturbed habitats, which is in agreement with the findings of Jurik (1985). Ashmun & Pitelka (1984) found that patches of *Aster acuminatus* are found to flourish in disturbed area of high light intensity. The greater density of associates on the undisturbed plots appears to have caused a decrease in the abundance of *C. asiatica*, which is in agreement with the observations of Putwain & Harper (1970), Raynal & Bazzaz (1975) and Tripathi & Dwivedi (1978), in other species. As could be expected, the adult population of *C. asiatica* showed better survival than the seedlings. No mortality occurred during the growing period which indicates that once the plant is established the mortality risk is greatly minimised. Mortality was concentrated only during winter months (Chapter III & IV) when temperature was quite low and soil moisture stress was high. Schellner *et al.* (1982) observed that ramets of violet can exchange carbon through the stolons and their survival is, therefore, not necessarily dependent on the availability of local resources as in the case of seedlings. Dependence on parental resources during establishment has been shown to increase survivorship of new offspring in natural populations of *Rubus vestitus* and *Solidago canadensis* (Kirby 1980, Hartnett & Bazzaz 1983). Absence of adult mortality in *C. asiatica* may be due to the persistent connection of parent and daughter rosettes during establishment as observed by Pitelka *et al.*

(1984) in Clintonia borealis. Many workers (e.g. Hartnett & Bazzaz 1983, Noble & Marshall 1983, Callaghan 1984, Pitelka & Ashmun 1985, 1986, Salzman & Parker 1985, Alpert and Mooney 1986) have emphasised that the major advantage of clonal habit is the integration of connected ramets through which resources such as water, mineral and photosynthates can be easily translocated. Harper & White (1974), Harper (1977), Harper & Bell (1979), Bell et al. (1979) and Bell & Tomlinson (1980) emphasised that vegetative spread is more economical than seed production in removing the daughter plants from the competitive influence of its parent. This probably explains the better survival of the vegetative offsprings of C. asiatica compared to the seedlings. The greater contribution of clonal growth to adult population was also observed by many workers (Tamm 1972, Anderson & Loucks 1973,Whigham 1974,Raynal 1979, Barkham 1980, Pitelka et al. 1985). During the 2-year study period the population size remained more or less constant in spite of seasonal fluctuations and rapid flux of births and deaths. This suggests that population of C. asiatica is self regulating. Lovett Doust (1981 a)reported similar results in Ranunculus repens.

(iv) Competition between populations raised from seedlings and from stem cuttings :

The study on the competitive interaction between the populations raised from the cuttings (C_c) and seedlings (C_s) reveals that C_c was more competitive than C_s (Chapter V). This is in agreement with the observations of Tripathi & Harper (1973) on Agropyron repens and A.caninum and Kushwaha et al. (1983 a) on Imperata cylindrica. Turkington et al. (1979) argued that the large differences in survival and growth between seedlings and transplants of Trifolium repens in permanent grassland may presumably be ascribed to the initial differences in size of the seedlings and ramets and resultant differences in their competitive ability. Zangerl & Bazzaz (1983) reported that larger food reserves in the rhizomes of Polygonum compared to its seeds permit the plants of rhizomatous origin to persist in resource limited environments where plants derived from seeds do not succeed. However, the relative yield total (RYT) which is greater than one indicates that the two populations can coexist provided there was no crowding as pointed out by Clay & Levin (1986). The much reduced size of seedling population of C. asiatica observed in nature is due not only to a small seed bank but also due to the unmeasured effects of competition from its adult plants and other associated species.

(v) Growth of C. asiatica in relation to various ecological factors under controlled conditions :

Ramet size is an important component of fitness in many plants (Werner 1975, Cook 1980, Pitelka *et al*.1980, Bradbury 1981, Solbrig 1981, Thompson & Beattie 1981). The larger cuttings emerged earlier as compared to the smaller ones (Chapter VII). This agrees with the findings of Brown *et al*. (1985) in *Aster acuminatus* and *Clintonia borealis*. The earlier emergence of larger cuttings could be ascribed to their greater storage of food reserves as suggested by Winn & Pitelka (1981). Many workers (Grime & Jeffrey 1965, Harper & Obeid 1967, Twamley 1967, Harper *et al*. 1970) reported that larger embryos with larger food reserves make it possible for a seedling to emerge from greater depth, survive longer and grow to a more aggressive size than smaller ones. Further, the larger cuttings produced greater number of stolons which may be attributed to larger food storage in them and their ability to produce more than one stolon at a time. The result is in agreement with the observations of Ashmun & Pitelka (1985) and Pitelka *et al*. (1984) in *Clintonia borealis* and Kingsolver (1986) in *Yucca glauca*.

The study pertaining to the effect of different light intensities reveals that low light causes drastic reduction in leaf area and dry matter yield (Chapter VI & VII). Similar results have been reported by Bennett & Rao (1968),Cruttwell (1968),Zimmerman (1976), Shamsi & Whitehead (1974) and Teramura (1983) in several other species. Seed and stolon production was also substantially reduced under low light condition. Werner (1975) found that in open condition even the smallest rosette in *Dipsacus fullonum* flowers and produces stolon and seeds, but in shade growth is limited. High light condition increased ramet height, yield, rhizome production and flowering in *Aster acuminatus*, while reduced light limited the growth and reproduction (Pitelka *et al*. 1980, Ashmun & Pitelka 1984, Pitelka *et al*. 1985). The response of *C. asiatica* to light conditions as observed in the present study indicates that it is a light demander and its growth is considerably reduced under low light condition.

The study pertaining to the interacting influence of light and nutrient on *C. asiatica* reveals that low light and high nutrient level has a strong negative effect on the growth of *C. asiatica* (Chapter IV). High NPK level particularly in low light, hampered the growth to such an extent that none of the plants could survive. Blackman & Templeman (1938) also found a reduction in the growth of *Agrostis tenuis* and *Festuca rubra* at ca. 40% daylight when ammonia or nitrate was added to the soil. Similar results were reported by McGraw (1985) in *Dryas octopetala*. The supressed growth of *C. asiatica* at high NPK level may be linked with increased soil acidity brought about by the addition of nitrogen fertilizer, as also argued by Sims & Atkinson

(1973). The effect of high NPK level is particularly conspicuous under low light intensity showing that light and nutrients influence the growth of *C. asiatica* in an interactive manner.Ogden (1974) found that at high nitrogen level rhizome growth was reduced in *Tussilago farfara* and he suggested that greater production of rhizome in nitrogen poor soils is a tactical response which serves to maintain and expand the clone in area which is unfavourable to tall competitors.

Soil texture and moisture too were found to affect the growth of *C. asiatica* (Chapter VII) with sandy soil supporting more vigorous growth than clay loam soil. Better growth of *C. asiatica* in sandy soil compared to the clay loam soil is consistent with the observations of Trivedi & Tripathi (1982 b) in *Spergula arvensis* and *Plantago major* and Yadav & Tripathi (1985) in *Eupatorium* spp.Sobrado & Turner (1986) reported that water deficit reduced the rate of net photosynthesis, and the dry weight of leaves, stems, roots and reproductive parts in *Helianthus petiolaris* and *H. annuus*. The differences in dry weights of the plant on the two soil types could be related to differential moisture and nutrient availability. The results also suggest that moisture requirement of *C. asiatica* is quite high.

The percentage allocation of biomass towards the roots and leaves was much greater than flowers and fruits in field condition (Chapter III), which suggests that the plant lays emphasis on vegetative reproduction. This is supported by the studies in controlled conditions (Chapter VI & VII), which also revealed that allocation towards vegetative reproduction, i.e. clonal growth, was much greater than towards sexual reproduction. Similar findings have been reported in several other species (Tamm 1948, 1972, Prime 1955, Anderson & Loucks 1973, Whigham 1974, Kawano & Nagai 1975, Barkham 1980). The investment into flowers and fruits in C. asiatica is constrained by the necessity of a primary investment into clonal growth as reported by Ericksson (1985) in Potentilla anserina. The individual parents in C. asiatica contained much more biomass than the daughters mostly because of the accumulation of biomass in old stem tissue, as also observed by Alpert & Mooney (1986) in Fragaria chiloensis. The relative cost of clonal growth and sexual reproduction is to some extent, dependent on the sizes of the cuttings that were planted. C. asiatica resembles other clonal herbs in which clonal growth is ramet - size - dependent (Hutchings & Barkham 1976, Barkham 1980, Cook 1980, Pitelka et al. 1980, Solbrig 1980, Meagher & Antonovics 1982, Pitelka et al. 1984).

The investment of C.asiatica into clonal growth was > 60% at high light regime irrespective of NPK levels, while it was only ca. 30% at low light regime. Less allocation to sexual and clonal growth at low light regime is in agreement with the findings of Ashmun & Pitelka (1984) who observed that in Aster acuminatus few ramets flower and less biomass is devoted to clonal growth under low light condition, while under high light condition, the plants produce more flowers and numerous clonal offsprings. The observed differences in allocation pattern in relation to light signifies the importance of this environmental factor. There was, however, no evidence to suggest that variation in soil moisture and texture had any significant effect on the allocation pattern.

C. asiatica seems to depend solely on clonal growth for maintaining its population. This confers a great adaptive advantage on the species as it can escape the adverse effect of environmental hazards on the sensitive seedling phase by laying least emphasis on reproduction by seeds. Turkington & Cavers (1978) found that in Trifolium repens clonal growth accounted for 12% of the biomass allocation and Ericksson (1985)found that at any given density, > 60% of the biomass was invested to clonal growth in Potentilla anserina. Tripathi & Harper (1973) found that an individual plant of Agropyron repens, a perennial weed which produces predominantly by vegetative means, produced

215 buds along an extensive rhizome system while it produced only 30 seeds which shows that energy input into clonal growth in such species is much greater as compared to seeds. Hawthorn & Cavers (1978) argued that the energy input into clonal growth might represent two ends (i) rapid means of producing potentially self-supporting offspring and (ii) as a means of sampling the immediate environment more effectively.

The present study reveals that C.asiatica prefers warm,humid and well lighted conditions for its good growth. Its capacity to grow successfully while in competition with other associated species confers on it an adaptive advantage in its natural habitat. The presence of biotic disturbance enhanced the rate of clonal multiplication and seedling recruitment. Further, the greater contribution of vegetative reproduction through clonal multiplication towards population growth confers another advantage on the species as the seedlings are not very competitive.

Though the present investigation highlights the population responses of C. asiatica under a variety of ecological condition and reaction of the species to various environmental factors both under field and controlled conditions,it also brings into focus certain aspects of its biology which need more intensive investigation. These are the following :-

(i) Long-term study of the population dynamics of the species.

(ii) Population differentiation.

Since the plant has great medicinal value and its medicinal properties have been emphasised by several workers, some of the medicinal aspects which call for detailed investigation are also listed below :-

(i) Analysis of the partitioning of the active principles in different plant parts, as affected by various environmental factors.

(ii) Cultivational practices that might optimise the exploitation of its active principles.

(iii) Medicinal application of the plant based on modern scientific approach.

The thesis embodies the results of ecological study of Centella asiatica (Linn.) Urb., a well known medicinal plant. The review of literature reveals a long list of the uses of C. asiatica in medicine. Besides having medicinal value, the clonal growth habit of the plant makes it a fascinating material for ecological study. The plant is a perennial herb belonging to the family Apiaceae. It grows abundantly in varied ecological conditions in Meghalaya. In the present study an attempt has been made to analyse the effect of a few important factors of the environment on growth, reproduction and population attributes of the plant.

The studies presented in the thesis cover the following aspects :-

(i) Seed germination.
(ii) Phenology and growth of C. asiatica in relation to altitude, season and associates.
(iii) Population dynamics of C.asiatica in a 2-year and 6-year old fallow.
(iv) Competitive interaction between individuals raised from seeds and cuttings.
(v) Effect of light regimes and NPK levels on the plant growth.
(vi) Effect of soil types, light regimes and moisture on the growth of C.asiatica raised from the stem cuttings of different sizes.

(i) Seed germination :

Fresh seeds and buried seeds of *C. asiatica* were collected from the three sites viz. Shillong Peak, Shillong and Barapani representing three different altitudes. The viability of the fresh seeds ranged from 80.0 - 86.5, while that of buried seeds ranged from 69.5 - 80.6%. Germination was tested both at constant and alternating temperatures, but the seeds germinated only at alternating temperatures. The seeds were exposed to 20°, 25° and 30°C temperature for 8 hours in light alternating with 10°, 15° and 20°C for 16 hours in darkness. The seeds showed better germination at higher temperature (30°C/15°C) than at lower temperatures (20°C/10°C). The seeds collected from the lower altitude (900 m) showed better germination than those from the higher altitudes (1500 & 1955 m). Buried seeds of *C. asiatica* germinated earlier and gave better germination than the fresh seeds. The scarification with sulphuric acid enhanced the seed germination.

(ii) Phenology and growth of *C. asiatica* in relation to altitude, season and associates :

(a) Effect of altitude :

Phenological study was carried out in permanent quadrats located at the three sites, Shillong Peak(alt1955m).

Shillong (alt. 1500 m) and Barapani (alt. 900 m). Individuals at different growth phases such as seedling phase, sprouting, flowering, seeding etc., were counted in March, June, September and December in 1983 and 1984. In March approximately 70% of the total population was in sprouting phase. Because of clonal habit of the plant, most of the individuals were at pre-flowering, flowering and seeding phases in June and September. The seedlings constitute a small percentage of the total population. In December the population of C. asiatica was predominantly composed of individuals that were seeding. The time of sprouting and maturing period were same at all altitudes. Plant growth was; however, better at lower altitude than at higher altitudes.

(b) Effect of season :

Phenology and growth of C. asiatica was studied at monthly intervals to find out the period during which maximum yield can be obtained.This study was conducted only at Shillong in the permanent quadrats of $1m^2$ size which were already marked. Phenology and growth parameters were recorded at monthly intervals over a 2-year period (June 1983 to May 1985). The phenology may be summarised as follows :-

Period		Growth phase
December - February	:	Dormant or inactive state of growth.
March - April	:	Sprouting of new leaves from the plant that had dried up during preceding winter months.
May - September	:	Active vegetative and reproductive growth phase. Seedling emergence also occurs during this period.
October - November	:	Progressive decline in growth.

(c) Effect of associates :

The study was conducted in an abandoned plot on the campus of the School of Life Sciences, NEHU, Shillong over a 2-year period from June, 1983 to May, 1985. In the presence of associates, *C. asiatica* produced longer petiole and stolon and greater leaf area and biomass, while in absence of associates the growth was reduced but clonal multiplication was favoured. It appears that a dense clonal growth offers more severe competition to individual plant as compared to the other associated plant species.

(iii) Population dynamics of C. asiatica in a 2-year and 6-year old fallow.

Population dynamics of C. asiatica was studied in a 2-year and 6-year old fallow located at Upper Shillong. In each fallow ,disturbed and undisturbed plots were created. Ramets of C. asiatica showed greater density in 6-year old fallow than in 2-year old fallow. The initial density of ramets was greater on the undisturbed than on the disturbed plot. However,the number of plants increased rapidly in the disturbed plot and plant density became higher than that in undisturbed plot in spite of lower initial density in the former. The population size was maintained primarily by vegetative means.None of the ramets died during the growing period. However, some ramet mortality was observed during winter season. Most shoots died at the end of the growing period regardless of when they emerged.Pattern of the shoot death was similar in both years of study.

The seedling recruitment was higher in 6-year old fallow than in 2-year old fallow. The number of seedlings that appeared on the disturbed plots was approximately double the number of seedlings observed on the undisturbed plots in both 2-year and 6-year old fallows. Unlike the adults or ramets, death of seedlings was more severe during the early life stages. None of the seedlings could attain flowering and they were killed with the onset of cold during winter.

Seed population in the soil was larger in 6-year fallow than in 2-year old fallow, however, the seeds collected from the latter fallow showed greater viability and germination.

(iv) Competitive interaction between individuals raised from seeds and cuttings.

The individuals raised from stem cuttings (C_c) were more competitive than individuals raised from seedlings (C_s). Number of stolons produced by 'C_c' was greater than that by 'C_s'. The total leaf area and yield were greater in monoculture than in mixture, while the reverse was true with 'C_s'.

The relative yield value of C_c was greater than that of C_s and the relative yield ratio of C_c to C_s was always greater than one, thus indicating that C_c is more competitive than C_s. The RYT worked out to be more than one at all harvests.

(v) Effect of light regimes and NPK levels on the growth of *C. asiatica*.

This study was conducted in net house condition with a view to assess the ecological requirements of *C.*

asiatica. Under low light-regime and high NPK level, the plants could not survive. Irrespective of NPK levels, the plants exhibited greater leaf area, leaf area ratio and dry-matter yield under high light regime than under low light. Production of seeds and stolons was also drastically reduced under low light. However, the plants grown under low light produced longer petioles.

The biomass allocation towards clonal growth was more under high light. However, allocation to mother rosette was more under low light. In all treatments the allocation towards seeds was comparatively less.

(vi) Effect of soil types, light regime and moisture on the growth of C. asiatica raised from the stem cuttings of different sizes.

The cuttings sprouted much earlier in the pots watered on alternate days than those watered at weekly intervals in both soil types and light regimes. Growth and development were highly size-dependeht. The larger stem cuttings sprouted earlier, showed a higher sprouting percentage and produced greater number of stolons than the small stem cuttings under high light regime, while such differences were not shown by the cuttings grown under low light. Sandy loam soil favours the growth of the plant, although at high water regime the plants grow well on both soil types.

Partitioning of dry matter towards clonal growth was much greater under high light. The plants produced by the larger cuttings allocated maximum resources to clonal growth. Under low light the resource allocation towards mother rosette was greater and the maximum allocation was recorded in plants resulting from the small cuttings. However, the differences due to soil types, moisture regimes and size of the cuttings were not large.

The present study highlights some of the important aspects of the biology of *Centella asiatica*. The greater contribution of clonal growth to the maintenance of population size is rather interesting and calls for more detailed investigation. The plant is widely used against stomachache, dysentery and other ailments. Its use as nerve tonic and blood purifier is widely acclaimed. In view of immense medicinal value of *C. asiatica*, clinical research based on modern scientific approach is worth undertaking to fully understand the mode of action of active principles contained in this plant. The field and greenhouse experiments have revealed interesting facts with regard to the population behaviour and ecological requirement of the species. These findings have both fundamental and applied value.

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