ECOLOGY OF EARTHWORM IN SOIL ECOSYSTEMS AT HIGHER ELEVATION OF MEGHALAYA

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TO WHOM IT MAY CONCERN

I certify that the thesis entitled "ECOLOGY OF EARTHWORM IN SOIL ECOSYSTEMS AT HIGHER ELEVATION OF MEGHALAYA" submitted by Km. Tuneera Bhadauria, 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 Ph.D. degree. This work has not been submitted for any degree of any other University.

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CONTENTS

PREFACE

Earthworms play an important role, in biological fertility build up in the soil ecosystem. Under shifting agriculture (locally called jhum) soil fertility build up during secondary succession after cropping is important, for sustaining this land use practice. Under shorter shifting agriculture cycle of 4 to 5 years that is prevalent in north-east India, yield under shifting agriculture is limited by restricted recovery of soil fertility, during the brief secondary successional fallow phase.

Improving soil fertility through biological means is important for sustainibility of this land use by the traditional societies living in the region. Hence the present study considers population dynamics of earthworms during the cropping and fallow phases of the shifting agriculture at a higher elevations (1500 m) in Meghalaya in north-east India. Apart from an understanding of the role of earthworms in nutrient cyling in the system under consideration here, it is hoped that the study would provide base line information for manipulation of earthworms in the soil for improving soil fertility through biological means.

The thesis has chapters dealing with the studies done on population dynamics of earthworms and their role in nutrient cycling. The thesis starts with a General

Introduction dealing with the review of literature relating to shifting agriculture and earthworm ecology. A general discussion and conclusion towards the end of the thesis summarizes the major outcome of this study. The literature cited in the text is placed at the end.

This study is one of the first of its kind from the humid tropics, that looks at perturbational effects of slash and burn and the subsequent cropping under shifting agriculture on earthworms, and follows it up through seral communities upto the climax vegetation.

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GENERAL INTRODUCTION

INTRODUCTION

Rotational bush fallow agriculture variously termed as shifting agriculture, slash and burn agriculture or locally called in India as jhum, is a traditional agriculture system of humid tropics. Shifting agriculture is practised in Latin America, Africa, Asia and New Guinea highlands. This agriculture is referred to by a number of local names among which Conuco, Milpa or agricultural nomada from Latin America, Zande from Africa, Jhum or Chena from Asia, Honunoo from south-east Asia and Tsembaga from New Guinea highlands are most commonly used (Conklin, 1957)

Shifting agriculture is practised on such a wide range of soils, amid so many types of vegetation and by people of such widely, carrying origin and cultures that it shows a great variation in the types of crops grown, the length of cropping and following periods and methods of cultivation. However all these variant forms show a general similarity in that they conform to the minimum defination involving a periodic shifting of site, and a cycle of cultivation that includes clearing of a forest by slash and burn method and then abandoning of the field for natural regeneration.

The native subsistance agriculture practised by the Hanunoo in Philippines (Conklin, 1957) and the Garos in the lower elevations of Meghalaya in north-east India (Ramakrishnan and Toky 1981a) are best examples of 'Shifting agriculture' in the humid tropics. In north-east India a piece of forested land which is allotted to the farmer by his tribal chief is clear cut during the dry season. Larger boles and branches are removed from the site and used as firewood. The slash is allowed to dry on the ground during the winter months which are rainless and burnt during March-April. Dried leaves and small branches are burnt <u>in situ</u> where as logs may be heaped up and burnt a few times. After the first few showers in April-May, weeding is done followed by sowing of a mixture of crops, dibbling the seeds using a digging stick.

CROPPING AND YIELD PATTERNS:

Shifting agriculture cycle is the time interval between two croppings on the same site, after a fallow period when forest regrowth occurs. Initially the agriculture cycle, was a long one of 20-30 years, but in the recent times - it has come down to a short cycle length of 4-5 years. This, is partly due to increased population pressure.

Mixed cropping is a universal feature under shifting agriculture. Mixed cropping is a practice where farmers select and combine cultivars in response to local conditions, with the object of obtaining optimal yield, spreading the labour requirement more evenly through time, reducing soil erosion and exploiting the positive yield interactions between the cultivars (Ruthenberg 1971; Norman, 1973; Toky and Ramakrishnan, 1981 a). The higher crop diversity usually makes it possible to combine the need for increased harvestable food portion, with the need for maintaining high biomass content in the system as a whole (Trenbath, 1974).

The differences in the composition of a crop mixture under agriculture cycles are due to differences in the crop mixture sown. The seed mixtures used for shifting agriculture cycle may vary considerably. Thus in north-ease India Toky and Ramakrishnan (1981 a) reported that cereals constitute the major component of seed mixture under longer shifting agriculture cycles, where as perennials and tuber crops are important under short agriculture cycles. Such a shift towards tuber crops under shorter agriculture cycles is important as these have better nutrient use efficiency, providing higher economic returns to the farmers.

Conklin (1957) describing Hanunoo shifting agriculture in the Philippines states that on the average 40-50 crops are planted on a single cultivated patch. Nye and Greenland (1960), reported that in the semi-deciduous regions of Ghana, cropping often starts with maize and when established, tuber crops such as yam and banana are planted with small patches of vegetable crops. In the moist savannah region of West Africa, Yam is grown on mounds of soil propared, with a variety of crops such as maize, squash and beans. In Tsembaga farming in Papua New Guinea (Rappaport, 1971) a variety of mixtures are taken together with Taro (colocasia), yam, sweet potato and cassava. The crops which are sown at the same time are harvested sequentially as needed (Nye and Greenland, 1960; Jurion and Henry, 1951; Toky and Ramakrishnan, 1981 a).

Weeds are a major cause of declining yield under shifting agriculture in many parts of the world (Bergeroo-Capagne, 1956; Watters, 1958) and include weeds such as _Eupatorium odoratum_ in Thailand (Zinke _et al_., 1978) and _Imperata cylindrica_ in Sarwak (Freeman, 1955).

According to Webster and Wilson (1973), in all probability weeds are more important limiting factor in tropical crop production than they are in temperate climate. Poor weed control is one of major causes of low yields especially on small holdings.

Toky and Ramakrishnan (1981) reported that the weed problem was more severe under shorter agriculture cycle, due to arrested succession at the weeds stage. According to Ruthenburg (1971) continuous imposition of short agriculture cycles tend to exaggerate the weed problem in the cropping season. Charter (1941) has described that the infestation of Imperata cylindrica is the reason for declining yield of maize in the forests of Latin America.

The importance of timely weeding on the yield of annual crops has been shown by different workers. Cutting et al., (1959) in Nyasaland reported that maize yielded 4284 kg ha^{-1} when weeded four weeks after germination, but attained only 3217 kg ha^{-1} when weeded six weeks after germination. Ducker and Hoyle (1947) reported that if the weeding was delayed until thinning in the cotton fields instead of being done two or three weeks earlier there was a sharp decline in yield. In a study done in Meghalaya, Swamy (1986) reported that here under shifting agriculture traditional weeding (where about 20% of weed biomass is retained <u>in situ</u> by farmer) has little effect on yield potential of crop mixtures compared to imposed weeding regimes at lower elevations of Meghalaya (Toky and Ramakrishnan, 1981)

The maintenance of soil fertility under hot and humid climate is a serious problem and is more severe in situations when agriculture cycle becomes short due to poor recovery of soil fertility, there by resulting in poor crop yield under short agriculture cycle (Nye and Greenland, 1960).

According to a study done at lower elevations of Meghalaya (Ramakrishnan and Toky 1981 a) total yields of crops under a short agriculture cycle of 5 years was markedly lower than that under a longer cycle, a major cause being poor fertility build up during the intervening fallow period. Watters (1971) reported that the decline in crop yield under short agriculture cycle was due to depletion of soil organic matter and deterioration of the soil physical conditions like water holding capacity, cationic exchange capacity and microbial and faunal activity in the soil. According to him agroecosystem under short fallow period suffered a decline in yield in case of three major staple crops in Venezuela: maize declined from 803 kg ha^{-1} to 640 kg ha^{-1} and yield of yucca and bean was reduced by 60% and 100% respectively.

SOIL NUTRIENT BUDGET UNDER SHIFTING AGRICULTURE:

When the forests are cleared and debris is burnt, all the cations are released on the surface soil as ash (Webster and Wilson, 1973; Toky and Ramakrishnan, 1981b). Heavy losses of organic carbon, nitrogen and sulphur occurs due to volatilization during the burn (Nye and Greenland, 1960; De Las Salas and Folster, 1976; Ramakrishnan and Toky, 1981b). For phosphorus though there are no obvious mechanism of volatilization, losses are reported through convection via particulates to the atmosphere (Freedman, 1981). There are conflicting reports on addition of phosphorus through fire, while Nye and Greenland (1960), Stark (1971) and Strömgaard (1984) indicate that burning results in addition of phosphorus to the system, there are others suggesting losses, of phosphate from the system (Lloyd, 1971; Harword and Jackson, 1975; Mishra and Ramakrishnan, 1983a).

Nitrification after burn is shown to be accelerated owing to high microbial activity due to rise in pH and temperature of the surface soil (Griffith, 1949; Moore and Jaiyebo, 1963; Ahlgren and Ahlgren, 1965). This increase is attributed partially to the removal of chemical inhibitors (Reed, 1951; Smith *et al.*, 1968; Rice, 1974; Saxena and Ramakrishnan, 1986).

The total concentration of cations in the soil solution depends upon the total concentrations of anions. A high level of nitrate ion due to increased biological activity (Ahlgren and Ahlgren, 1965; Wells, 1971) balances a corresponding concentration of cations in the soil solution, and therefore heavy losses through water occurs (Bormann *et al.*, (1968); Lewis, 1974). According to Bormann *et al.*, (1968) and Likens*et al.*, (1978) quantitative importance of nitrification would determine the quantity and quality of cations lost from the deforested system. Toky and Ramakrishnan (1981b) reported that during early months of monsoon in Meghalaya north-east India, heavy losses of cations through leaching were due to increase in nitrate ions intheleachate and also to high volumes of leachate being lost during these months. Heavy losses of cations and anions also occurred due to the large volume of surface water flow and high concentrations of nutrients in it. They also emphasised that the loss of water through run off and percolation and the consequent loss of sediment, increased with the shortening of agricultural cycle, at lower elevations in Meghalaya north-east India.

SECONDARY SUCCESSION AND NUTRIENT CYCLING:

The pattern of secondary succession and the rapidity with which forested community develops depends upon the degree of destruction and the clearing of the underground propagules of the community that existed prior to the operation. The length of the agriculture cycle also determines the pattern of vegetation development.

In the recent past various attempts have been made to understand the processes and patterns of vegetation succession. Clements (1916) and Odum (1969) in their relay floristic model pointed out that each set of species makes the environment less favourable for itself and more favourable for the following sets of species. Such a replacement continues untill the community reaches its climax stage. Egler (1954) proposed that initial floristic composition dominates the subsequent stage of succession after major perturbation. Grime (1977) described succession as the replacement of species essentially with rudral strategy by species with increasing stress tolerance. As the productivity of the site increased during succession the shift is towards a competetive strategy.

Richards (1952) in his study of processes of secondary succession in moist evergreen forests reported that the early phases of succession was dominated by weeds including grasses, which aree shortlived and ephemeral. In the next phase, shrubs dominated the community. The young secondary forests tended to be even-aged and often dominated by single species. In due course the secondary forest become mixed in age structure and floristic composition, the mature forest being highly heterogenous.

Ramakrishnan et.al., (1981) in their study on processes of vegetation development on abandoned sites subsequent to slash and burn agriculture at Meghalaya in north-east India, reported that during early succession herbaceous communities were dominant.

This phase was soon replaced by shrubs, bamboo and trees. If the agriculture cycle is short, succession would be arrested indefinately at the pioneer weed stage (Saxena and Ramakrishnan, 1984). This has also been noted in 'Lua' forest in Thailand where Eupatorium odoratum is the predominant weed (Zinke et al., 1978).

The literature on nutrient cycling in temperate forest is vast, (Remezov et al., 1964; Rodin and Bazilevich, 1967; Whittaker et al., 1979) the information on tropical and subtropical forest is limited (Greenland and Kowal, 1960; Nye, 1961; Jordan and Kline, 1972; Golley et al., 1975). However certain generalizations are possible:

(i) the annual uptake and return of nutrients may be greater in a tropical forest than in other type of vegetation

(ii) a larger proportion of the entire chemical inventory of the system is held in the vegetation

(iii) in tropical forests the percentage of the vegetation in green parts, the proposition lost per year as litter, and the rate of decomposition of litter are greater than in temperate forests

(iv) the rate of uptake is strongly influenced by the rate of evapotranspiration.

During the fallow period, nutrients are taken up by the vegetation from varying depths in the soil according to its root range, part of nutrient is stored in the vegetation, a part is returned to surface soil by rainwash from leaves and twigs, by litter and twig fall and in the form of dead root and root exudates.

Rapid revegetation of a disturbed site decreases nutrient losses, chanelling of water into evapotranspiration, cuts down the losses through runoff and erosion. Shading decreases soil temperature, which results in lower decomposition and nitrification rates and reduced supply of water soluble ions available for removal of drainage water (Marks and Bormann, 1972). Losses of nutrients are also reduced by growing vegetation through their incorporation into developing biomass (Vitousek and Reiners, 1975). Foster *et al.*, (1980) studied the effects of ragweed (*Ambrosia artemissifolia*) on nutrient cycling in a one year old field and showed its role in nutrient conservation. Similarly the early successional weeds under shifting agriculture system in Meghalaya north-east India as reported by Toky and Ramakrishnan (1981a)

Ramakrishnan <u>et</u> <u>al</u>., (1981)check runoff and infilteration losses through water and soil during initial fallow phase after cropping.

Nutrient cycling probably varies with the nutrient supply to the system, with the time available for the system to develop on the site and also the environmental conditions. The accumulation of the nutrient and their release through litter fall increases with the age of the fallow and becomes stable in mature forests (Stark, 1971; Toky and Ramakrishnan, 1983).

The transfer of nutrients from the subsoil to topsoil probably does not begin until after the first year or two of fallow; during this initial period the topsoil is further depleted by leaching. Results obtained by Popenoe (1959) for the nutrient content of various soil horizons under regenerating forest fallow in Guatenmala showed an initial depletion of nutrients in surface soil, after which the content of potassium, calcium and magnesium rose in the top 2? inches and fell in layers below as the vegetation developed. Similar results are also reported by Ramakrishnan and Toky (1981a) during fallow development at lower elevation in Meghalaya in north-east India.

Nye and Greenland (1960) reported that in 40- year old fallow vegetation at Kade, Ghana, the major contribution of organic matter, nitrogen, calcium and magnesium to the surface soil came from leaf and twigs where as rainwash contributed remarkably large quantities, of potassium and significant amounts of phosphate.

PINE FOREST ECOSYSTEM:

Considerable information on conifer forests is available from the temperate countries of higher latitudes (Ovington, 1959; Will, 1968; Foster and Morrison, 1976). The conifer forest represented by Pinus Kesiya in north-east India forms an early successional system coming up after shifting agriculture (Ramakrishnan et al., 1981).

The ground storey vegetation under pine forest is reported to be absent or poorly developed. This could be due to faster growth rate of Pinus species which makes greater demand on the soil compartment at the expense of ground level which is adversely affected (Ovington, 1959; Foster and Morrison, 1976). Besides with slower docomposition of pine litter (Das and Ramakrishnan, 1985) the needles tend to accumulate an the soil surface thus hampering seedling regeneration at the ground level. Besides, the highly acidic soil under pine

(Ovington, 1968; Will, 1959, 1968; Maclean and Wein, 1978) also could retard ground vegetation.

Litter production is reported to be maximum under older pine stands as compared to younger ones (Wiegert and Monk, 1972; Cole et al., 1975; Gessel and Turner, 1974) though some workers have reported a decline in litter production after certain age (Ebermayer, 1876; Zavitkovski and Newton, 1971). It was reported by Ramakrishnan and Das (1983) through their study done in Meghalaya north-east India, that in younger pine stands 98% of litter fall is comprised of needles. However this percentage usually declines in older stands of pine as also supported by other workers (Wiegert and Monk, 1972; Cole et al., 1975; Gessel and Turner, 1974).

The mean annual productivity of pine increases with stand age. The net primary productivity usually peaks in younger pine forests and declines subsequently (Ejunjobi, 1975; Madgwick, et al., 1977) because of its fast growing nature. Forrest and Ovington, (1970) reported a net primary productivity Value of 14.4 mt ha^{-1} yr^{-1} in *Pinus radiata* stands of 12-year age and Satoo (1968) reported 15 mt $ha^{-1}yr^{-1}$ in 15- year old stand of *Pinus densiflora* Das and Ramakrishnan, (1987) reported a higher value of 30 mt $ha^{-1}yr^{-1}$ in a 7- year old stand and 20 mt $ha^{-1}yr^{-1}$ in 22- year old stand. The higher productivity of the pine forests could be related to higher photosynthetic efficiency of the needles with a high net assimilation rate per unit of foliage (Satoo, 1968; Forrest and Ovington, 1970).

RAIN FOREST ECOSYSTEM:

Rain forest is restricted to equatorial zones. They are characterized in particular by extremely small annual temperature fluctuations and higher precipitation range. However seasonal rainforests as in north-east India may show fluctuations in a year, is multilayered which may be upto 5-6 layers. Scattered throughout the main vegetation layers of tropical rain forest are lianas and epiphytes growing on branches or tree trunks. Ground vegetation is usually absent in tropical rain forest because the light which penetrates to the ground is less, as it is intercepted by different vegetation layers, there by resulting in poor growth (Orth, 1939; Evans, 1956; Ashton, 1958).

Litter production in mature rain forest ranges between 20.7 t ha^{-1} to 74. 01 t ha^{-1}-(which includes dead trunks and branches) Walter (1971) reported that in tropical mature forest soil of Amani (East Africa) litter layer is composed of dead leaves and branches. In Meghalaya north-east India Boojh and Ramakrishnan (1983) reported that in the mature forest leaves constitute major portion of litter; litter production is spread through out the year but more litterfall occurs during the dry period.

Productivity of the intact rainforest is very high so long as there is rapid cycling of scarce nutrients (Odum, 1971). Information about the net primary productivity of rain forest is scarce. The net primary productivity for rain forest in Congo was estimated to vary between 23.9 to 31.5 t $ha^{-1}yr^{-1}$ (Medina and Zelwer, 1972), Value for low montane Peurto Ricon forest as reported by Odum and Jordan (1970) was much lower (12.3 t $ha^{-1}yr^{-1}$). Average value for tropical humid forests given by Rodin et. al.,(1975) is 29.2 t $ha^{-1}yr^{-1}$.

Soil in tropical rain forest of Amani (East Africa) has been reported by Walter (1971) to be quite permeable and thus strongly leached. Soil reaction is acid pH (5.3 - 4.6). Boojh and

Ramakrishnan, (1983) also reported for mature forests at higher elevations of Meghalaya, that the soil is highly leached, acidic and deficient in bases and mineral elements.

Walters (1971) reported that a mature forest in which there is no human interference, is a self sustaineable closed system including the soil; such a system is in dynamic equilibirium. The more mineralization of dead plant material in the soil is favoured by climatic factors, the more rapid is availability of nutrients from dead organic matter for reabsorption by living plants. These nutrients are immediately absorbed by roots lying on the surface forming root mats. Such a direct nutrient uptake hypothesis (Stark, 1970) necessiates distribution of finer roots in the surface soil layers. Therefore, the amount of nutrient capital necessary for the continued growth of the lush type of vegetation is tied up in the small amount of undecomposed dead plant fragments (Walter, 1971).

Sioli (1958) reported that in a virgin forest in Amazon area, destruction of forest for agricultural purposes led to sudden release of nutrients. Due to absence of plant cover which could absorb these nutrients most of them were washed out by rain. Plantations on cleared mature forest soils had to be abandoned after three years, because of exhaustion of soil nutrients and second growth forest capueira followed instead of original vegetation thereby emphasising the fragility of mature forest ecosystem .

ECOLOGY OF EARTHWORMS:

Earthworms constitute more than 80% of the total soil fauna. According to their habits life styles they have been classified by Bouche (1977) as Epiges' (litter dwellers), Endoges' (residing the organomineral layer of soil) or Anecquies' (deep burrowers).

Wallwork (1983) considers the epiges and endoges to be the product of - selection because the population undergoes erratic changes in size in an opportunistic manner, as they are directly exposed to unpredictable environmental conditions. The reproductive rates of populations are high to counteract high juvenile mortality, and physical factors particularly those associated with climate. The epiges and endoges' reproduce parthenogenetically (Jackine and Selander, 1979) which is a method of channelling a considerable portion of available energy into reproduction to ensure continous existance of the species (Edwards and Lofty, 1977). Also the individuals are characterized by smaller body size and their body colour blends with the background in order to escape from predators (Wallwork, 1983).

On the other hand, anecquie's are considered to be the product of K-selection as these species are deep burrowers and hence the effect of the physical environment is predictable and benign, the climate changes have little influence on population life style. In temperate regions, Lumbricus terrestris and Allolobophora Longa are little influenced by environmental changes, they diapause under unfavourable conditions, but as they are deep burrowers, food supply may be a limiting factor resulting in competetion for available resources (Wall work, 1983). Anecquies usually exhibit an efficient utilization of energy by individuals, rather than the production of offsprings that may or may not survive; they will produce few offsprings only which would have higher chances of surviving.

Development to maturity is long, as body size is large. They can regenerate amputed segment which is an out come of selection to minimize the affect of predation on population without eleminating it completely as a method of regulation.

POPULATION DYNAMICS:

According to Andrewartha and Birch (1954) population levels are an outcome of physical effects on natality and mortality. The operation of these effects will cause populations to increase during times of plenty and decrease during times of stress.

The number of earthworms vary from 1-850 M^{-2} in temperate soils, (Satchell, 1969). The number of earthworms are more in mull soils than in mor soils fallows and moorlands. The numbers in regularly cultivable arable soils are highly variable. On the other hand, little information is available on the populations from tropical soils. Block and Banage (1968) recorded population size between 7.4 M^{-2} and 101.8 m^{-2} in Ugandan soils and Madge (1969) has recorded 33 m^{-2} in Nigerian grass lands. Duweini and Ghabbour (1965) recorded 8-788 m^{-2} in Egyptian soils.

The population structure is dependant upon the season and environmental conditions. The cocoon production by the worms is dependant upon soil temperature, moisture and food supply. Evans and Guild (1948) in their culture experiments and Gerard

(1967) through his field studies showed that seasonal fluctuations of the soil climate also cause the number of cocoons produced by different species of earthworms to vary. There are usually more immatures than adults in a population although their relative proportions vary seasonally. For example Raw (1962) reported that the proportion of <u>Lumbricus terrestris</u> individuals of different ages in his sample from an orchard were in the ratio of 8:13:31 for mature, large immature, small immature.

Earthworms are not randomly distributed in the soil (Guild, 1952). The distribution of earthworm populations could be the result of interactions of many factors which could be physico-chemical factors like soil pH, moisture, temperature or available food or reproductive potential and dispersive powers of the species (Murchie, 1958).

It has been noticed that earthworms are very sensitive to soil pH. Most workers are of the view that the worms prefer a neutral soil (Bodenheimer, 1935; Petrov, 1946). However <u>Eisenia foetida</u> has been reported to prefer soils with a pH between 7-8.0 but in contrast to these certain tropical species of <u>Megascolex</u> thrives in acid soils from pH 4.5 - 4.7 (Bachelier, 1963) and <u>Bimastos Ionbergi</u> is numerous in soils between pH 4.7 and 5.1 (Wherry, 1924).

Soil moisture affects the distribution and activity of worm populations. Prolonged droughts markedly decrease size of earthworms, and populations may take two years to recover when conditions become favourable. Olson (1928) surveyed an area of Ohio U.S.A. for earthworms and reported largest population of earthworms occurred in soils containing between 12% and 30% moisture. Gerard (1960) showed that lack of moisture causes earthworms to diapause thus affecting their activity. On the other hand, moist soil resulted in increased activity.

Population distribution is greatly affected by the soil temperatures because the activity, metabolism, growth and reproduction of earthworm are all influenced by temperature. The fecundity rate of worms is high and they can be killed by extreme temperatures. For instance it has been suggested that earthworm populations in arable soils in United states may be destroyed by frost (Hopp, 1947) and that the worms show vertical migration. Dowdy(1944) reported that Diplocardia sp moved to lower levels at temperature below 6°c. Grant (1955) showed individuals of Allolobophora caliginosa preferred soils of 10-23° c and individuals of E. Foetida soils of 16°c - 23°c.

The distribution of organic matter in soil greatly influences the distribution of earthworms. Large amount of dead roots and other organic matter in pastures, and decaying leaves in woodland usually coincide with large earthworm populations (Edwards and Lofty, 1972a) and it is probably the gradual decrease in soil organic matter, when pasture is ploughed and used for arable crops, that leads to a decrease in earthworm populations (Hay et.al., 1978)

Satchell (1955) calculated indices of dispersion for adults and immatures he found that adults were nearly randomly dispersed but the immatures were aggregated. Hence, a species with distinct seasonal abudance can be expected to pass from a very aggregated phase in the breeding season in early summer to an almost random phase in winter.

Effect of fire on soil fauna is limited. In all the sites studied earthworms are markedly reduced by fire (Ahlgren, 1974). A 50% reduction in population of earthworms resulted from burning off litter in the Duke forest (Pearse, 1943). In studies of Illinois prairie Rice (1982) found lower population of earthworms on burnt land, though according to her this difference in population is affected mostly by post fire loss of soil moisture than by actual heat of fire. When shifting cultivation is practised animals inhabiting the soils would be affected by both direct heat from burning and consequent changes in habitat (Watanabe and Ruaysoongnerg, 1984).

CAST PRODUCTION:

By producing casts earthworms play a vital role in soil turnover (Satchell, 1967; Edward and Lofty, 1972a). The number of cast produced varies seasonally and is an index of earthworm activity (Evans and Guild, 1947). Casting in tropical species is mostly confined to wet season (Madge, 1969; Gates, 1961) cast production in tropics ranges from 50 t $ha^{-1} yr^{-1}$ in Ghana (Nye, 1955) to as high as 2600 t $ha^{-1} yr^{-1}$ in Nile valley (Beauge, 1912). The giant Notoscolex sp in Burma produce large tower shaped casts weighing 1.6 kg (Gates, 1961).

Casting in temperate zone by earthworms varied from 18.7- 100 t ha^{-1} which is equivalent to a soil layer of 5mm thick being annually deposited (Darwin, 1881; Guild, 1955). The cast size varies depending upon the species. The weight of cast of

European species seldom increase 100 g. Worm casts are usually more neutral than the underlying soil (Finck, 1952; Nye, 1955).

NUTRIENT CYCLING:

Role of earthworms as an important decomposer group has been shown by different workers (Satchell, 1967; Lavelle, 1977; Senapati and Dash, 1984). They play an important role in litter fragmentation (Satchell, 1967; Dash and Patra, 1977). Earthworms also play a major role in incorporation of organic matter (Barley and Kleinig, 1964; Rhee, 1963), improvement of soil acration (Noble et al., 1970; Rhee, 1977), acceleration of humification (Darwin, 1881), conversion of organic nitrogen (Barley and Jennings, 1959; Lee, 1983) and phosphorus (Mackay et al., 1983; Mansell et al., 1981) into plant assimilable forms. Acceleration of humification relates to the catabolism of labile organic nutrients and retention of recalcitrant molecules such as nucleic acids (Hartenstein and Hartenstein; 1981).

Increase in available nitrogen and phosphorus for plants due to earthworms can be attributed to the apparent primary nutritional need by earthworms of microrganisms as a source of these minerals in their egesta (Flack and Hartenstein, 1984) followed by excretion of excessive nitrogen primarily as ammonia while feeding and urea when fasting (Needham, 1957) as well as higher phosphatase activity in castings than in soil (Satchell and Martin,1984).

Earthworm cast contain more plant nutrients than the soil matrix but less than the plant litter (Graff, 1970 ; Vimmerstedt and Finney, 1973). Thus they cannot increase the total amount of nutrients in the soil. But can make them more available (Barley and Jennings, 1959; Sharplay and Syers, 1977). They may increase the rate of nutrient cycling thereby increasing the quantity available at any given time.

Earthworms influence the supply of plant nutrients in the soil through death and decay of animal tissue. The amount of nitrogen released annually into the soil mainly as dead tissue protien and as excretory mucus, urea, uric acid and ammonia is estimated as between 18-92 kg ha^{-1} depending upon the size and activity of earthworm populations in temperate conditions (Syers and Springett, 1984). In New Zealand, contribution of earthworm fauna to the annual cycle of phosphorus and sodium was found 2-9 kg ha^{-1} (Syers and Springett, 1984).

PRESENT STUDY

The shifting agricultural practice followed by the Khasi tribe, at higher elevations of Meghalaya in north-east India is a modified version of its typical type (Toky and Ramakrishnan, 1981a); Mishra and Ramakrishnan, 1983a). Normally the lower branches of sparsely distributed pine trees alone are cut instead of the whole tree. Further unlike its typical form where slash is burnt _in situ_ and the seeds are dibbled directly into the soil ash complex as is practised at lower elevations in Meghalaya, (Ramakrishnan and Toky, 1981) at higher elevations the slash is placed in parallel rows running along the slope, covered over by a thin layer of soil forming elevated seed beds (ridges), alternating with compacted furrows and the slash is subjected to a slow burn. Planting of the crops is confined to the ridges alone; both organic and inorganic fertilizers may be used (Mishra and Ramakrishnan, 1983a).

Farmers do multiple cropping. Under a shorter agriculture cycle of five years, usually a mixture of 2- 2 crops are grown of which potato is important along with Zea mays and Brassica oleracea, while under a longer agriculture cycle of fifteen years or more, usually a mixture of as many as 9 species may be included with main emphasis on potato along with other tuber crops such as Ipomoea batata and Colocasia antiquorum, some cereals like Zea mays, legumes such as Phaseolus vulgaris and vegetables such as Cucurbita maxima are also sown. Potato alone is sown as a second crop in the same year. Such a shift in emphasis in crop mixtures is significant and is related to soil nutrient status (Ramakrishnan and Toky 1981 ; Mishra and Ramakrishnan, 1983a).

Secondary succession takes place on the abandoned land subsequent to shifting agriculture. This agriculture practice usually results in progressive reduction in the pools of species originally present.

At higher elevations of Meghalaya in North-East India upto first five to six years of fallow regrowth weedy communities such as Eupatorium sp Imperata cylindrica are predominant. This phase passes on to rapidly regenerating pine trees (Pinus kesiya) along with broad leaved trees such as *Schima Wallichii*. These would subsequently develop into a mature broad-leaved forest with trees such as *Quercus* sp. and *Castanopsis* sp. (Boojh and Ramakrishnan, 1983).

PINE FOREST:

Pinus kesiya or pine is a high elevation early successional, endemic tree species restricted to north-east India and is found at an altitude of 800 - 1900 m in Meghalaya, under a high rainfall of about 200 cm annually.

Total production of litter and annual productivity of Khasi pine is reported to be higher than the other pines of the world (Das and Ramakrishnan, 1986). A comparison of the nutrient status of the soil with pine forests, in different parts of the world, showed fertility status of *Pinus kesiya* soil to be higher. This may be due to more favourable soil temperature and rainfall conditions and also due to rapid turnover of nutrients through faster leaf production, litterfall and decomposition compared to a temperate pine forests (Ramakrishnaan and Das, 1983). Khasi pine is also reported to be more efficient in nutrient release, as is also indicated by low residence time and high turnover rates of nutrients on the forest floor. Thus under prevailing environmental conditions in Meghalaya in north-east India *Pinus kesiya* is efficient as an early colonizer in soils of poor fertility.

CLIMAX VEGETATION:

Sacred groves are representatives of climax sub-tropical humid evergreen montane forest communities at Mawphlang near Shillong in Meghalaya north-east India at an altitude of 1900 meters. This forest community is maintained in a comparatively undisturbed state because of the cultural traditions of the local Khasi tribe who believe that sylvan dieties would be affended, if trees are cut or flowers and fruits are removed.

Rainfall in the region is very heavy. The temperature is even with a miximum of about 24°c and average minimum of 16°c during the summer. The winter maximum is 16°c and minimum 8°c.

The vegetation is a mixed evergreen broad leaved forest consisting of oaks and laurels as dominants. *Quercus griffithii*, *Q. dealbata*, *Schima khasiana* are the important tree species. The shrub strata here consists mostly of shade loving species. Ground layer is usually absent because of the presence of a multilayered canopy which restricts light penetration to the ground level. The trunks and branches of trees are heavily loaded with epiphytes, mosses and lichens.

Forest floor is covered by a thick layer of litter. Soil is highly leached acidic and deficient in bases and mineral elements. A fine root mat plays an important role in direct nutrient uptake from the decomposing litter.

At higher altitudes of Meghalaya north-east India, broad-leaved tropical montane vegetation represents the climax stage but owing to the practice of shifting cultivation the forests have been converted to cultivable land for agriculture purpose thereby destroying its original vegetation.

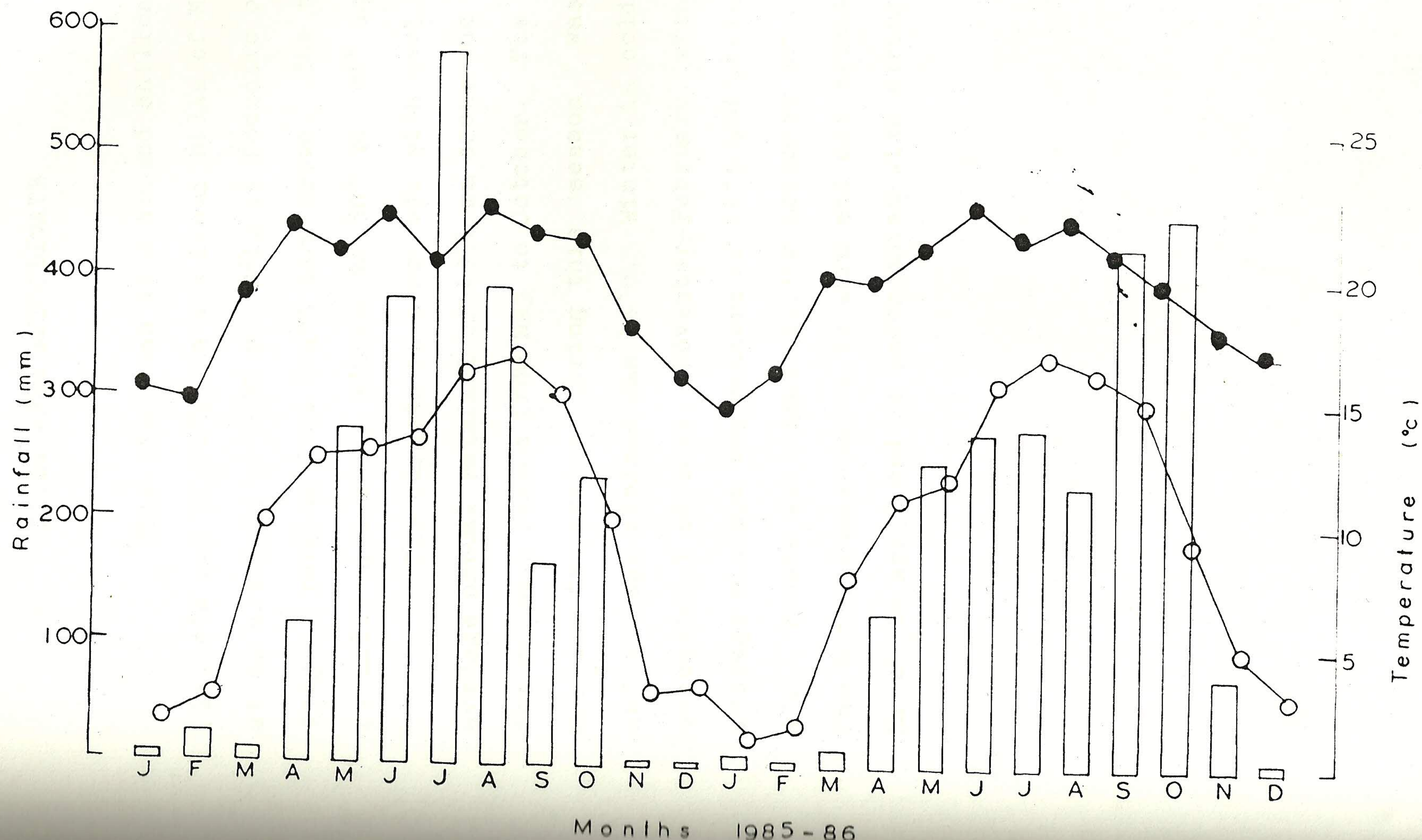
The development of vegetation subsequent to shifting agriculture represents a successional gradient. As succession progresses, the diversity increases *Pinus kesiya* takes over and is a single species dominant in secondary successional forest. In the mature phase represented by the sacred groves, the species diversity is extremely high.

In the present study an attempt has been made to analyse the pattern and processes of population dynamics of earthworms during cropping under 5- and 15-year shifting agriculture cycles starting from the pre-burn stage and followed throughout the cropping season. Qualitative quantitative studies on population dynamics in relation to environmental changes during fallow regrowth of upto fifteen years and in secondary successional pine forest was done and compared with that under the climax vegetation represented by the sacred grove at high altitudes of Meghalaya in north-east India.

The study also includes quantitative measurements of cast productions, and the role of earthworms in the processes of soil turnover and nutrient cycling as a whole, in agroecosystems under 5 and 15-years agriculture cycles, and during secondary succession of about 15-years. This study would help in an understanding of the role of earthworms in the decomposer system under shifting agriculture at higher elevations of Meghalaya. Further, it would give comparative information of the ecology of the earthworms under different land use management practices, providing better understanding of the differential adaptive strategies of the populations and the role in nutrient cycling. From an applied view point this study is important to the management of soil fertility in the humid tropics.

Fig.I. Ombiothermic diagram for the study area. Mean monthly maximum (●) and minimum (O) temperatures; monthly rainfall (open Column.)

Fig.-I



Rainfall (mm)
600
500
400
300
200
100
J F M A M J J A S O N D J F M A M J J A S O N D
Months 1985-86
25
20
15
10
5
Temperature (°c)

STUDY AREA AND CLIMATE

This study was done around Shillong (25.34°N and 91.56°E) in the Khasi hills of Meghalaya, at an altitude of 1500 m. Soil is Podzolic of laterite origin, ranging from light dark brown. The terrain is hilly with steep slopes, of 30° to 40° angle.

The climate is monsoonic with most of the average annual rainfall of 1971 mm occurring during the monsoon season from May to October. The average maximum temperature during this season was 21°c and average minimum was 14°c. Winter is cold with occassional showers, (November-February) with an average miximum temperature of 16°c and minimum of 4°c. Frosts are common during December and January. The brief summer which is warm and dry extends from March to April and is accompanied with strong winds.