DYNAMICS OF BURIED WEED SEED POPULATION IN CROP FIELDS UNDER 'JHUM' (SHIFTING AGRICULTURE) AND TERRACE CULTIVATION IN MEGHALAYA

By

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I certify that the thesis entitled ***"Dynamics of buried weed seed population in crop fields under 'Jhum' (shifting agriculture) and terrace cultivation in Meghalaya"*** *submitted by* ***Mr. Uttam Kumar Sahoo,*** *for the* ***Degree of Doctor of Philosophy*** *of the North-Eastern Hill University, Shillong, embodies the record of original investigation by him under my supervision. He 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.*

SHILLONG
THE 9th ***APRIL 1992***

(R. S. Tripathi)
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CONTENTS

CHAPTER I

General Introduction

'Soil seed bank' represents seed reserve or seed pool which is partly composed of seeds produced on the area and partly of the seeds blown from elsewhere (Cohen, 1966). The seeds generally enter into the soil either in dormant condition or the dormancy is imposed upon them. These seeds form the soil seed bank. It remains there in dormant state as long as the unfavourable conditions persist. The longevity and size of the soil seed bank depends upon the life span of the seeds and species composition of the seed pool. It partly reflects the history of vegetation and is also likely to contribute to its future (Major & Pyott, 1966). The dormant fraction of the seed bank is likely to continue to many generations of the plants, sometimes over decades. Therefore, seed bank may be said to represent a store of 'evolutionary memory'.

Seed bank has a strong link to the survival of a plant population. A clear understanding of the dynamics of a plant population requires a thorough knowledge of the seed population dynamics in soil. The study of seed population dynamics in soil in the context of crop fields encompasses such aspects as 'seed rain' (*sensu* Harper, 1957), weed seed input through farmyard manure, contaminated crop seeds and other agencies, weed seed dispersal, status of the weed seed bank in soil, fate of the buried weed seeds in time and space, weed seed losses caused by various agencies and weed seed population flux as a whole.

Most weed seeds undergo a period of dormancy after their dispersal. Depending on the species and the prevailing environmental conditions, the dormancy in seeds may last from few days to many decades. Such seeds continue to remain in dormant condition in soil as long as the unfavourable conditions persist in soil-seed environment. Therefore, the soil seed bank partly contains the seeds shed or blown onto it in the current seasons and partly of the seeds which have remained dormant from preceding years. This may also include some species no longer growing there. Thus the seed content of the soil partly reflects the past vegetational history of the land. The knowledge of various aspect's relating to soil seed bank may be helpful even in forecasting the future weed vegetation.

Most weeds shed seeds before the crop harvest by virtue of their rapid growth and short life cycle. Therefore, before the weed plants die, they leave enormous quantities of seeds in the crop fields, which increases the size of the weed seed bank in soil and causes weed infestation in several subsequent years. Thus "One year's seeding seven years' weeding" is not just a saying, it has a scientific basis too.

Weeds share much of the light, water, nutrients and other resources of the agroecosystems and adversely affect the crop yield. Thus, one of the prerequisites for improving crop productivity is to keep the crop fields free from weeds as far as possible employing various control measures including the application of herbicides. The herbicides, no doubt, kill the weed plants, however, the weed seeds lying at different depths of soil remain unaffected. Such seeds contribute to the recruitment of weeds when the conditions become favourable for germination and seedling emergence in subsequent generations. Therefore, the weed seed population in soil is a key factor in determining the dynamics of weed populations in crop fields.

In situations where effective weed control practice is lacking, the unchecked weed growth and successful seeding by weeds result in accumulation of seeds in soil in large numbers. This large weed seed reserve can contribute to the severity of weed infestation only when it contains sufficient quantity of viable seeds. In fact, the germinability of buried weed seeds, their longevity and dormancy mechanism regulate the weed infestation in subsequent years. The intensity of weed infestation, temporal and spatial variability in weed population and composition of weed flora in agroecosystems are strongly influenced by the nature and dynamics of weed seed bank in soil.

Weed problem is a very common feature in all agroecosystems. The problem, in particular, is far more acute in shifting agriculture (locally called 'Jhum') where modern weed control measures are not employed. Though the terrace cultivation has been recommended as an alternative to 'jhum' as one of the measures to minimize deforestation and soil erosion and to improve crop yield, traditional 'Jhum' cultivation is still the chief agronomic practice of the tribal people of north-east India. The crop fields under both 'Jhum' and terrace cultivation in Meghalaya are heavily infested by a large variety of native and exotic weed species owing to the favourable climatic conditions for their growth and absence of efficient weed control measures.

The crop fields under 'jhum' cultivation are usually left as fallow for about 4-5 years before they are brought again under cultivation. There is a rapid and luxuriant growth of weeds during the fallow period. In 'jhum' cultivation, manual hand weeding is the sole method employed for weed control; there is no application of herbicides. On the contrary, the crop fields under terrace cultivation are subjected to continuous cropping and the fallow period, if any, happens to be of a short duration. Therefore, the agro-ecosystems under terrace cultivation do not get enough time to develop protective vegetational cover. Moreover, the regular crop rotation and application of herbicides suppress the growth of weeds. Besides, mechanical as well as manual hand weedings are also frequently done to control weeds. Thus the 'Jhum' and terrace cultivation, both of which are prevalent in the hill region of Meghalaya vary considerably from each other. The variations in cultivation practices bring about changes in phenologies of weeds, and dispersal abilities of the colonizing species (Swaine & Hall, 1983; Uhl et al. 1981), as a consequence of which the dynamics of weed seed population in soil may also be influenced.

Weeds produce seeds in large numbers, a good proportion of which becomes incorporated into the soil weed bank of crop fields. Though a part of the soil seed bank, of course, gets exhausted with time, a large fraction of the buried weed seed population still remains there in viable state to perpetuate the weed problem. Therefore, it is important to know the fate of the weed seeds that are dispersed into an agroecosystem. These weed seeds subsequently get incorporated in the soil seed bank. The following pertinent questions could be raised with regard to the fate of weed seed bank in soil and related issues.

1) Do all the seeds entering the soil form an integral component of the soil seed bank as well as the weed flora?

2) How long do they survive in soil?

3) How does the burial affect their dormancy mechanism and actual germination?

4) How and to what extent do the prevailing cultivation practices influence the fate of buried weed seed population?

These are some of the questions which need to be answered through manipulative field studies and 'control' experiments.

Keeping the above points in view, the present study on the dynamics of buried weed seed population in different crop fields under 'jhum' and terrace cultivation has been made to cover the following aspects:

1) Weed seed input to the crop fields through seed rain, contaminated crop seeds and FYM.

2) Species composition of the weed flora and soil seed bank.

3) Existing status of the soil seed bank.

4) Fate of the buried weed seed population.

5) Change in seed viability and dormancy of seeds of a few selected weeds due to burial.

6) Weed seed loss from the crop fields.

The experimental data on various aspects mentioned above have been presented in Chapters IV to X. The General Introduction (present chapter) outlines the significance of weed seed bank in soil and sets out the objective of the thesis. The literature pertainining to various aspects of weed seed bank in soil, such as fecundity of weeds, weed seed input into the soil, viability, dormancy and germinability of the buried weed seeds, change in buried weed seed population in time and space and loss of weed seeds from the soil seed bank have been briefly reviewed in Chapter II (Review of Literature). Chapter III deals with the soil, climate and vegetation and also describes the salient features of the seeds of a few selected weed species. Although the data contained in Chapters IV - X have been critically discussed in the corresponding chapters, the major findings of the entire work have also discussed in an integrated manner (Chapter XI, General Discussion).

The studies relating to the dynamics of weed seed population in arable soil have engaged the attention of several workers in the Temperate countries. The studies include species composition of soil seed bank (Robinowitz, 1981), vertical distribution of weed seeds in soil (Cousens & Moss, 1990), status of the soil seed bank (Brenchley & Warington, 1930, 1933, 1936), determination of germinable, dormant and non-viable fractions of soil seed bank (Thurston, 1960), effect of cultivation on distribution of weed seeds in soil (Chepil, 1946; Moss, 1988) and loss of weed seeds from soil (Roberts, 1970). However, such studies are few and far between in the tropical and sub-tropical regions of Indian Sub-continent, and the need for studies pertaining to these aspects under Indian conditions has been emphasized by Tripathi (1977). Although Professor Tripathi and his collaborators (Mukherjee _et_ _al_. 1980; Tripathi & Yadav, 1981 and Pradhan, 1990) have published some useful material on the subject, a detailed treatment of the dynamics of weed seed bank in soil has been lacking in these publications.

A screening of literature reveals that the papers published on weed seed bank in soil and related areas may be appropriately reviewed under the following heads.

Seed Production

Generally, weeds produce a large number of seeds than they require for their perpetuation as they have to face numerous hazards during their life cycle. The number of seeds a weed produces, varies from species to species, even the actual number of seeds per plants varies considerably within a species, and it solely depends on the size of the plant, its growing conditions, the predatory attack and the type of pollination during the flowering and fruiting periods (Harper, 1957). The seed production of annuals varies from that of biennials and perennials. It also depends on the spatial distribution of neighbouring plant species, as the neighbours growing aside usually react making disproportionately to the yield per unit area (Harper, 1960).

The number of seeds produced by a plant in certain species influences the abundance of their seeds in the soil (Salisbury, 1978). This is true in the case of <u>Poa</u> <u>annua</u> and <u>Juncus</u> species (Harper, 1977). While estimating the seed production by a weed, it is very important to note the maturity date of the plant or its optimal shedding period (Sayre, 1953). The seed production roughly measures the pernicity of a weed and is, indeed, a central point to their survival and evolution.

Seed Dispersal

Although the dispersal of seeds from the parent plant is necessary for the future propagation and population growth of the species, it may also irretrievably alter the balance of growth and food supply of the host community (Pijl, 1972). The size of the weed seed bank in soil is greatly dependent upon the forces of dispersal and seed rain. Besides seed rain, the application of FYM, sowing of contaminated crop seeds, irrigation water, dust and dirt adhered to the farm tools and birds, rodents, grazing animals and man are other important sources of weed seed input into the soil. The size, shape and other morphological features possessed by seeds determine the extent and the type of dispersal mechanism.

A number of studies relating to the dispersal of seeds through irrigation water is available. Egginton & Robbins (1920) observed 156 weed species from three irrigation ditches in London; most frequent species found were prostrate pigweed, rough pigweed, tall marshelder, knotweed, black bindweed, curled dock and common dandelion. Sowing of unclean crop seeds may cause an appreciable increase in weed seed population and once introduced, new species may build up rapidly. Numerous studies are also available concerning the viability of seeds in manure (Salzmann, 1939; Rosenfels, 1940; Dastgheib, 1989) and how long it must be composted to reduce the content of viable seeds (King, 1974). Weed seeds may be carried through stubbles, husks and stalks during transportation. They may be dispersed through the dirt, soil or mud adhered to the wheels of the vehicles, ploughs, cultivators or other implements as threshing machines, hay balers and portable seed cleaners and in recent years even the air planes.

Whatever may be the mode of seed dispersal, seeds of terrestrial plants usually fall in a continuous leptokurtic distributions with the mode under or near the parent plants and steadily declining number further away (Levin & Kerster, 1974; Howe & Phillips, 1988). Fugivores may influence the floral composition within local communities. Continuous visitation of fugivores may also influence the phenological pattern of the plants. Fire appears to be the most important factor in overcoming seed coat impermeability in many communities, thereby breaking dormancy and favouring subsequent emergence (Saxena, 1981).

Soil seed bank

The soil seed bank is strongly linked with the past history of the vegetation and land tenure practices. The size of the soil seed bank is a resultant of many factors such as, (i) accumulation of seeds, (ii) dissemination of seeds, (iii) input of weed seeds through contaminated crop seeds, (iv) application of FYM, and (v) losses of seeds due to immediate germination, predation by birds and rodents, removal by wind and water, and losses due to death and decomposition. The size of the seed bank largely depends upon these factors and the environmental conditions which regulate the above parameters. Therefore, the existing status of the soil seed bank at a given time depends upon the balance of gains and losses. The gains in seed number result largely from the amount of seeds shed in the fields, which is determined by plants' abundance and seed production and the proportion of seed population that gets buried in the soil, while the losses, are due to germination, predation, removal, death and decomposition. Both gains and losses are influenced by current and previous environmental and managemental factors (Sagar & Mortimer, 1976; Harper, 1977).

The soil seed bank is analogous to a bank where transactions are available in different forms. Harper (1977) regards the dormant state of the seeds in soil seed bank as 'deposit account' and the viable-dormant fraction where the only hindrance to germination is due to shortage of water and favourable temperature as 'current account'.

Species composition of the soil seed bank and weed flora

Several attempts have been made to relate the species composition of the soil seed bank and weed flora of a given crop field. In some studies (Robinowitz, 1981), it has been shown that the seeds of such species which are absent from a crop field are also represented in the soil seed bank. There are also reports showing that even though the plants grow in a given field the soil seed bank may not contain their seeds (Saavedra et al., 1990). The species composition of the soil seed bank and weed flora of a given area in a particular climatic region are influenced by (i) past history of the land, (ii) cultivational practices such as type of crop grown, crop rotation, use of farmyard manure (FYM), application of herbicides and pesticides, plough design and frequency of ploughing and (iii) sources of seed input to the soil and losses from the soil seed bank.

Most of the studies show that the seed rain (i.e. species coming through seed rain to soil) resembles the soil seed bank more than the bank resembles the seed rain. For example, Robinowitz (1981) observed that most of the species present in the seed rain are also present in the soil seed bank, but majority of the component species of the seed bank are not present in the rain. As argued by Templeton & Levin (1979), the species falling in the latter category form the memory of past ecological conditions.

Soil disturbance acts selectively on the composition of weed flora and soil seed bank. The disturbance may make the prevailing conditions suitable for the germination of seeds in some species, while in others, it may create adverse conditions and thereby, it could influence the species composition of a community to a greater extent (Carretero, 1977; Roberts, 1981). The relationship between the number of seedlings emerging and the number of viable seeds present in soil has been studied by a number of investigators. Robers & Dawkins (1967) have noted that this relationship could be more or less constant from year to year under a constant cultivational regime. However, Jensen (1969) found a little correlation between the overall weed population in different crop fields with seed numbers in the soil. Kropac (1966) noted a wide variation in the percentage of viable seeds in the top 20 cm soil which produced seedlings. This relationship is influenced by the frequency of disturbance in the crop fields. Roberts (1958) concluded that in a rotation of vegetable crops with frequent disturbance, about 10% of viable seeds in the top 15 cm of soil gave rise to seedlings during a whole year period. His values for uncropped plots cultivated twice and 4-times a year were 7% and 9% respectively of the viable seeds in the top 23 cm soil. Barralis (1972) found that in a rotation of spring and autumn sown crops, an average of 5-6% of the total viable seeds in the top 10 cm soil produced seedlings in the crop fields, while the values reported by Carretero (1977) ranged from 2.8 to

15.5% of the viable seeds in the top 10 cm.

Estimation of soil seed bank

Two types of approach are seen while quantifying the soil seed bank. In the first approach, the number of buried viable seeds has been estimated by taking soil samples and maintaining them at a favourable temperature for seedling emergence, stirring the soil at different intervals and counting the number of seedlings when they emerge (Brenchley, 1918; Brenchley & Warington, 1930; 1933; 1936; Milton, 1939; Livingstone & Allesio, 1968; Roberts, 1958). In the second type of approach, the seeds in soil samples are either counted directly under a dissecting microscope (Olsted & Curtis, 1947) or are extracted from the soil samples by floatation in concentrated salt solution (Roberts & Ricketts, 1979).

The most important step involved in the estimation of soil seed bank is the collection of soil samples. Roberts (1981) prefers a large number of soil samples of smaller sizes over a small number of samples of larger sizes. Many methods have been used to test the viability of buried weed seeds. The viability has been tested through rapid germination method (Kropac, 1966) in certain cases. The direct examination of embryo after soaking seeds in tetrazolium salt solution (Malone, 1967; Misra, 1968; Hayashi & Numata, 1971) has proved to be a better method for viability measurement. In a few cases, the seeds are considered to be 'apparently viable' if they appear to be intact and resist gentle pressure (Zelenchuk, 1961; Hayashi et al., 1978; Roberts & Ricketts, 1979; Roberts, 1981).

Vertical distribution of seeds in soil

The vertical distribution of seeds in soil determines the changes in weed seed population to a great extent. Seeds shed from the parent plants or dispersed from other sources after landing on the surface, take up different positions depending on the variation in their size and shapes. The physiology of seeds at the time of seed shedding and degree of hydration changes in seeds influenced the seed burial to a certain extent (Harper et al., 1970). As reported by Harper et al. (1965), in the seeds having upwardly directed hairs, the movement of awn serves to regulate the depth of burial.

Cultivation systems have a profound effect on the vertical distribution of weed seeds in soil (Chepil 1946; Soriano et al. 1968; Roberts & Feast, 1973a; Hakansson, 1983; Moss, 1988). During cultivation the seeds present on the soil surface may be thrown to deeper soil layers and those buried at deeper layers may be brought to the soil surface (Moss, 1988). Thus, the seeds placed on the soil surface immediately before cultivation may become residents of deeper soil layers till further disturbance in the soil (Roberts, 1981). Vertical distribution of seeds is broadly dependent on the ploughing efficiency which is influenced by several factors such as plough design, skill of operation, depth of ploughing, soil type, soil moisture regime and amount of trash present in the soil (Chepil, 1946; Kazantseva & Tuganaev, 1972; Goeden & Ricker, 1973; Moss, 1988).

In many studies on vertical distribution of seeds in soil no clear-cut depth-related trend has been observed in agricultural soils which are frequently disturbed and there is fairly similar depth-distribution irrespective of the seed size (Howle & Caviness, 1988). Most of the work done on vertical distribution of weed seeds in soil shows that each species has a critical depth of availability (Moore & Wein, 1977), however, this may change with different micro-topography. Milton's depth profile on vertical distribution of seeds in soil shows a sharp fall in seed density with increasing soil depth (Roberts, 1981). In another study, Brenchley (1917) suggested that there is always a high abundance of seed population in the top 2.5 cm of soil and there is rapid decline in seed density with increasing soil depth. In undisturbed situation, however, Robinson & Kust (1962) have found a higher seed density of small seeded species in deeper soil layers. In a crop rotation with regular ploughing, the seeds become distributed fairly uniformly throughout the working depth, while, in stubbles and undisturbed situations, the concentration of seeds may be very high in the surface layer of soil (Roberts, 1970).

The vertical distribution of seeds in soil is also related to the species-specific emergence and the physical condition of the soil. In many studies in situ germination in soil has been seen immediately after seed shedding (Roberts, 1981), which is an important factor regulating the distribution of seeds in different soil depths. The weed species in arable land differ in their response to cultivation (Wilson & Cussans, 1975), and thus the distribution pattern of their seeds may change with cultivation methods. The 'long cycle' weeds (having great longevity and marked dormancy) appear to be well adapted to ploughing (Moss, 1988). The annual inversion of the soil surface due to cultivational practice buries the newly shed seeds of such species to deeper soil layers and prevent their germination at a time when the seedlings were unlikely to survive. However, the burial of freshly shed seeds by ploughing in the 'short cycle' weeds exploits their seed producing capacity as only few seedlings are expected to be established successfully if they germinate at deeper soil depths. Such species are again at a disadvantage if insufficient number of viable seeds are returned towards the surface, due to reploughing, to compensate for the number of seeds buried (Moss, 1988). In arable soil, earthworms (Darwin, 1859, McRill & Sagar, 1973), moles (Janzen, 1971) and rodents (Kjellson, 1985) also influence the vertical distribution of seeds in soil.

Germination of weed seeds and their emergence

The germination of weed seeds and their emergence largely depend on the microclimatic variabilities of soil-seed environment.

Soil moisture is an essential factor for the weed seed germination. King (1974) studied *Taraxacum* spp. where he found that the germination of 4 apomicts was highest in the range of 60-80% of the maximum water holding capacity of the soil. Soil moisture beyond this range, i.e. at the 90% of the water holding capacity was too high for the seeds and caused reduction germination to the extent of 20-60%, while moisture ranges between 30-40% of the water holding capacity were too low. Moisture stress suppresses the seedling emergence which has also been reported by Sharitz and MacCormick (1973), Mack (1976) and Cook (1980). Solbrig (1980) and Wellington & Nobel (1985) have reported that moisture stress is the major cause of seedling death.

Seeds of certain species have greatly differing temperature requirements according to variety and provenance and their germination physiology is often adapted to the particular environment (Bewley & Black, 1982). In others, the germination characteristics of seeds from geographically distant populations show remarkable similarity, indicating stability of germination response during spread of the species (Thompson, 1978; Pandey & Dubey, 1988). Alternate drying and wetting may be helpful in the removal of inhibitory substances from the seeds and may favour seed germination (King, 1952). Many researchers have reported that alternate temperature causes maximum germination (Davis, 1930; Tripathi, 1968b; Thompson et al. 1977). Kolk (1947) observed that the germination of weed species is more in the temperature range of 5° and 22°C than 10° and 22°C. Alternate temperature stimulated the germination of Sinapsis arvensis but had very little effect upon Centaurea cyanus, Stellaria media and Galium mollugo (King, 1974). The alternation of pH levels by time and fertilizer applications also affects the periodicity of germination of weed seeds (Ellenberg, 1950).

The relationship between seed germination and other environmental conditions such as availability of light and presence or absence of NO^{-3} N in soil seed environment are known for a variety of species, explaining their success in different successional stages. Early successional species are known to be light sensitive and require more light intensity for their germination (Bazzaz, 1968, 1970, 1979; Wesson & Wareing, 1969a, 1969b, Gary, 1987) in contrast to the late successional herbaceous species which may be insensitive to light or require very low light intensity (Saxena, 1981). The enhanced germination of a few early successional species in the presence of NO^{-3} N has been associated with a sharp increase in this ion in the early stages of vegetation development (Hayashi & Numata, 1971; Koller, 1972; Harper, 1977; Peterson & Bazzaz, 1978). Pattern of weed seedlings in relation to cultivation and rainfall has been well documented (Stoller & Wax, 1973; Vincent & Cavers, 1978). Roberts & Potter (1980) reported that both rainfall and cultivation favour the emergence of weed seedlings.

Seed structure may also be one of the factors facilitating germination of weed seeds. Large seeds may have difficulty in obtaining sufficient water from temporarily available water supplies because of their low ratio of surface to volume (King, 1952), while in smaller seeds this problem, generally, does not arise as this ratio increases with decrease in seed size. The various trends obtained by Ferner (1983) indicated that a plant with large seed size suffers a double disadvantage; firtly, its seed dispersibility is disproprotionately reduced by the relatively large seed coat and secondly, its low seedling-embryo weight ratio disproportionately reduced its establishment.

Soil compactness plays an important role in the germination of weed seeds. However, soil pressure has little influence on the normal retardation of germination (Hanf, 1944). He (Hanf, 1944) has also emphasized the role of soil air (soil aeration) in the germination of weed seeds. Even in the most quiscent state, buried weed seeds carries on respiration, which indicates that they are viable. The absence of viable seeds in certain kinds of soils as in peats and waterlogged soils (King, 1952), depicts the importance of soil aeration and other associated factors.

The exchange of gases at the soil surface as well as in the deeper soil layers plays a vital role in many important processes including the supply of O_2 to the buried seeds in the soil. Soil respiration is the resultant of the microbial decomposition of the litter, root exudates and dead roots as well as buried viable seeds in the soil. The soil CO_2 concentration is inversely related to O_2 concentration (Russell, 1961). Soil CO_2 is quite important as high CO_2 concentration in soil can have a direct effect on seed dormancy and future weed infestation (Lewis, 1949). Lewis (1949) outlined the respiratory mechanism of buried weed seeds and observed that buried seeds require O_2 at a rate that is proportional to temperature, but such seeds enter the anaerobic or activated state if the rate of O_2 availability is too low at a given temperature (Shull, 1914).

The hard coated seeds in nature germinate after being in the soil for long period of time (Becquerel, 1907). Germination occurs due to the leaching action of the soil water (Singh, 1969) and due to the growth of soil micro-organisms on and about the seed coat and perhaps due to the rupture of the seed coat through the abrasive action of soil (King, 1952) or through soil animal activity (King, 1974). The biochemical changes occurring within the seed coat during ageing undoubtedly increase its permeability to water and thus help in germination. The softening of hard seed coat and removal of allelopathic chemicals caused by the disturbances like fire has also been reported to promote germination in a variety of species (Ashton, 1970; Ballard, 1973; Christensen & Muller, 1975a, b; Rai & Tripathi, 1984b; Tripathi _et al_. 1981). Many methods have been proposed by the scientists in the laboratory to shorten the dormancy period in weed seeds (Tripathi, 1969; Singh, 1969) and stimulate them to germinate (Huang & Hsiao, 1987). As for example, seeds may be pretreated with GA (Hsiao, 1979a, Huang & Hsiao, 1987; Kasera & Sen, 1987a), washed continuously in running tap water for longer period (Singh, 1969; Kasera & Sen, 1987b), seed coat may be rolled with an abrasive substances such as sand (Tripathi, 1960; 1969) or they may be treated with concentrated sulphuric acid (Tripathi, 1960, 1968a, 1968b; 1969; Huang & Hsiao, 1987) or may be treated with sodium hypochlorite (Hsiao, 1979a, 1979b; 1980; Hsiao et al. 1981; Hsiao & Quick, 1984, 1985; Huang & Hsiao, 1987).

Dormancy in weed seeds

Harper (1957) recognised three types of dormancy: the seeds which are 'born dormant' (innate dormancy), those which 'acquire' dormancy (induced dormancy) and those seeds that have domancy 'thrust' upon them (enforced dormancy). According to Thurston (1960), induced and natural dormancy are equivalent to environmental and inherent dormancy, respectively, proposed by Brenchley & Warington (1930, 1933, 1936). Similarly, Crocker's (Crocker, 1938) use of primary and secondary dormancy are nothing but the sub-division of inherent dormancy of Thurston (1960).

A seed becomes innately dormant in certain species due to the embryo being immature at the time of seed dispersal (Howe & Chancellor, 1983), while in other cases it is due to the thick impermeable seed coat which prevents the passage of water or oxygen (Shull, 1914; Atwood, 1914; Willemsen, 1975) or it may be imposed chemically by the presence of inhibitory compounds either in the seed coat or in the embryo

(Naylor & Christie, 1956). A seed attains enforced dormancy due to environmental constraints such as inappropriate soil moisture regime (Arai& Kataoka, 1956), low soil temperature (Wesson & Wareing, 1967; Mukherjee _et_ _al_. 1980), lack of light (Wesson & Wareing, 1967, 1969a; Black, 1969) or soil atmosphere (Bibbey, 1948; Harper, 1957), while induced dormancy develops due to acquired condition of inability to germination caused by some experience after ripening. The most crucial factor in the induction of dormancy, however, is the restricted gas exchange during the time that the seeds are buried in soil (Hay, 1962). During the induction of dormancy, perhaps electrons instead of going to O_2 are passed to another acceptor, which in its reduced form block the electron transport system at some specific locus during glyoxylate metabolism, thereby preventing germination (Hay, 1962).

Seeds of a number of species in the soil seed bank pass through an annual cycle of dormant and non-dormant periods. The study of Courtney (1968) on _Polygonum aviculare_, Roberts & Neilson (1982a, 1982b) and Baskin & Baskin (1977, 1978) on _Ambrosia artemisiifolia_ indicated that the seeds go through a remarkable regular cycle with a peak of germinability at a particular time followed by dormancy afterwards. Seasonal change in dormancy during burial of seeds in soil has also been reported in both summer and autumn annuals (Karssen, 1982; Baskin & Baskin, 1985; Karssen et al. 1988). Seeds of summer annuals are dormant in autumn, lose their dormancy in winter and re-enter the dormant state in summer. Winter annual seeds pass through these stages in spring, summer and winter respectively. In general, dormancy is released during the season preceding the periods with adverse conditions for plant survival (Vegis, 1964; Baskin & Baskin, 1985).

Life span of seeds in soil

Several records pertaining to the life span of seeds in soil are vailable in literature (Crocker, 1909, 1945, 1948; Madsen, 1962; Kivilaan & Bandurski, 1981). Such records are obtained from the experiments that are supposed to have been laid in the soil for decades, conducted by one investigator, while the results are reported by another. Such determinations are based on recently excavated soils (Youngman, 1952) or recently ploughed meadows or pastures (Brenchley, 1918; Chippendale & Milton, 1934) of long standing. Few evidences on the survival of seeds are also available directly from the experiments in which the seeds were buried and their viability was determined after varying periods (Egley & Chandler, 1983; Conn & Farris, 1987; Conn, 1990).

The landmark studies of Brenchley & Warington (1930,

1933) reveal that the buried seeds can survive in soil for longer period of time. This has stimulated the interest of many researchers on this aspect (sensu Major & Pyott, 1966; Kropac, 1966; Roberts, 1970, 1981, Grime, 1979; Cavers, 1983). The probable longevity records for seeds buried in soil reported by a number of workers reveal a wide range of life span in soil. As for example, the seeds can remain in viable conditions for more than 50 years (Peters, 1984; Crocker, 1938) or 80 years (Darlington & Steinbauer, 1961) or even 300-400 years (Ogha, 1926). Libby (1951), by using the residual carbon (C^{14}) isotope in few fruits, determined their age at 1040 years (±210 years) and reported that those seeds remained dormant, but were capable of germination.

Hard coatedness in seeds contributes to the long life span (Ewart, 1908, Becquerel, 1907). However, the buried seed experiment of Beal (1894) reported that many seeds remain viable for onger period in moist soil than in ordinary dry storage in the air. Size of the seed is probably of no significance in determining the longevity of seeds in soil. Seeds of weeds, generally, retain their vitality for longer period in soil than the seeds of cultivated plants (Duvel, 1902).

According to Crocker & Barton (1953) "Dormancy in weed seeds are of ecological and agricultural significance" as this mechanism rgulates their distribution in time and space by: (i) preventing preharvest deterioration in damp season, (ii) rendering competition with the crop plants less severe, (iii) delaying their germination under unfavourable conditions, and (iv) emerging during fallow period and thus checking soil erosion.

Seed deterioration in soil

Various classic attempts have been made to determine the rate of loss of seeds from the soil seed bank due to factors other than predation such as, decay & decomposition and germination (Darlington, 1931, 1951; Darlington & Stein-baguer, 1961; Duvel, 1902; Goss, 1924; Toole & Brown, 1946; Schafter & Chilcote, 1969). Similarly, the seed destruction by soil pathogens has been demonstrated by Christensen & Lopez, 1963). Measures of overall rates of seed loss from seed bank have been made only on some agricultural soils (Roberts, 1970). A long linear decay of seed bank occurs with the passage of time if the new seed entries are prevented in disturbed and undisturbed soils. This implies that the seed population within a soil seed bank undergoes a continuous and constant death risk (Roberts, 1970). A conspicuous decline in soil seed bank after cropping period has been attributed to intense weeding (McCormick & Buell, 1957; Bazzaz, 1968) and also to seed loss through water and sediment losses from the steep slopes during cultivation (Toky & Ramakrishnan, 1981).

From the above review of literature, it is evident that although soil seed bank studies have engaged the attention of a large number of researchers in other countries, there has been no serious attempt to monitor the buried seed population in the agroecosystems of the Indian sub-continent. The review of Indian literature on the weed population biology reveals that some aspects like plant population dynamics (Yadav & Tripathi, 1981; Rai & Tripathi, 1984a; Tripathi, 1985), reproductive strategies (Trivedi & Tripathi, 1982a, 1982b), allelopathic potential (Tripathi et al. 1981; Rai & Tripathi, 1982; 1984b) and competitive ability (Pradhan & Tripathi, 1983, 1984) of important weeds of crop fields and ruderal habitats, have been studied in considerable detail. However, the studies relating to spatial distribution and dynamics of buried seed population in agroecosystems have not attracted sufficient attention of agricultural scientists and ecologists of the country, although a few studies have been carried out by Saxena (1981) on total soil seed bank of herbaceous species in different ages of jhum fallows and by Yadav & Tripathi (1982) on the soil seed bank and fate of buried seed population of ruderal weeds like Eupatorium adenophorum, E. odoratum and E. riparium. The present study on the dynamics of soil seed bank in the crop fields under two contrasting types of cultivation practices prevalent in Meghalaya viz., 'jhum' and terrace cultivation, seeks to contribute to our understanding of this important aspect of weed biology, which has been hitherto grossly neglected in our country.

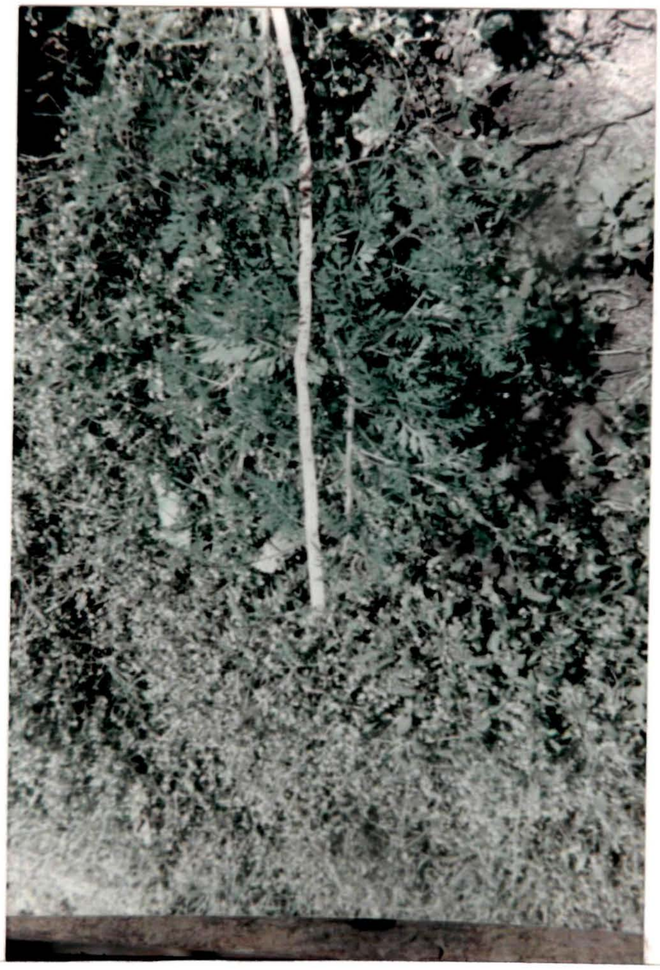
CHAPTER III

The study sites, soil, climate, vegetation, and salient features of seeds of a few selected weeds.

STUDY SITES

A few crop fields representing 'Jhum' and terrace cultivation have been selected for the present study. The crop fields under 'Jhum' are located at Upper Shillong (longitude 91°56' E, latitude 25°34' N, altitude 1825 m asl) which is 12 km south of Shillong. In case of terrace cultivation, a few crop fields are located on the farm of Central Potato Research Station (CPRS) at Upper Shillong, while some of them are located on the ICAR farm at Barapani (longitude 91°54'-63' E, latitude 25°39'-41' N, altitude 952 m asl), which is situated 22 km north of Shillong, the capital of Meghalaya. Based on the mode of sowing and intensity of cultural operations, the terrace field located on the farm of ICAR, Barapani was again divided into two categories viz., 'terrace-normal' and 'terrace-dibbling'. The crop fields under continuous cropping without fallow period and subjected to more intensive cultural operations were considered as 'terrace-normal'. In the crop fields considered as 'terrace-dibbling', the disturbance in form of agricultural operations was minimal and the crop sowing was done through dibbling and only one crop was grown during a year. Both categories of crop fields at Barapani are adjacent to each other. In Upper Shillong, however, the 'Jhum' fields and terrace fields

A close view of the luxuriant growth of weeds in 'jhum' field during the four year long fallow period.



Ambrosia artemisiifolia (lower part of the plate) and *Galinsoga ciliata* (upper part of the plate) growing in the cabbage field (crop already harvested) under 'jhum' cultivation at Upper Shillong.

are 4 km apart. The geographical location of the study sites is given in Fig. 3.1 and the various crops grown in these fields during the study period are enumerated in Table 3.1. The study was conducted from October 1988 to September 1990 at Upper Shillong and from March 1989 to February 1991 at Barapani.

The 'Jhum' fields belong to a local farmer and were left abandoned since last four years before they were again brought under cultivation in 1988. The terrace fields at Upper Shillong form a part of CPRS farm which was established in 1969. These fields have been under continuous cultivation since 1981. The terrace field at Barapani form a part of ICAR farm and are under continuous cultivation since 1983.

The 'Jhum' fields at Upper Shillong are more slopy (39.4% slope) compared to the terrace fields (34% slope), whereas the 'terrace-normal' and 'terrace-dibbling' fields at Barapani have equal degree of slope (32.4% slope).

CLIMATE

The south-west monsoon and north-east winter wind influence the climate of the study sites. The monthly rainfall and temperature data of the study sites at Upper Shillong and Barapani are given in Fig. 3.2 and Fig. 3.3 respectively. The months from May to October experience heavy rainfall,

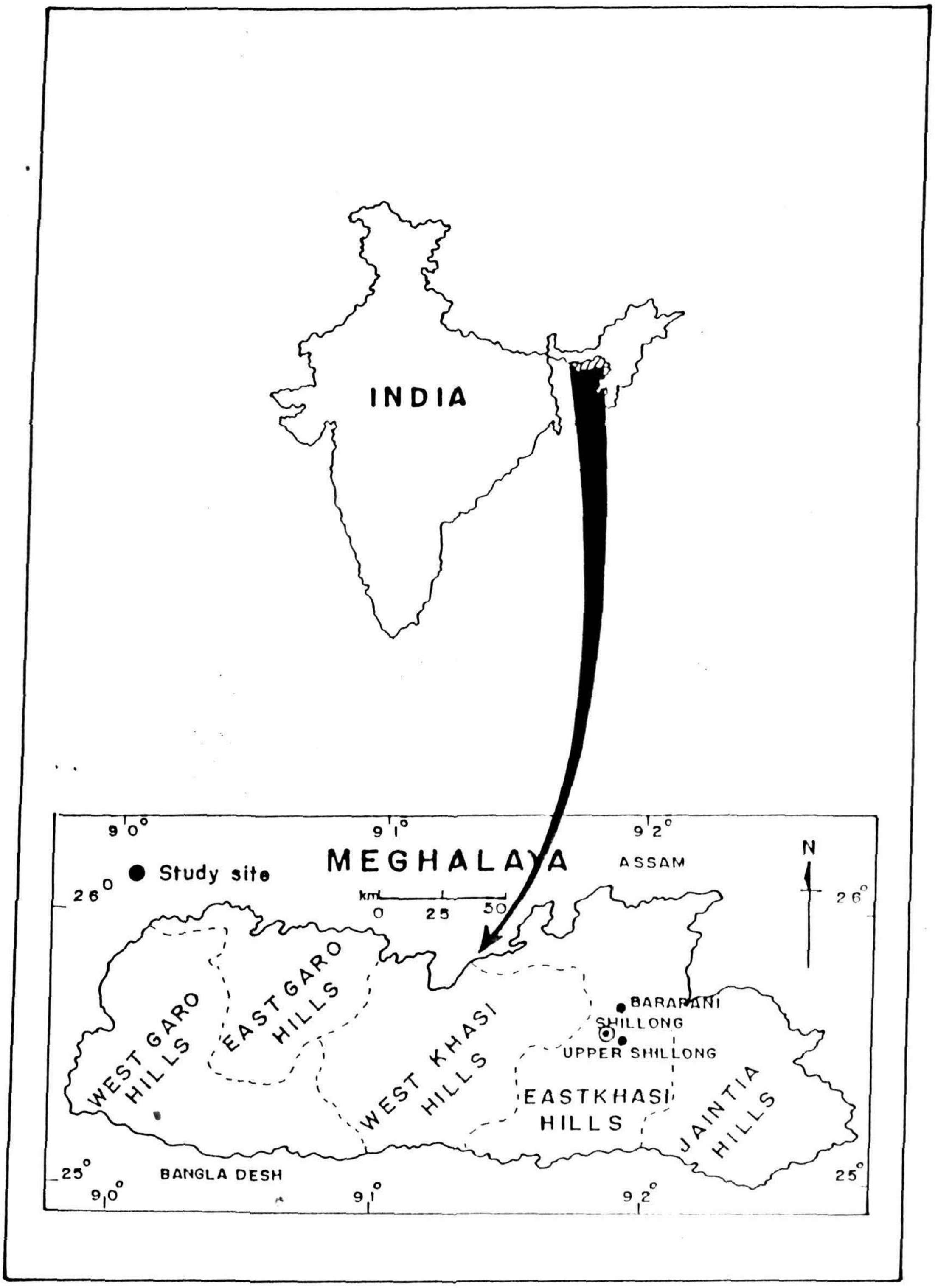


Fig. 3.1. Map showing geographical location of the study sites.

Table 3.1 - Crops considered for the purpose of present study.

Site	Crop
Upper Shillong (Jhum)	Potato, cabbage, radish and cabbage-radish mixed crop
Upper Shillong (Terrace)	Potato, cabbage, radish and cabbage-radish mixed crop
Barapani (Terrace-normal)	Linseed, maize, mustard and paddy
Barapani (Terrace-dibbling)	Linseed, maize, mustard and paddy

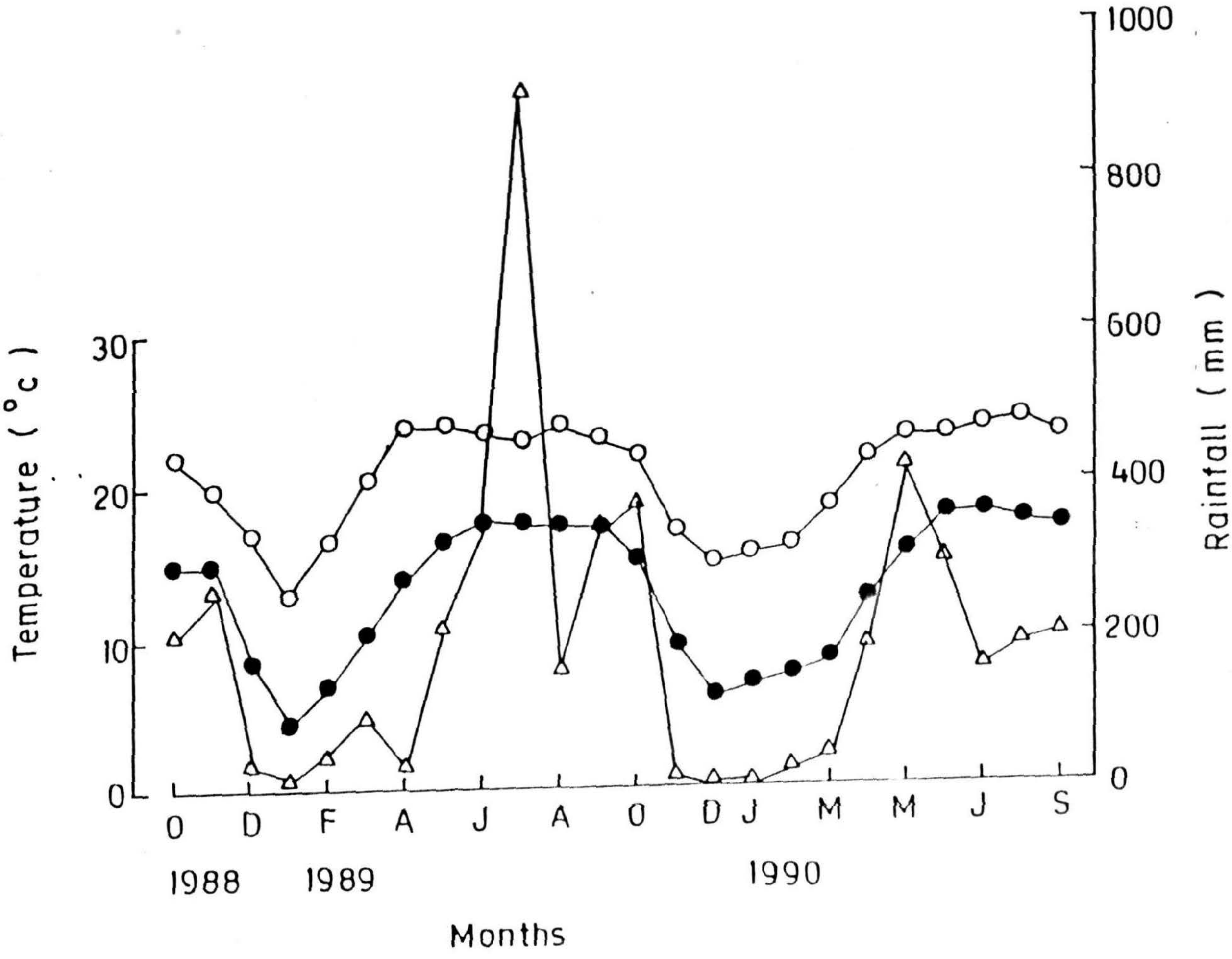


Fig. 3.2. Mean maximum (O-O) and minimum (●-●) temperature (°C) and rainfall (mm) (△-△) for Upper Shillong during October 1988 to September 1990.

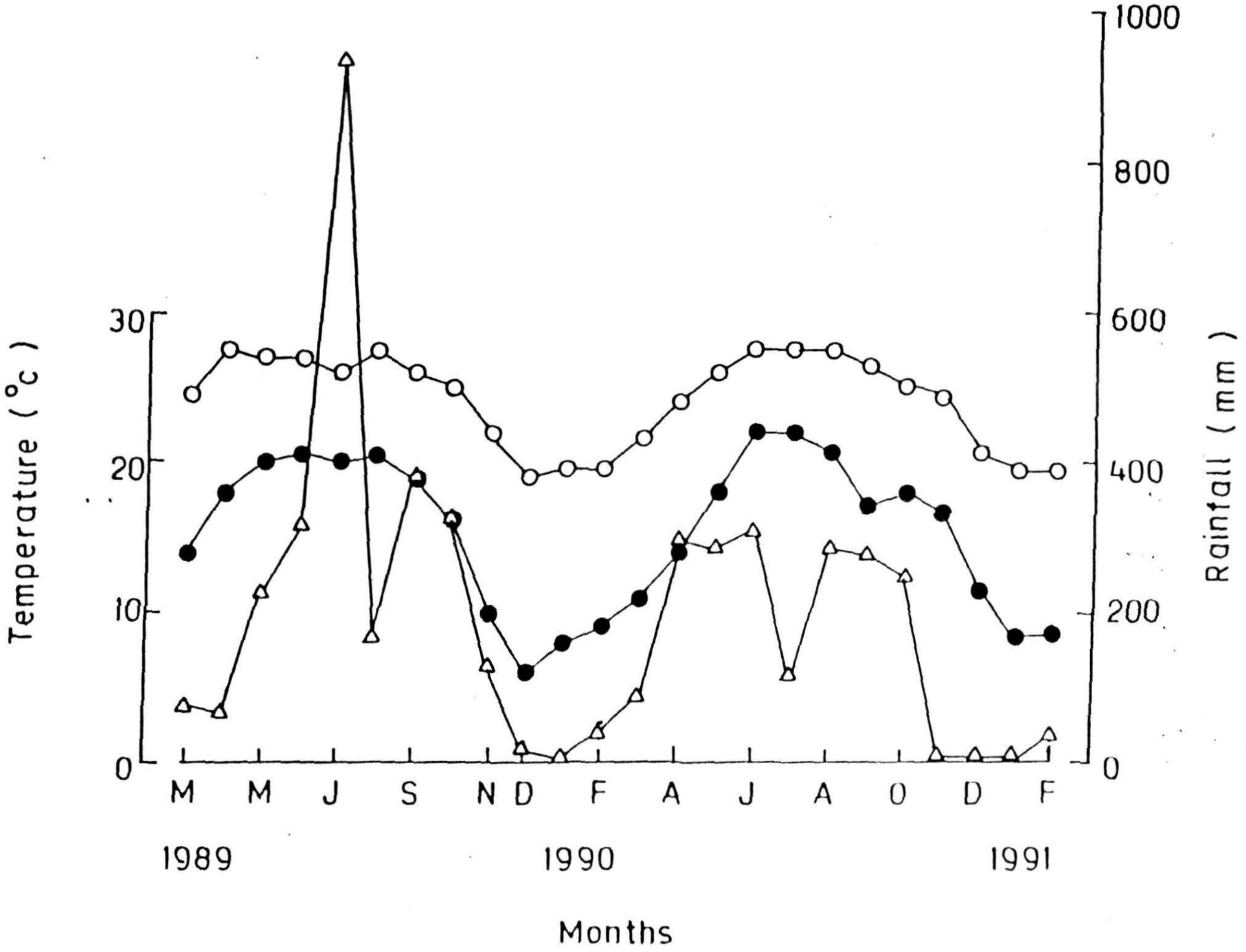


Fig. 3.3. Mean maximum (O-O) and minimum (●-●) temperature (°C) and rainfall (mm) (△-△) for Barapani during March 1989 to February 1991.

although occasional showers are received during November to March as well. June and July are the wettest months of the year. Based on the temperature and rainfall data, the year can be divided into four seasons:

i) Spring or mild summer (March to April).
ii) Rainy or wet summer (May to September).
iii) Autumn (October).
iv) Winter (November to February).

The 'spring' season is characterised by a gradual increase in temperature over that in the preceding winter months. With further increase in temperature, the 'spring' gives way to 'summer' which is characterised by gusty wind (upto May) and abundant rainfall. With the retreat of monsoon, the season changes and the fall of temperature heralds the advent of autumn. 'Autumn' is cool and pleasant and represents a transition period between 'rainy' and 'winter' seasons. 'Autumn' is followed by winter season lasting from November to February, and is characterised by low temperature, negligible rains, occasional forst in the nights and short photoperiod.

SOIL

The Shillong plateau embracing Upper Shillong and Barapani is made up largely of Pre-Cambrian rocks, moderately undulated, acutely folded and steeply dipping with an overturned fringe of Mesozoic and Tertiary sediments (Pascoe, 1950-64). The soil of the study sites is lateritic, silty loam to clay loam, pale brown to deep brown in colour and acidic (pH 5.1-5.7) in reaction (Tables 3.2 and 3.5). The depthwise variation in proportion (%) of soil particles, organic matter content (OMC), water holding capacity (WHC) and pH in 'Jhum' and terrace fields at Upper Shillong and Barapani are given in Tables 3.2-3.6.

The particle fractionation and textural class for four soil layers of different crop fields under both 'Jhum' and terrace cultivation at Upper Shillong (Table 3.2) revealed that the proportion of clay is more in the crop fields where mixed cropping was done while in all other crop fields, the proportion of silt is more. The depthwise distribution of soil particles indicated that the deeper layers are more clayey compared to those of surface soil layers. In general, the coarse particles (2-0.002 mm) declined with increase in soil depth, whilst the fine particles showed a reverse trend. The proportion of coarse particle was higher in the 'Jhum' fields, while that of fine particles was geater in terrace fields compared to the 'Jhum' fields (Table 3.4).

The particle fractionation and textural class for different crop fields in ICAR farm at Barapani (Table 3.5)

Table 3.2 - Particle fractionation and textural class of soils of different crop fields under both 'Jhum' and terrace cultivation at Upper Shillong.

Crop field	Depth (cm)	'Jhum'				Terrace			
		Sand(%)	Silt(%)	Clay(%)	Textural Class	Sand(%)	Silt(%)	Clay(%)	Textural Class
Potato	0-5	25.9	44.0	30.1	SL	25.9	53.0	21.1	SL
	5-10	25.9	40.0	34.1	SL	19.9	46.0	34.1	SL
	10-15	23.9	44.0	32.1	SL	0.9	46.0	53.1	CL
	15-20	13.9	40.0	46.1	CL	3.9	38.0	58.1	CL
Radish	0-5	15.9	54.0	30.1	SL	19.9	49.0	31.1	SL
	5-10	15.9	50.0	34.1	SL	11.9	52.0	36.1	SL
	10-15	16.9	42.0	41.1	SL	9.9	46.0	44.1	SL
	15-20	1.9	48.0	50.1	CL	6.9	41.0	52.1	CL
Cabbage	0-5	23.9	40.0	36.1	SL	12.9	51.0	36.1	SL
	5-10	24.9	35.0	40.1	CL	3.9	56.0	40.1	SL
	10-15	11.9	43.0	45.1	CL	3.9	42.0	54.1	CL
	15-20	13.9	37.0	49.1	CL	1.9	43.0	55.1	CL
Mixed (Cabbage + radish)	0-5	15.9	36.0	48.1	CL	18.9	42.0	44.1	CL
	5-10	15.9	36.0	48.1	CL	7.9	46.0	46.1	CL
	10-15	7.9	40.0	52.1	CL	3.9	44.0	52.1	CL
	15-20	1.9	40.0	58.1	CL	0.9	41.0	58.1	CL

SL - Silty loam; CL - Clay loam.

Table 3.3 - Water holding capacity (%) of soil at four different depths in the crop fields under 'Jhum' and terrace cultivation at Upper Shillong.

Crop field	'Jhum'				Terrace			
	Soil depth (cm)				Soil depth (cm)			
	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20
Potato	40.0±0.9	39.3±0.5	48.3±1.7	54.7±2.0	39.7±1.0	44.7±0.5	62.0±1.9	55.3±1.1
Radish	37.3±0.5	4.8±0.0	50.0±0.9	54.7±0.5	41.7±0.5	49.3±0.5	49.3±1.1	61.7±0.5
Cabbage	45.7±0.3	48.7±0.5	50.0±0.9	58.0±0.9	41.0±0.5	48.3±1.4	56.7±0.5	61.0±0.5
Mixed (Cabbage + radish)	38.7±0.5	41.0±2.2	59.3±0.5	65.7±0.3	65.7±0.3	68.0±0.9	67.0±1.3	74.0±2.9

± S.e.m., n=3.

Table 3.4 - Organic matter content (%) of soil at four depths in the crop fields under 'Jhum' and terrace cultivation at Upper Shillong.

Crop field	'Jhum'				Terrace			
	Soil depth (cm)				Soil depth (cm)			
	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20
Potato	3.7±0.1	3.7±0.1	2.9±0.1	2.5±0.1	3.0±0.0	2.6±0.1	2.4±0.1	1.6±0.1
Radish	3.9±0.1	3.7±0.1	3.7±0.1	3.0±0.0	3.3±0.0	3.0±0.0	2.5±0.1	2.1±0.0
Cabbage	3.0±0.0	2.9±0.1	2.6±0.1	2.4±0.1	2.9±0.1	2.6±0.1	2.4±0.0	1.6 ±0.2
Mixed (Cabbage + radish)	3.0±0.0	2.9±0.1	2.6±0.1	2.6±0.1	3.0±0.0	2.6±0.2	2.4±0.2	1.8 ±0.1

± S.e.m., n=3.

Table 3.5 - Important characteristics of soils of different crop fields at ICAR farm, Barapani.

	Crop fields			
Soil parameters	Linseed	Maize	Mustard	Paddy
Coarse particles:				
Sand (%)	29.1±0.9	22.4±0.7	28.1±0.4	24.8±0.4
Silt (%)	32.2±0.9	26.1±0.7	38.0±0.4	32.1±0.4
Total (Sand+Silt)	61.3±0.9	49.5±0.7	66.1±0.4	56.9±0.4
Fine particles	38.7±0.9	50.5±0.7	33.9±0.4	43.1±0.4
Textural class	Clay loam	Clay loam	Silt loam	Clay loam
OMC (%)	2.6±0.2	2.81±0.2	2.2±0.1	2.3±0.2
WHC (%)	62.0±2.1	62.5±1.5	58.5±1.6	55.7±0.8
pH	5.4±0.0	5.5±0.1	5.5±0.1	5.5±0.1

± S.e.m., n=4. OMC - organic matter content, WHC - water holding capacity. The values are pooled means of four different soil depths.

Table 3.6 - Depthwise variation in proportion (%) of soil particles, organic matter content (OMC), water holding capacity (WHC) and pH of soil in the crop fields of ICAR farm at Barapani.

	Depth (cm)			
Soil parameters	0-5	5-10	10-15	15-20
Coarse particles:				
Sand (%)	20.0±0.3	22.1±0.7	22.1±0.7	18.8±1.1
Silt (%)	40.0±0.9	36.8±0.7	35.7±0.4	38.2±1.0
Total (Sand+Silt)	60.0±2.9	58.9±3.0	57.8±3.3	56.9±3.0
Fine particles	40.0±2.4	41.1±2.9	42.2±0.7	43.1±0.4
Textural class	Silt loam	Clay loam	Clay loam	Clay loam
OMC (%)	3.0±0.1	2.6±0.2	2.3±0.1	2.1±0.1
WHC (%)	55.6±0.8	58.5±1.3	59.8±1.4	63.8±1.9
pH	5.5±0.0	5.5±0.1	5.5±0.1	5.4±0.1

± S.e.m., n=4. The values are pooled means of four different crop fields.

revealed that the proportion of silt is more in the mustard field while in other crop fields, the proportion of clay is more. The depth distribution of soil particles indicated that the proportion of clay is more in all the soil layers except in the surface layer (Table 3.6). Like different crop fields under 'Jhum' and terrace cultivation at Upper Shillong, the coarse particles in the crop fields of ICAR at Barapani also showed a decline with increase in soil depth but unlike the crop fields at Upper Shillong, they showed a higher proportion of sand particles than silt particles (Table 3.5).

The organic matter content was always higher in the 'Jhum' fields than in terrace fields and declined with increasing soil depth (Table 3.4). Conversely, water holding capacity was higher in the terrace than in the 'Jhum' fields and was inversely related with depth. Among the different crop fields at ICAR farm, maize field had a slightly higher organic matter content than other fields and in each case, organic matter content declined with increase in soil depth (Table 3.5). pH ranged between 5.1 and 5.7 without showing any definite trend through depth and season.

VEGETATION

The natural vegetation of the study area is characterised by the preponderance of evergreen tree species. The natural vegetation at Upper Shillong represents sub-tropical evergreen forest, which gives an indication that probably, the entire area was once covered with this type of vegetation and it has now been considerably degraded due to prevailing slash and burn agriculture or 'Jhum' and other human activities. The common species in the relic patches include *Myrica esculenta*, *Quercus griffithii*, *Betula alnoides*, *Rhododendron arboreum*, *Castonopsis* spp. and *Dendrobium* spp. The agricultural food crops in Upper Shillong area include potato, cabbage, radish and maize, of which potato is the major rainfed crop of the region.

The natural vegetation at Barapani also represents a sub-tropical evergreen forest which is composed of *Alnus nepalensis*, *Schima* spp., *Quercus* spp., *Cedrus deodara*, *Cryptomaria juncea*, *Rhododendron arboreum*, *Exbucklandia* sp. and *Albezzia lebbek*. The agricultural food crops in Barapani area include paddy, maize, linseed, groundnut, green pea, mustard, lentil, soyabean, guava, cucumber, pine apple, lemon, pumpkin, bitter gourd etc.

The agroecosystems comprise a variety of native and exotic weed species, of which, the most common are *Galinsoga* spp., *Oxalis* spp., *Drymaria cordata* and *Spilanthes paniculata*.

Weed seeds sometimes resemble so much with the crop

B. pilosa growing in a crop field under terrace cultivation at ICAR Farm, Barapani.

A close view of the terrace field at ICAR Farm, Barapani.

Spergula arvensis **infesting the potato field at CPRS Farm, Upper Shillong.**

Galinsoga parviflora **growing in the linseed field at ICAR Farm, Barapani.**

Emergence of fresh cohorts of weed seedlings in maize field after weeding.

seeds in shape, size and colour that the contamination of the latter with weed seeds cannot be avoided. Such contaminated crop seeds are one of the major sources of weed infestation. Therefore, it is very important to distinguish the weed seeds from the crop seeds. Some of the characteristic features of seeds of a few important weed species infesting the crop fields under study are described below:

Ageratum spp. (Family-Asteraceae)

Seeds small to medium size (average length 2.7 mm, breadth 0.6 mm, thickness 0.4 mm), several sided, elongated with a thick bunch of white hairs on the top, black coloured.

Ambrosia artemisiifolia (Family-Asteraceae)

Seeds vary from 2-10 mm in length, 1-2 mm in breadth, 0.5-0.7 mm in thickness, obvoid to oblanceolate, generally provided with spines near the top, hard seed coat, grey coloured.

Arundinella benghalensis (Family - Poaceae)

Average seed length 1mm, breadth 0.7 mm, thickness 0.7 mm, obvoid to oblanceolate, pointed at the top, pink coloured.

Bidens pilosa (Family - Asteraceae)

Seeds vary from 0.5-2 cm in length. Seeds are linear and several-sided to flat-oblong or flat-lanceolate, having

2-4 awns which are generally barbed and extend from the top. Colour is brown to black.

Borreria hispida (Family - Rubiaceae)

Average seed length 0.5 mm, breadth 0.6 mm, thickness 0.4 mm, oval to obvoid, smooth surface, dark-brown coloured.

Digitaria adscendens (Family - Poaceae)

Average seed length 3.2 mm, breadth 1.5 mm, thickness 0.2 mm, elongated and flattish, lemma and palea hard and enclose grain tightly, brown coloured.

Eleusine indica (Family - Poaceae)

Average seed length 2 mm, breadth 1.5 mm, thickness 0.5 mm, oval to obvoid, seeds freed easily from outer covering, black coloured.

Eragrostis unioloides (Family - Poaceae)

Average seed length 0.8 mm, breadth 0.6 mm, thickness 0.4 mm, concave or flattish on one side (plano-convex), contain a short, erect stalk (rachilla) at the base of the grain enclosing floret ordinarily on its concave side, seeds free from outer covering, brown to black coloured.

Fimbristylis complanata (Family - Cyperaceae)

Average seed length 0.6 mm, breadth 0.4 mm, thickness 0.4 mm, S-angled, ovate to lens-shaped, smooth surfaced, bristles absent, black coloured.

Galinsoga spp. (Family - Asteraceae)

Average seed length 3.2 mm, breadth 0.7 mm, thickness 0.3 mm, elongated and inverted cone shape tapering towards base. From the top of seeds a bunch of whitish hairs emerge, black coloured.

Polygonum alatum

Seeds vary from small to large size; average seed length 1.5 mm, breadth 1.7 mm, thickness 0.4 mm, mostly triangular, but some are flattish and lens-shaped, surface smooth and shiny, semi-transparent, outer wall (pericarp) is firm, inner wall (testa) is free from pericarp and adhered to true seed, black to dark brown or light brown in colour.

Richardsonia piolosa (Family - Rubiaceae)

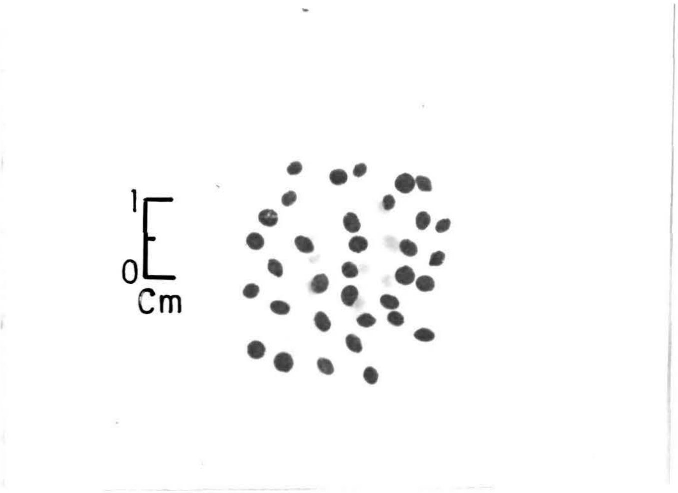
Average seed length 2.6 mm, breadth 1.7 mm, thickness 0.8 mm, seeds ovate of obvoid, two-tipped, two sided, tapering towards apex, rough and hairy, brown coloured.

Setaria spp. (Family - Poaceae)

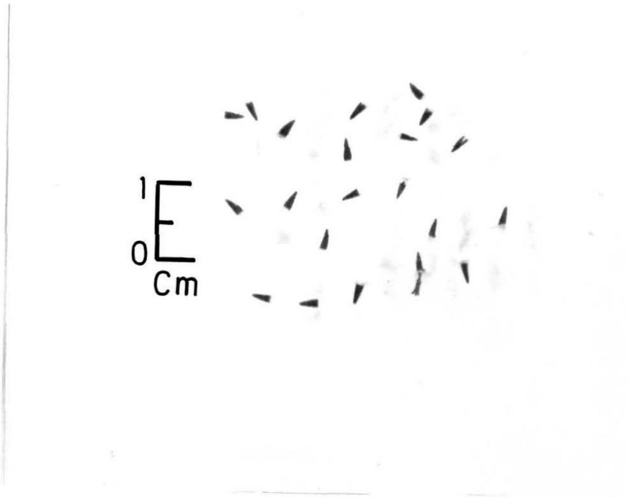
Average seed length 3 mm, breadth 2 mm, thickness 1.5 mm, flattish on one side (Plano-convex), a dark rounding dot present near the flattish face, embryo covers the seeds from the bottom to top, grey coloured.

Spergula arvensis (Family - Caryophyllaceae)

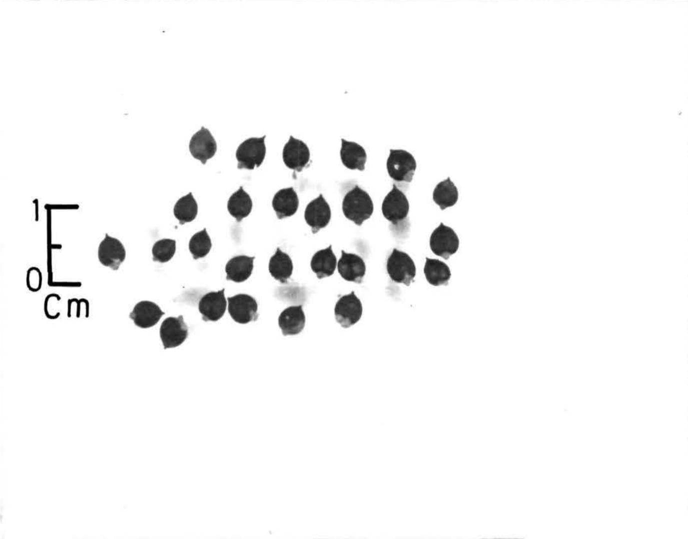
Seeds small to medium size, average length 1.0 mm, breadth 0.9 mm, thickness 0.7 mm, globose-lenticular with a narrow, light coloured encircling rim or flange, provided with whitish papillae scattered over most of the surface, dull black coloured.



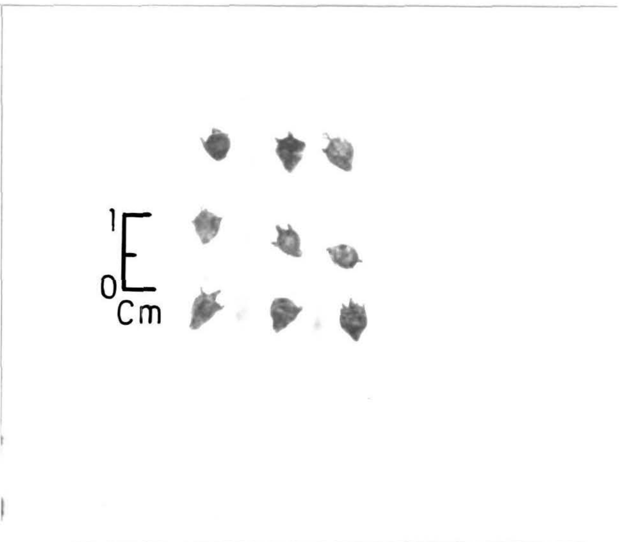
Spergula arvensis



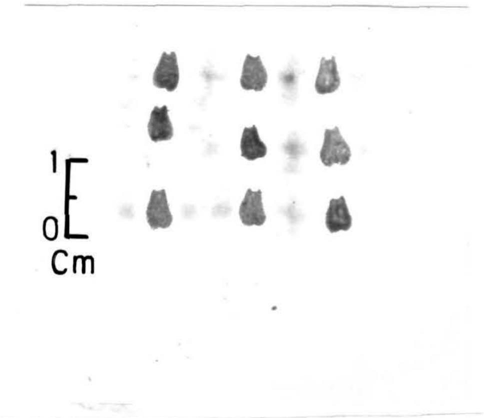
Galinsoga spp.



Polygonum alatum



Ambrosia artemisiifolia



Richardsonia piolosa

Bidens pilosa

Seeds of six dominant weed species.

CHAPTER IV

Weed flora and weed seed bank in soil of different crop fields under 'Jhum' and terrace cultivation at Upper Shillong.

INTRODUCTION

The freshly shed seeds from the parent plants entering the soil may be either readily germinable or in dormant state. Many a time even readily germinable fraction of seed population may acquire enforced or induced dormancy on burial (Harper, 1957; Yadav & Tripathi, 1982). These seeds constitute the soil seed bank. The composition, density and vertical distribution of seed populations in soil strongly influence the future weed infestation in the crop fields (Kropac, 1966; Artyushin & Libershtein, 1976; Carretero, 1977). Several studies have been made to analyse the effect of cultivation method, crop rotation and herbicide application on the composition of weed flora and relative prevalence of viable weed seeds in soils of different agroecosystems (Roberts, 1958; 1962; Moore & Wein, 1977; Roberts & Ricketts, 1979; Menges, 1987; Chaem, 1988; Moss, 1988; Ball & Miller, 1989; Churel et al. 1989; Van Esso & Ghersa, 1989; Cousens & Moss, 1990; Dessaint et al. 1990a; 1990b). However, the information related to these aspects from tropical agroecosystems, particularly those in Indian subcontinent is extremely meagre.

The hill agriculture in Meghalaya mostly represents traditional slash and burn agriculture (locally called 'Jhum').

However, recently terrace cultivation has also started in localised farming areas. Thus the agroecosystems of Meghalaya provide an opportunity to study the seed bank of arable land under two contrasting cultivational practices in the same climatic regime.

This chapter presents a comparative analysis of weed seed bank in soil in the crop fields under 'jhum' and terrace cultivation at upper elevation of Meghalaya. Species composition, density and vertical distribution of seeds in soil during summer and autumn cropping seasons in four crop fields occupied by potato, cabbage, radish and cabbage + radish (mixed) and during the intervening fallow period after the crop harvest (Table 4.1) were studied over a period of two years (October 1988 to September 1990). The results are discussed in relation to season, crop type, intervening fallow and crop rotation.

MATERIALS AND METHODS

Twenty soil cores (5.727 cm diameter) down to 20 cm depth were collected randomly from each field at monthly intervals during October 1988 to September 1990. These were brought to the laboratory and divided into four equal sections corresponding to 0-5, 5-10, 10-15 and 15-20 cm soil depths. Each sample was air-dried and passed through a 2 mm metallic sieve to remove the stones, large roots and litter particles.

Table 4.1 - Crop rotation and duration of cropping and fallow periods in 'Jhum' and terrace fields during 1988-90.

Crop field	Crop rotation	'Jhum'		Terrace	
		Cropping period	Fallow period (days)	Cropping period	Fallow period (days)
Potato	(P-P-C-P-C)				
	P	11.9.88 - 30.12.88		16.9.88 - 7.1.89	
	P	5.4.89 - 1.8.89	96	No cropping	
	C	22.8.89 - 12.1.90	21	No croping	266
	P	1.4.90 - 23.7.90	80	8.4.91 - 30.7.90	458
	C	18.8.90 - 12.12.90	25	25.8.90 - 22.12.90	24
Radish	(R-P-C-P-R)				
	R	13.9.88 - 30.12.89		13.9.88 - 28.12.88	
	P	5.4.89 - 1.8.89	96	5.4.89 - 1.8.89	98
	C	22.8.89 - 12.1.90	21	22.8.89 - 2.1.90	21
	P	1.4.90 - 23.7.90	80	8.4.90 - 30.7.90	97
	R	3.9.90 - 18.12.90	40	13.9.90 - 25.12.90	43
Cabbage	(C-P-C-P-C)				
	C	5.9.88 - 30.12.89		12.9.88 - 25.12.88	
	P	5.4.89 - 1.8.89	96	7.4.89 - 1.8.89	103
	C	22.8.89 - 12.1.90	21	27.8.89 - 2.1.90	26
	P	5.4.90 - 25.7.90	84	8.4.90 - 30.7.90	97
	C	18.8.90 - 12.12.90	22	25.8.90 - 22.12.90	24
Mixed	(C+R-P-C-P-C+R)				
(Cabbage +Radish)	C+R	6.9.88 - 30.12.89		13.9.88 - 28.12.88	
	P	5.4.89 - 1.8.89	96	7.4.89 - 1.8.89	100
	C	22.8.89 - 12.1.90	21	27.4.89 - 2.1.90	26
	P	5.4.90 - 25.7.90	84	8.4.90 - 30.7.90	97
	C+R	18.8.90 - 12.12.90	23	25.8.90 - 22.12.90	25

P - Potato, C - Cabbage, R- Radish.

All the samples from each depth were mixed to yield a composite sample from which three 100 g samples were drawn to determine the number of weed seeds present in them. Each sample was washed gently with a jet of water in a tier of 1.5, 0.7, 0.5 mm mesh sieves arranged in descending order. The uppermost sieve retained the larger (<1.5 mm) seeds, which were transferred to a flat tray. The lighter seeds were recovered by floatation method by using water and the heavier ones by using concentrated calcium chloride solution (Roberts & Ricketts, 1979). The seeds which settled down in water but floated in calcium chloride solution were assumed to be viable if they remained firm under gentle pressure (Zelenchuk, 1961) and the seeds which floated in water but sunk in calcium chloride were considered viable when they gave positive response to tetrazolium test (Malone, 1967). The recovered seeds were counted and identified upto species level. In those cases where species level identification was not possible due to similarity in seed morphology, they were identified upto genus level. The unidentified seeds were kept in separate lot and were considered as such. The seeds were categorized into different sizes species wise as well as depthwise and their weight was recorded. The annual reduction in the size of the viable weed population was estimated by taking a control plot adjacent to each crop field where the seed input was prevented by weeding the plot at frequent intervals but all other cultivational practices were as usual. The reduction in soil seed population over 2-yr period was computed by subtracting the value obtained at the end of the study from the soil seed bank at the beginning of the study.

ANOVA was used to test the significance of variation in seed population and seed weight due to soil depth, type of cultivation, intervening fallow period and crop fields.

RESULTS

Species composition of the weed flora and weed seed bank in soil

The weed flora of the crop fields under study was composed of a total of fourteen species. Twelve species were common to potato and cabbage fields, while seven species were observed in radish and cabbage + radish mixed fields under both 'Jhum' and terrace cultivation (Table 4.2). The seeds of these weeds were also represented in soil seed bank.

Seeding period of weeds

The time of seed formation for different weed species varied only slightly in different crop fields (Table 4.2). Most of the weeds shed their seeds during cold season (Nov-Feb). *Spergula arvensis* produced seeds thrice in a year. *Galinsoga ciliata*, *Setaria glauca*, *Setaria pallied-fusca*

Table 4.2 - List of weeds composing the weed flora and represented in the soil seed bank together with the time of their seeding in different crop fields under 'jhum' and terrace cultivation.

Species	'Jhum'				Terrace			
	Potato	Radish	Cabbage	Mixed	Potato	Radish	Cabbage	Mixed
Ambrosia artemisiifolia Linn.	WPWS (Nov)	WPWS (Nov)	WPWS (Nov)	WPWS (Nov)	WPWS (Nov)	WPWS (Nov)	WPWS (Nov)	WPWS (Nov)
Brachiaria villosa (Lamk) A. Camus	WPWS (*)	-	WPWS (*)	-	WPWS (*)	-	WPWS (*)	-
Digitaria adscendens (HBK) Henr.	WPWS (Aug,Oct)	WS	WPWS (Dec,Sept)	WPWS (Feb,Oct)	WPWS (Aug,Nov)	WS	WPWS (Nov,Aug)	WPWS (Feb,Sept)
Drymaria cordata (Willd.)	WPWS (*)	-	WPWS (*)	-	WPWS (*)	-	WPWS (*)	-
Eleusine indica Gaertn	-	WP (*)	-	WP (*)	-	WP (*)	-	WP (*)
Galinsoga ciliata (Rafin Blake	WPWS (Jun,Nov)	WPWS (Jun,Nov)	WPWS (Jun,Nov)	WPWS (Jun,Oct)	WPWS (Jul,Nov)	WPWS (Jul,Nov)	WPWS (Jul,Nov)	WPWS (Jul,Nov)
Isachne sp.	WPWS (*)	WS	WPWS (*)	WS	WPWS (*)	WS	WPWS (*)	WS
Lindernia numularifolia (Don)	WPWS (*)	-	WPWS (*)	-	WPWS (*)	-	WPWS (*)	-
Oxalis latifolia HBK	WPWS (*)	-	WPWS (*)	-	WPWS (*)	-	WPWS (*)	-

Table 4.2 (Contd.)

Species	'Jhum'				Terrace			
	Potato	Radish	Cabbage	Mixed	Potato	Radish	Cabbage	Mixed
Polygonum alatum Ham.	WPWS (Feb)	WPWS (Feb)	WPWS (Feb)	WPWS (Feb)	WPWS (Mar)	WPWS (Mar)	WPWS (Mar)	WPWS (Mar)
Pycreus latispicatus Cl.	WPWS (Dec)	WS	WPWS (Dec)	WS	WPWS (Dec)	WS	WPWS (Dec)	WS
Setaria glauca Beauv.	WPWS (Oct,Jul)	WPWS (*)	WPWS (Oct,Jul)	WPWS (Oct,Jul)	WPWS (Oct,Jul)	WPWS (*)	WPWS (Oct,Jul)	WPWS (Oct,Jul)
Setaria pallide-fusca (Schumach) Stapf & C.E. Hubb	WS	WPWS (Oct,Jun)	WS	WP (*)	WS	WPWS (Oct,Jun)	WS	WP
Spergula arvensis L.	WPWS (Nov,May)	WPWS (Nov,May)	WPWS (Nov,May)	WPWS (Nov,Apr, Aug)	WPWS (Nov,Aug)	WPWS (Nov,Jun, Sept)	WPWS (Nov,Jun, Sept)	WPWS (Nov,Jun, Sept)

WP - Weed plants present in the weed flora of the crop fields.

WS - Weed seeds present in the soil seed bank.

Asterisk indicates absence of seed setting.

Dashes indicate species absence.

and *Digitaria adscendens* showed two phases of seed formation, whereas *Ambrosia artemisiifolia* and *Polygonum alatum* produced seeds only once in a year. *Brachiaria villosa*, *Eleusine indica*, *Oxalis latifolia* and *Lindernia nummularifolia* and *Isachne* sp., however, did not produce seeds during the study period.

Out of the fourteen weed species observed in the seed bank, eight were common to all the crop fields. But the species like *B. villosa*, *D. cordata*, *E. indica*, *L. nummularifolia*, *O. latifolia* and *S. pallide-fusca* were restricted only to certain crop fields (Table 4.2).

Seasonal variation in soil seed bank

The seed population of different species varied markedly in different seasons in both 'Jhum' and terrace fields (Fig. 4.1-4.3). *S. arvensis* showed three distinct peaks namely, winter, summer and rainy. The size of seed population gradually declined after each peak. In the crop fields where mixed cropping was done, peak was observed only during winter season. *G. ciliata* showed two peaks, one during autumn and another during rainy season. In between the two peaks, the seed density was quite low in all the crop fields. *P. alatum* and *A. artemisiifolia* peaked during winter. The former did not show any clear trend, while the latter showed a depletion in soil seed bank with time. However, in potato and radish + cabbage (mixed) crop fields on the terrace land,

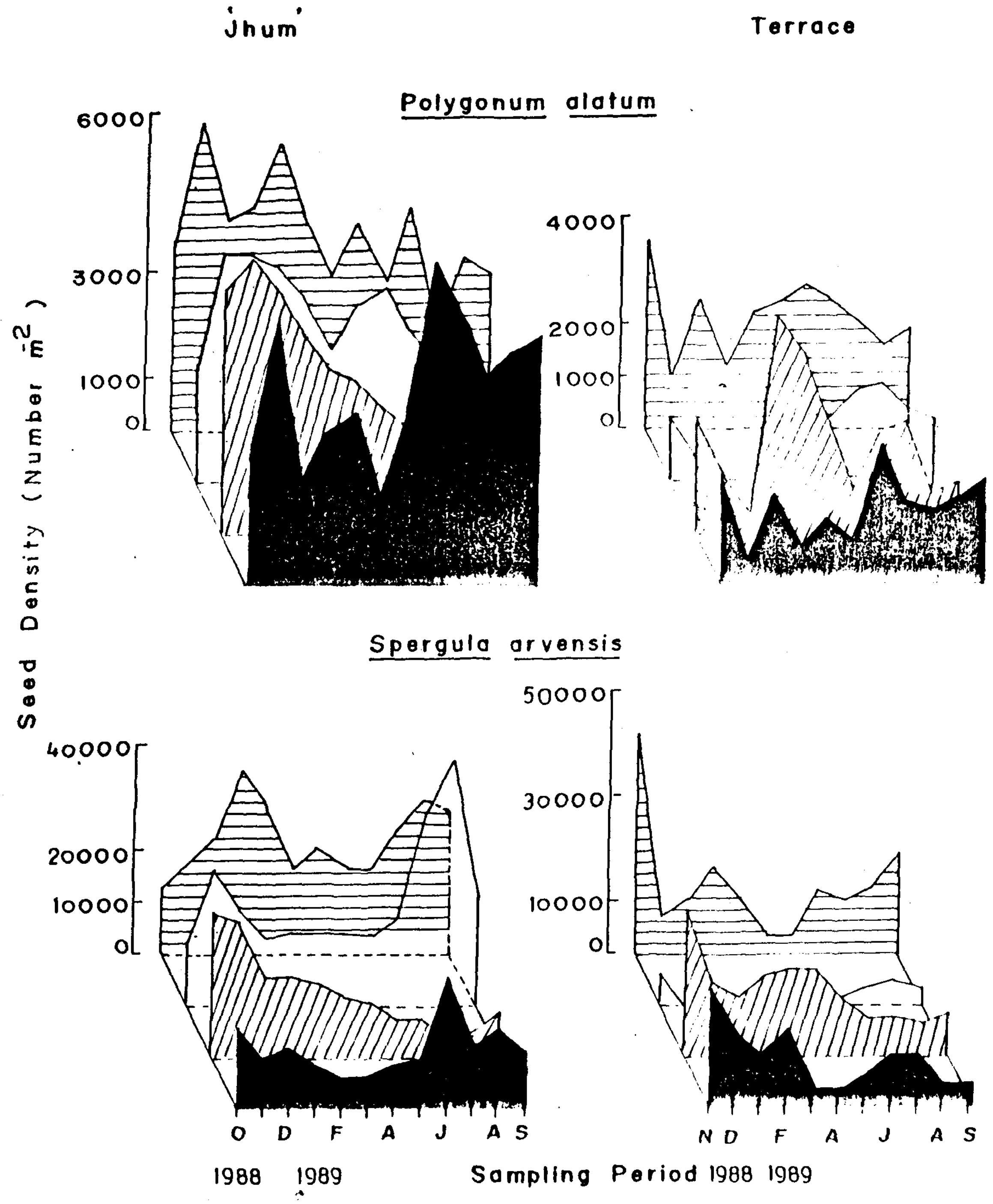


Fig. 4.1. Seasonal variation in soil seed bank of S. arvensis and P. alatum in different crop fields under 'Jhum' and terrace cultivation. □, potato; ■, radish; ▤, cabbage; ▨, mixed (cabbage + radish) crop field.

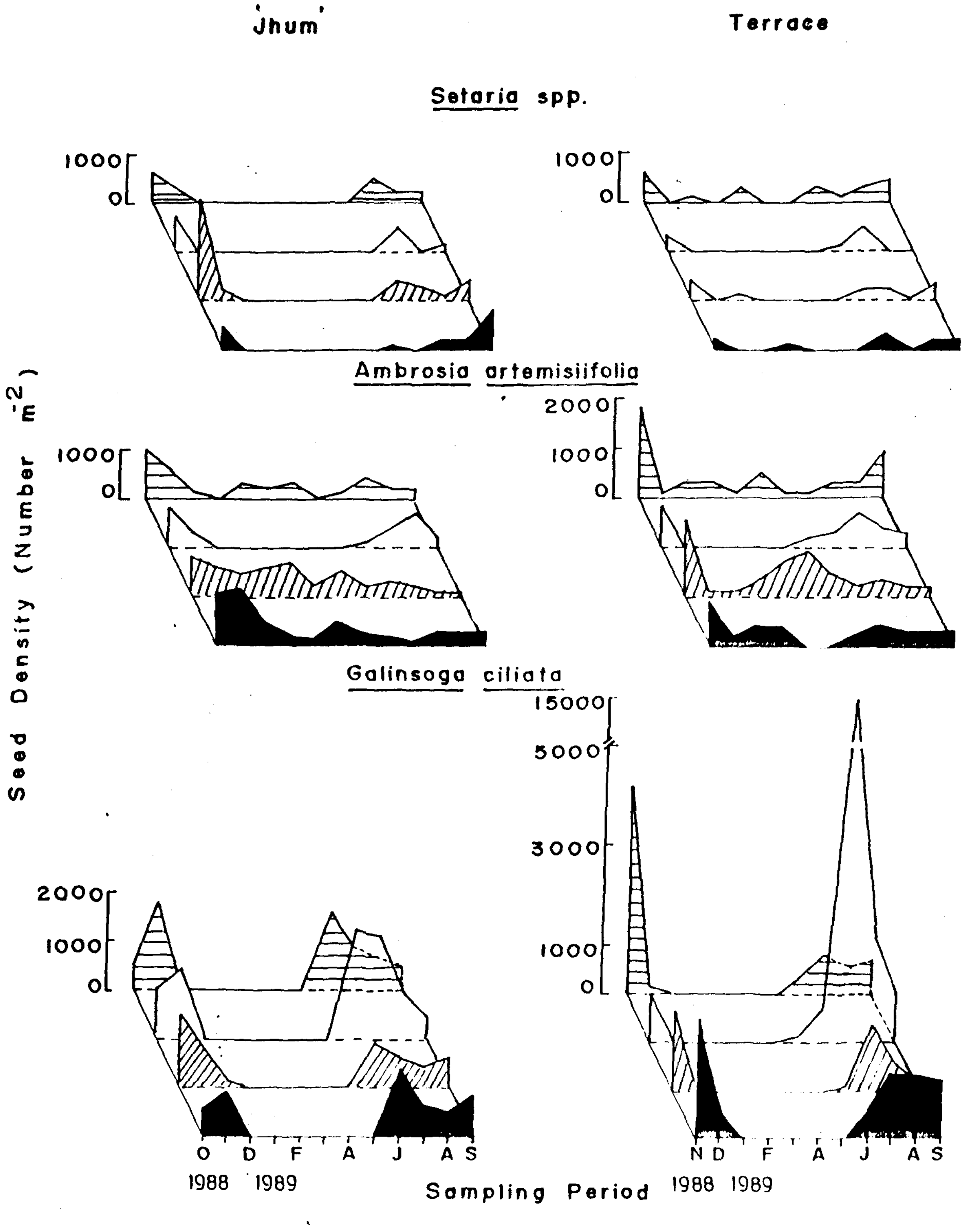


Fig. 4.2. Seasonal variation in soil seed bank of G. ciliata, A. artemisiifolia and Setaria spp. in different crop fields under 'Jhum' and terrace cultivation. Key as in Fig. 4.1.

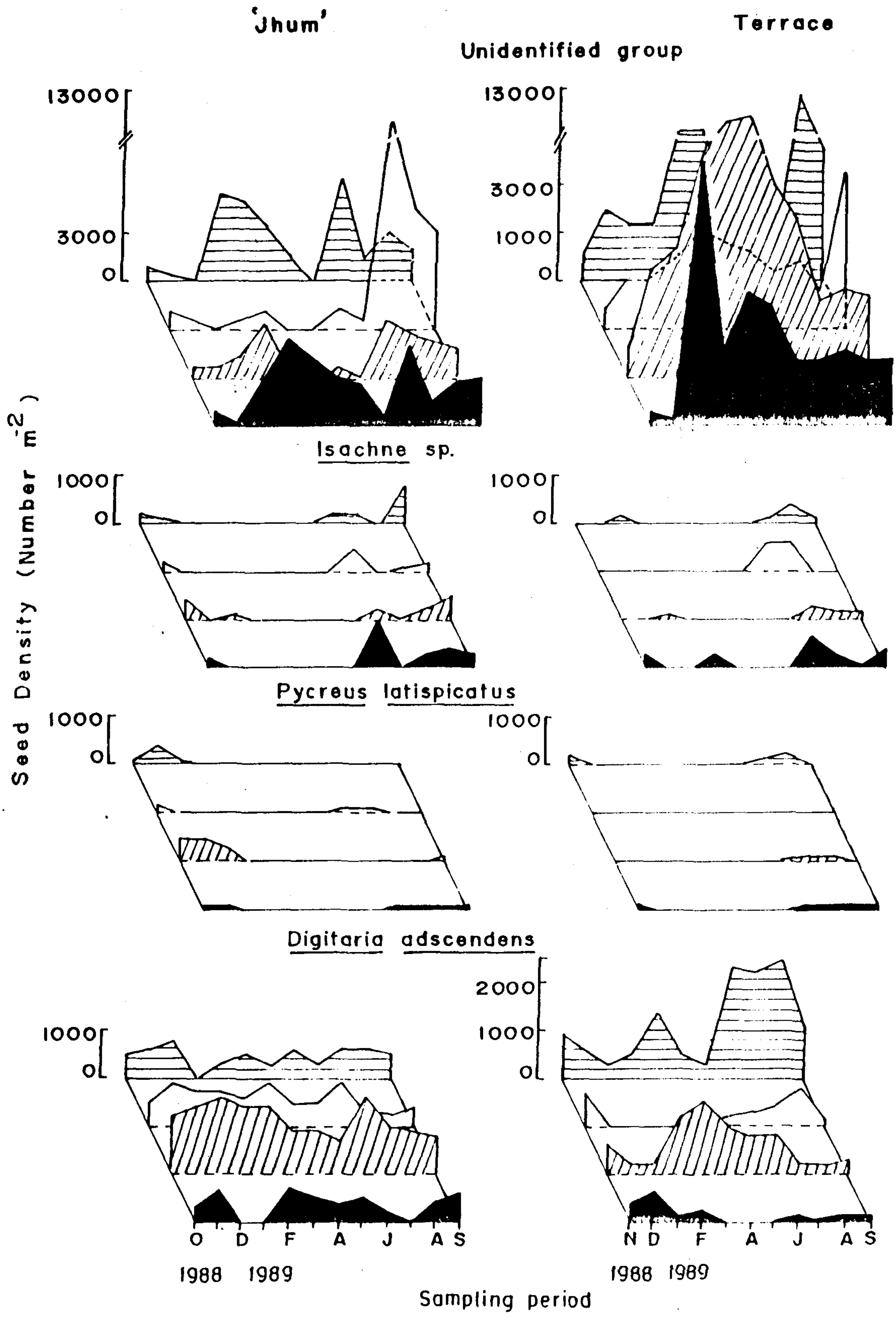


Fig. 4.3. Seasonal variation in soil seed bank of D. adscendens, P. latispicatus, Isachne sp. and unidentified group of species in different crop fields under 'Jhum' and terrace cultivation. Key as in Fig. 4.1.

one more peak was noticed during rainy season. The monthly variation in soil seed population was quite low between the peaks. D. adscendens seed population did not show any clear cut trend in time and space; the peaks were observed at different times in different fields. The soil seed bank showed more or less similar dynamics in all 'Jhum' fields during fallow period, while each crop field under terrace cultivation differed from the other in terms of soil seed population dynamics. In case of terrace fields the highest seed density was recorded in the cabbage and potato fields during the rainy season, while the cabbage + radish mixed crop fields exhibited maximum weed seed population during February. The radish field showed gradual depletion in weed seed population with time. The unidentified seed population was markedly high in the cabbage fields compared to others. The total weed seed population in cabbage, potato and radish crops in the 'Jhum' fields showed two peaks while in the field where mixed cropping was done, only one peak was noticed.

Most of the species showed a similarity in the seasonal variation in soil seed bank during the second year of study. P. alatum, however, peaked during rainy season as well in addition to the peak observed during winter season. The soil seed bank did not show any significant variation when the data of the first year were compared with those of the second year.

Table 4.3 - Mean weed seed density (number m^{-2}) in soil down to 20 cm depth in different crop fields under 'jhum' and terrace cultivation.

Type of cultivation	Crop	Seed density
'Jum'	Potato	24,612 ± 1,243
	Radish	18,624 ± 1,366
	Cabbage	27,594 ± 3,111
	Cabbage + Radish	19,408 ± 2,187
Terrace	Potato	5,789 ± 441
	Radish	15,399 ± 1,404
	Cabbage	20,650 ± 2,779
	Cabbage + Radish	17,429 ± 1,927

± S.e.m.; the values are pooled means of the two years.

Species ranking

The ranking of the species was done on the basis of their seed population size. S. arvensis showing highest seed density, secured the first rank in all the crop fields. But the rank of other species varied in different crop fields (Fig. 4.4). The density of unidentified seeds in the terrace fields was higher compared to the 'Jhum' fields. However, most of the species showed higher seed population density in the 'Jhum' fields than in terrace. S. arvensis contributed Ca. 64% to the total soil seed bank, while the remaining 36% was contributed by the rest of the species (Table 4.7). G. ciliata contributing 5% to the total weed seed population in terrace fields ranked second. In the 'jhum' field, however, P. alatum ranked second and it contributed 16% to the total soil seed bank (Table 4.7).

Depthwise distribution of seed population in soil

Total weed seed population showed a well marked depth-wise distribution in all the fields. The seed density declined with increasing soil depth (Fig. 4.6). This was also true for S. arvensis and G. ciliata (Fig. 4.5). In few species, this trend was observed in certain crop fields, while in certain other species no such trend was noticed. The distribution of seeds of all the weed species varied significantly ($P < 0.05$) with soil depth, crop and method of cultivation except G. ciliata, A. artemisiifolia and Isachne sp. The seed population of the former two species showed a significant $(P<0.05)$ variation with soil depth and crops, but did not vary significantly with the method of cultivation, while Isachne sp. did not show significant variation with any of these variables (Fig. 4.6). There was a significant $(P<0.05)$ interaction between cultivation method and crop type in the case of all the weed species except Isachne sp. A. artemisiifolia which showed a significant $(P<0.05)$ interaction between the method of cultivation and soil depth, while D. adscendens showed a significant $(P<0.05)$ interaction between crop type and soil depth.

Seed size and weight

The population of small size (0.99-1.628 mm) seeds of S. arvensis and G. ciliata was maximum in the surface soil and it declined with soil depth. Other species did not show such trend. Medium size (1.64-2.31 mm) seeds were more common in P. alatum and A. artemisiifolia, while P. latispicatus and Isachne sp. had more seeds of large size (2.32-2.97 mm). The proportion of heavier seeds declined significantly $(P<0.05)$ with soil depth. The seed weight and size were positively related in all the species (Fig. 4.7).

Ratio of seedlings to viable seeds

The ratio of weed seedlings to total viable weed

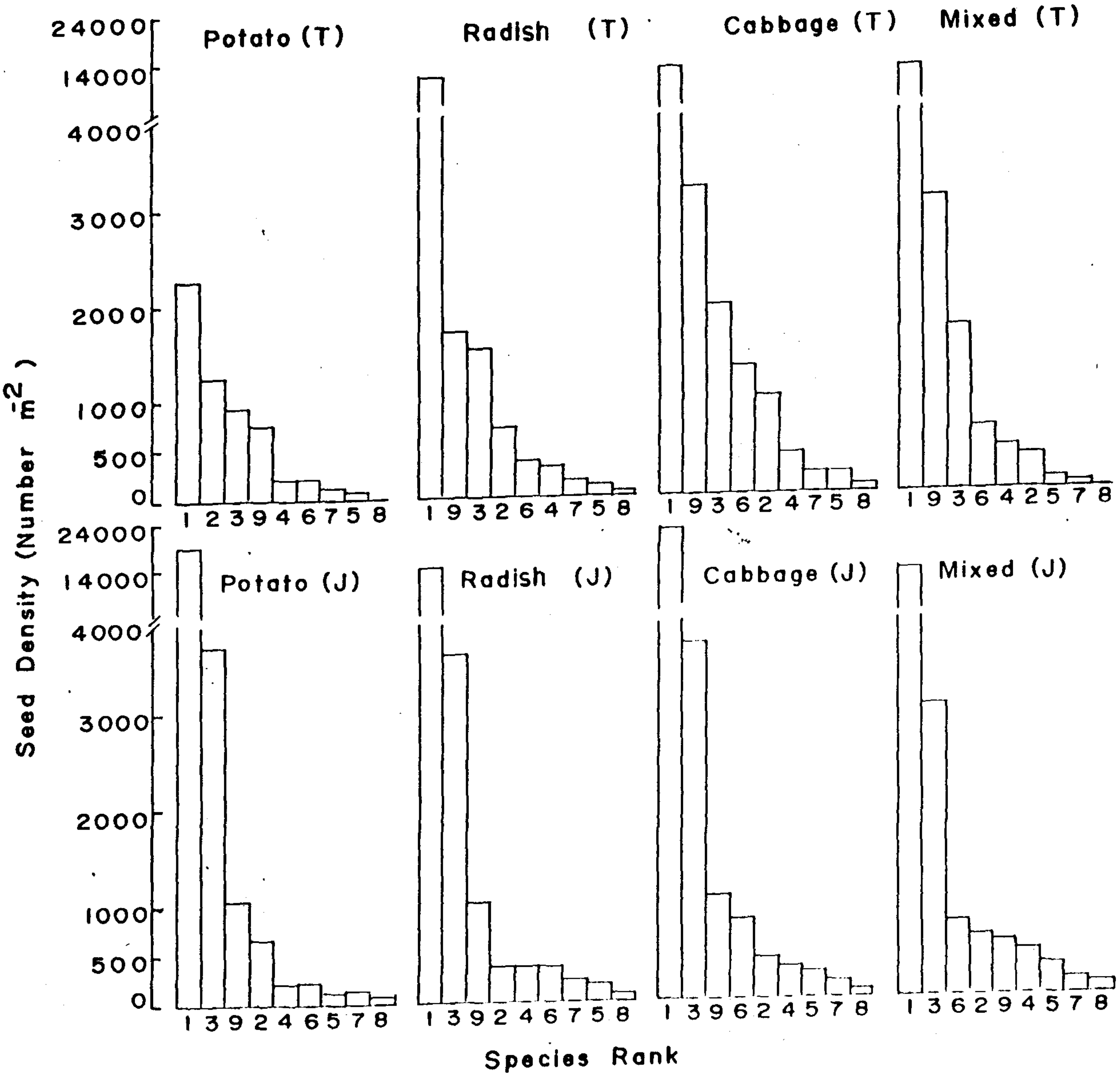


Fig. 4.4. Ranking of the species according to their seed density in the soil seed bank of different crop fields under 'Jhum' and terrace cultivation. J, 'Jhum'; T, Terrace cultivation; 1, *S. arvensis*; 2, *G. ciliata*; 3, *P. alatum*; 4, *A. artemisiifolia* 5, *Setaria* spp; 6, *D. adscendens*; 7, *P. latispicatus*; 8, *Isachne* sp.

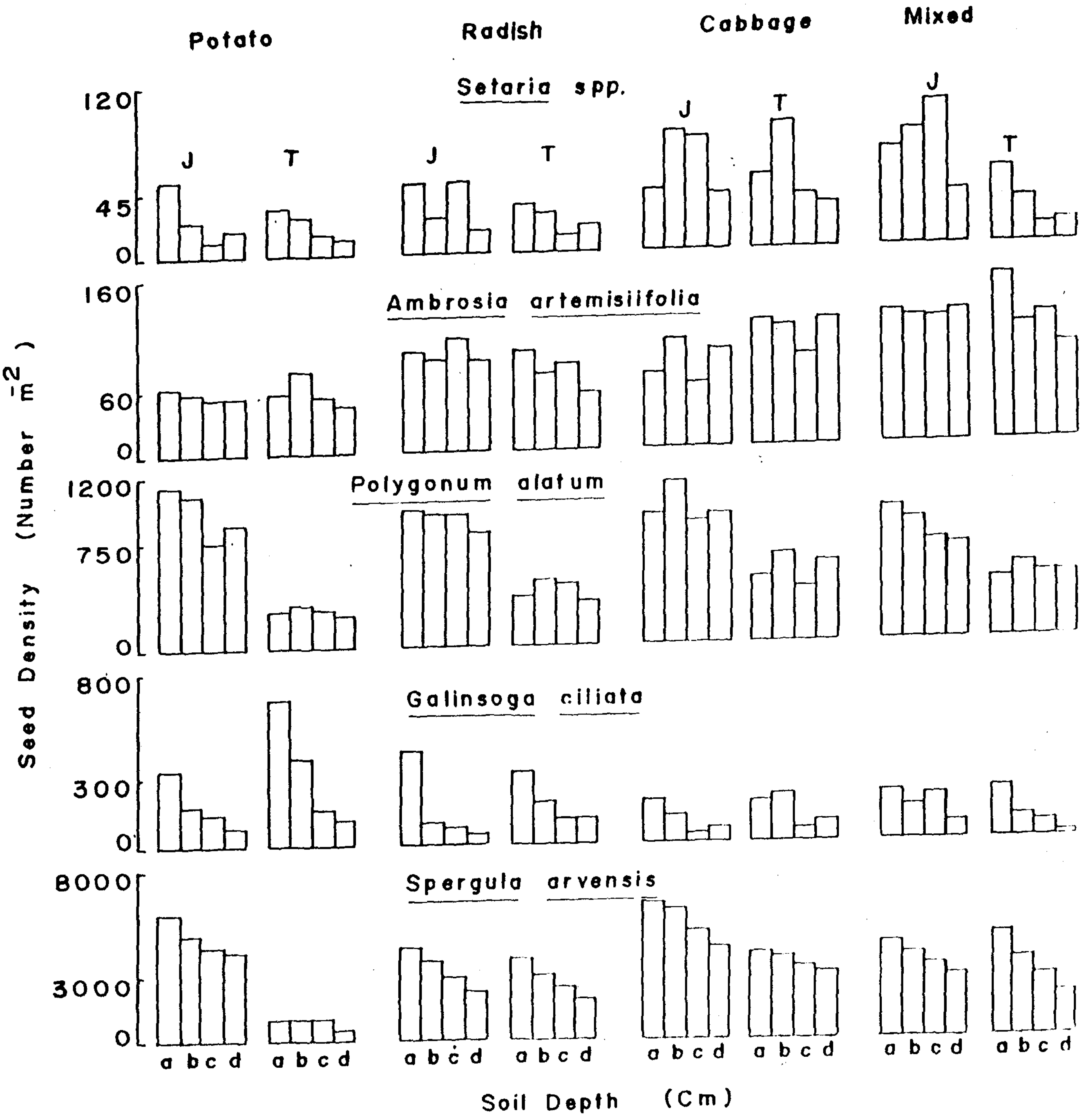


Fig. 4.5. Vertical distribution of the seeds of S. arvensis, G. ciliata, P. alatum, A. artemisiifolia and Setaria spp. in soil seed bank of different crop fields under 'Jhum' and terrace cultivation (values are mean seed density of two years), a, 0-5; b, 5-10; c, 10-15; d, 15-20 cm soil depths; J, 'Jhum', T, Terrace cultivation. Please note the change in scale.

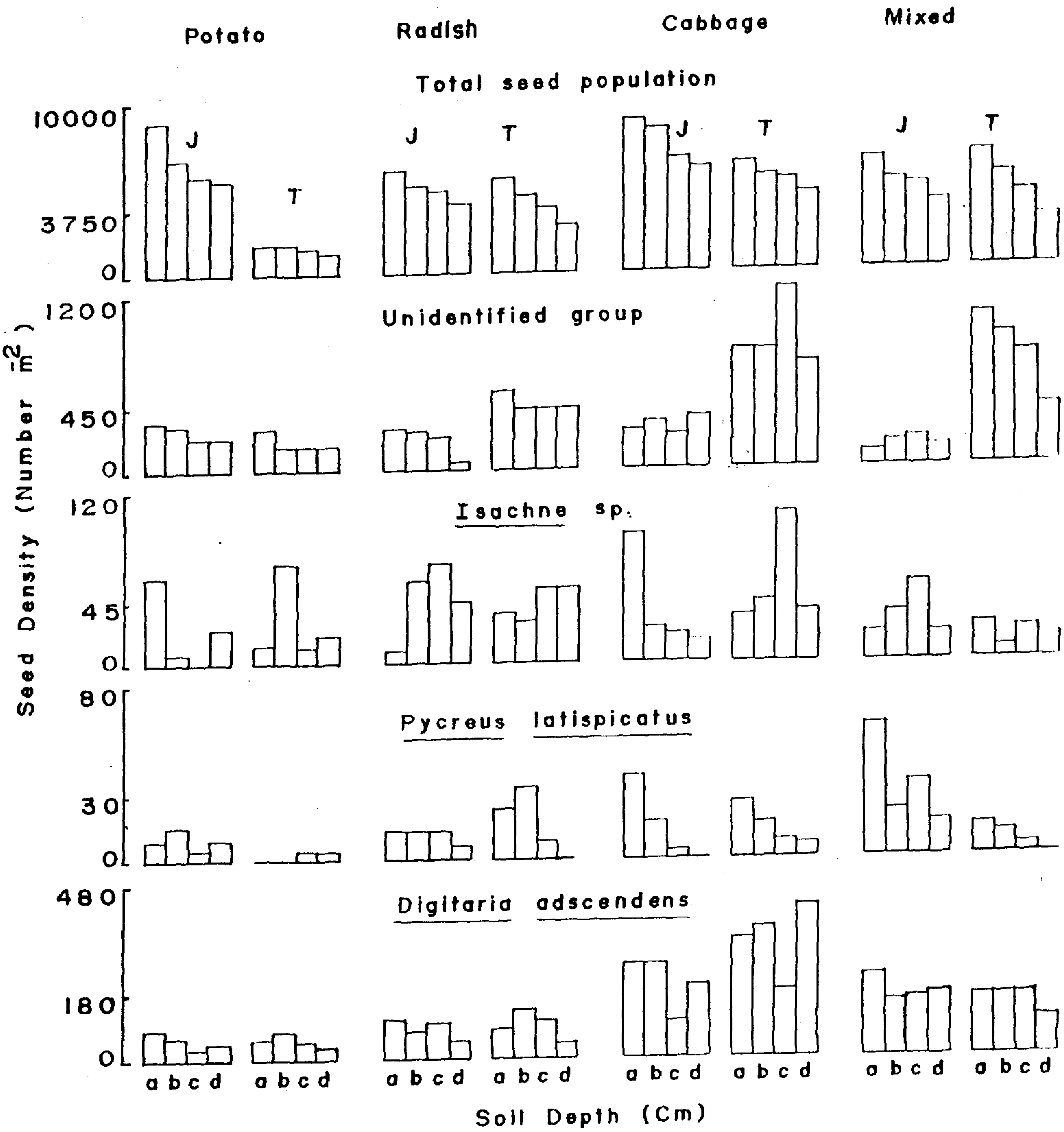


Fig. 4.6. Vertical distribution of the seeds of D. adscendens, P. latispicatus, Isachne sp., unidentified group and total weeds in soil seed bank of different crop fields under 'Jhum' and terrace cultivation. Key as in Fig. 4.5. Please note the change in scale.

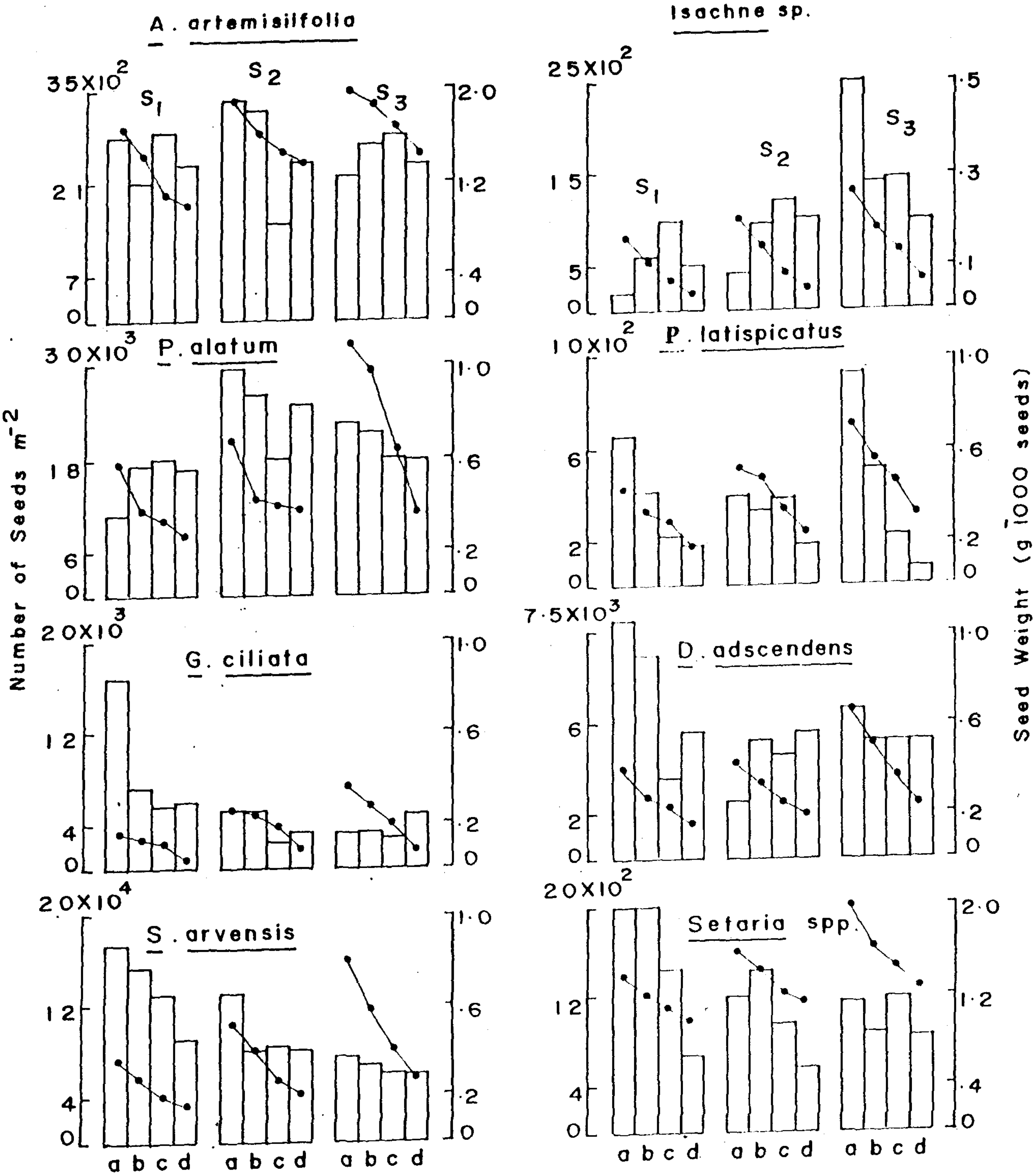


Fig. 4.7. Population and weight of the seeds of three different sizes present at different soil depths, a, 0-5; b, 5-10; c, 10-15; d, 15-20 cm soil depths; S_1, smaller; S_2, medium; S_3, larger size seeds; seed weight values represent the weight of 1000 air-dried seeds.

seeds at 0-20 cm soil depth indicated a significant difference (P< 0.05) between the crop fields (Table 4.5). The ratio was higher in the 'Jhum' fields compared to the terrace. During the cropping season, maximum seedling recruitment was recorded in the radish field and minimum in the cabbage field (Table 4.4). The weed seedling recruitment during the fallow periods was significantly (P< 0.05) lower than those observed during cropping season (Table 4.5).

Reduction in size of the seed bank

The reduction in viable weed seed population was maximum in the radish field in both 'Jhum' and terrace fields (Table 4.6). The viable seed population in soil suffered least reduction in the cabbage field under 'Jhum' and in potato field under terrace cultivation. During the second year (1989-90), viable seed population in soil decreased significantly (P < 0.01) in both 'jhum' and terrace fields (Table 4.6).

DISCUSSION

The successful input of seeds into the soil seed bank occurs mainly through seed rain (Robinowitz, 1981). In agroecosystems weed seed input into the soil also occurs through contaminated crop seeds, manure, irrigation water, machinery and other farm tools, livestock, birds and wind

Table 4.4 - Percentage of viable weed seeds that emerged as seedlings during cropping and fallow periods in different crop fields at 0-20 cm soil depth under 'jhum' and terrace cultivation.

Crop field	'Jhum'		Terrace	
	Crop period	Fallow period	Crop period	Fallow period
Potato	10.0	8.4	9.6	3.2
Radish	12.2	9.4	11.6	8.3
Cabbage	8.4	6.6	7.5	6.9
Cabbage + Radish	10.8	9.4	10.4	8.0

Table 4.5 - Analysis of variance of the data on percentage of viable weed seeds that emerged as seedlings during cropping and fallow periods in different crop fields under 'jhum' and terrace cultivation.

Source of variation	df	Mss	F value
Cultivation type	1	5.8682	3.662 Ns
Crop	3	8.4132	5.2503 **
Cropping period/Fallow period	1	25.7305	16.0572 *
Cultivation type x crop	3	1.1951	0.7458 Ns
Cultivation type x cropping period/Fallow period	1	1.6203	1.0111 Ns
Crop x Cropping period/ Fallow period	3	1.5344	0.9575 Ns
Cultivation type x crop x Cropping period/Fallow period	3	1.6024	0
Error	15	4.7636	0

*Significant at $P < 0.01$, **Significant at $P < 0.05$,

Ns - Not significant.

Table 4.6 - Reduction (%) in viable weed seed population in soil seed bank in different crop fields under 'jhum' and terrace cultivation over 2-year period.

Type of cultivation	Crop	Reduction in viable seed population (%)	
		1988-89	1989-90
'Jhum'	Potato	25.4	33.8
	Radish	28.0	35.6
	Cabbage	24.2	32.0
	Cabbage+Radish	26.4	34.0
	Mean reduction	26.0	34.0
Terrace	Potato	18.0	32.0
	Radish	38.2	51.8
	Cabbage	35.8	49.6
	Cabbage+Radish	36.0	48.8
	Mean reduction	32.0	46.0

(Tripathi, 1977; Dastgheib, 1989). The timing of seed rain is dependent on the phenology of weed species. Some weeds (e.g. *A. artemisiifolia*, *Isachne* sp., *P. alatum*, *P. latispicatus*, *S. glauca* and *S. pallide-fusca*) showed one flush of seed formation, while a few others (e.g. *D. adscendens*, *G. ciliata*) showed two flushes and yet others (e.g. *S. arvensis*) showed more than two flushes of seed formation during the crop season.

As expected, soil seed population of most weed species was largest after the seed rain in both types of agroecosystems. The 'jhum' fields always had markedly high seed density in soil. The probable reason for this is the four year long fallow period before doing cultivation in 1988, which favoured luxuriant growth of weeds and large input of seeds into the soil seed bank. On the contrary, continuous cultivation for the last eight years with regular use of herbicides and crop rotation in the terrace fields was responsible for lower weed seed density in soil. The findings are comparable with those of Roberts (1962) who showed that when the soil containing a naturally occurring population of viable seeds was subjected to frequent cultivation, the number of seeds surviving decreases exponentially. Roberts and Dawkins (1967) showed that the decrease was more rapid when the soil was cultivated rather than when allowed to remain undisturbed.

They recorded 12% annual decrease in the buried seed population in the undisturbed and uncropped soil and 30-36% when disturbance was caused four times a year. In the present study the less disturbed 'jhum' field showed 26% decrease while the more disturbed terrace field exhibited 32% decrease in soil seed bank over 1 year period, and there was further decrease after two years (34% in 'jhum' and 46% in terrace fields).

The seasonal changes in the weed seed population in soil may be related to the prevailing environmental conditions which may influence seed germination, survival of seeds and replenishment of seeds. The decline in seed bank with time, however, suggested that the seeds which entered the soil seed bank in dormant condition, germinated during the subsequent months after their dormancy was broken. During rainy season a large fraction of seed population germinated and since the seed input was also low during this season, a marked reduction in the soil seed bank was observed. An appropriate soil moisture regime and relatively high temperature during this period probably favoured seed germination. Fernandez-Quintanilla et al. (1986) also observed that soil seed density was quite low during the greatest flushes of seedling emergence following periods of relatively high rainfall extending over several days. Soil seed bank is also influenced by soil temperature (Roberts & Feast, 1970; Montegut, 1975). The larger soil seed bank observed during winter agrees with Thompson & Grime (1979) and may be attributed to low soil temperature which restricted seed germination. There was a gradual depletion of the soil seed bank until the next seed shedding period in most species, particularly G. ciliata whose seed population in soil decreased substantially. Similar behaviour was also seen in grass species like Setaria spp., Isachne sp. and P. latispicatus. The density of the seed population in soil was comparatively higher in the cabbage field under both 'jhum' and terrace cultivation followed by potato, mixed crop (cabbage + radish) and radish fields (Table 4.3). This may, presumably, be related to germination behaviour of weed seeds, as influenced by the microclimatic variability in the crop fields.

The data on seed bank clearly show a great variation in distribution of seeds with soil depth as also reported by other workers (Rampton & Ching, 1966; 1970; Taylorson, 1970; 1972; Roberts & Feast, 1972; Stoller & Wax, 1974; Yadav & Tripathi, 1982). In the present study seed density of S. arvensis and G. ciliata as well as the total seed population declined with increasing depth, but other species deviated from this trend. The variation in the pattern of vertical distribution of seeds of different weeds may be attributed to several factors. Moss (1988) reported that the persistence of viable seeds was directly influenced by the condition of cultivation, as the seeds placed on soil surface immediately before cultivation behave differently from those buried in soil in undisturbed situation. The vertical distribution of seeds in soil is also influenced by the depth of ploughing, plough design, and soil type (Chepil, 1946; Moss, 1988) which determine the extent of soil inversion and distribution of seeds in soil. The seed weight although varied significantly with soil depth, its distribution at different depths was not related to size.

The weed species differ in their potential to persist in soil seed bank, and based on their distribution in the agroecosystems, three categories were recognised, viz., (i) weeds present both in soil seed bank and weed flora, (ii) weeds present only in the seed bank, and (iii) weeds present only in weed flora. *A. artemisiifolia*, *B. villosa*, *D. adscendens*, *D. cordata*, *G. ciliata*, *Isachne* sp., *L. nummularifolia*, *O. latifolia*, *P. alatum* and *P. latispicatus* belong to the first category. The second category is represented by *D. adscendens* in radish field and *Isachne* sp. in radish as well as mixed (cabbage + radish) crop fields. *E. indica* represented the third category in radish field and mixed (cabbage + radish) crop fields of both the 'jhum' and terrace cultivation. It was interesting to note that although the seeds of *Isachne* sp. and *D. adscendens* were present in radish field and mixed crop field, their seedlings were absent from these fields, whereas they were present in the neighbouring fields. Conversely, in the case of *E. indica*, seedlings were present in the field but seeds were not present in the soil. Evidently, the seeds which are produced in one crop fields are dispersed to the neighbouring fields. The soil seed bank in various crop fields under both 'jhum' and terrace cultivation, probably represents an accumulation of seeds over years during which the seed flora and vegetation mosaic might have changed considerably due to increasing human interference. This may explain the observed differences in the species composition of the weed flora and soil bank as argued by Roberts (1981), Wilson *et al*. (1985) and Morgan & Neueschwander (1988).

CHAPTER V

Weed flora and weed seed bank in soil of different crop fields under terrace cultivation at Barapani.

INTRODUCTION

The persistence of weed flora depends upon the buried seeds in soil, underground vegetative plant parts and transport of propagules to the crop fields. Besides the supply of weed seeds/propagules, other factors which largely determine appearance and growth of weeds in crop fields are the agronomic practices, type of crop grown and the time of crop sowing (Saavedra _et al._, 1989, 1990). The replenishment of weed seed bank and increase in its size are brought about by the copious seeding of weeds that grow in the crop fields from year to year. Thus the weed flora and soil seed bank of a particular crop field are interdependent. The relationship between weed flora and viable soil seed bank is known for a number of weed species in other countries (Roberts, 1981).

Unlike the terrace cultivation at Upper Shillong which is of only one type, the terrace cultivation at ICAR farm at Barapani is of two types. In the first type the crop sowing is done after ploughing (referred to in this thesis as 'terrace-normal') and in the second type the crop sowing is done by dibbling (referred to in this thesis as 'terrace-dibbling'). In the 'terrace-normal' fields the weed control measures such as herbicide application, mechanical weeding and hand weeding are quite common, while in the 'terrace-dibbling' there is no weeding. In the latter fields, therefore, the weeds grow more luxuriantly. The differences in the agronomic practices in the two types of terrace cultivation would also affect the weed seed bank in soil.

The crop fields under 'terrace-normal' category are frequently cultivated with no or little fallow period compared to the fields under 'terrace-dibbling' where crop sowing is done only once in a year. This difference in the two types of terrace fields may also cause differences in their weed flora and soil seed bank. The present chapter compares the weed seed reserve in soils and weed flora of the crop fields under two categories of terrace cultivation (Table 5.1) at Barapani.

MATERIALS AND METHODS

Species composition, density and depthwise distribution of seeds in soil during summer and autumn cropping seasons in the crop fields under maize, mustard, linseed and paddy and during the intervening fallow period after the crop harvest were studied over a period of two years (March 1989 to February 1991).

Twenty soil cores (5.727 cm diameter x 20 cm depth)

Table 5.1 - Crop rotation and duration of cropping & fallow periods in different crop fields under terrace cultivation at ICAR Farm, Barapani during 1989-91.

Crop field	Crop rotation	Cropping period	Intervening Fallow period (days)**
Maize	(Mz-Gn-Mz-Gn-Mz)		
	Mz	21.1.89 - 22.6.89	
	Gn	4.7.89 - 25.10.89	12
	Mz	1.3.90 - 15.7.90	155
	Gn	20.7.90 - 10.11.90	5
	Mz	14.3.91 - 16.7.91	95
Mustard	(Ms-Mz-Gn-Ms-Mz-Ms)		
	Ms	10.11.88 - 7.3.89	
	Mz	3.5.89 - 25.8.89	27
	*Gn	10.6.89 - 3.11.89	-
	Ms	3.12.89 - 8.4.90	30
	Mz	12.5.90 - 12.9.90	35
	Ms	27.11.90 - 25.3.91	76
Linseed	(L-Gn-L-Gn-L)		
	L	12.11.88 - 20.2.89	
	Gn	20.7.89 - 8.12.89	150
	L	12.12.89 - 10.3.90	12
	Gn	25.7.90 - 10.12.90	137
	L	15.12.90 - 20.3.91	5
Paddy	(Pd-B-Gn-Pd-B-Gn)		
	Pd	8.3.89 - 5.6.89	
	B	10.6.89 - 2.10.89	5
	*Gn	15.7.89 - 2.12.89	-
	Pd	28.12.89 - 3.4.90	26
	B	1.6.90 - 25.9.90	59
	Gn	12.12.90 - 26.3.91	78

Mz - maize, Gn - groundnut, Ms - Mustard, L - Linseed, Pd - Paddy, B-bean.

* Groundnut was sown in the same fields about 7 weeks after the sowing of maize or beans.

** Includes the day on which the preceding crop was harvested and the date on which the next crop was sown.

were collected from each crop field at monthly intervals between March 1989 to February 1991. These were brought to the laboratory and cut horizontally into four soil layers corresponding to four different soil depths and were processed as described in Chapter IV.

RESULTS

Species composition of the weed flora and weed seed bank in soil

The weed flora of the crop fields under study was composed of a total of thirty-two species, of which thirteen were common to all the crop fields, while sixteen species were observed in maize and paddy fields. The number of weed species was highest (24) in the maize field under terrace cultivation where tilling was done and lowest (19) in linseed field on tilled terraces. The number of weed species in the crop fields where sowing was done by dibbling was always lower than in the corresponding crop fields of tilled terraces.

The seeds of these weeds were also represented in the soil seed bank. The seeds of six weed species viz. Fimbristylis complanata, Hypochaeris radicata, Isachne albens, Lindernia sp., Oxalis corniculata, Paspalum distichum could not be seen in any of the crop fields although these species were represented in the weed flora of most of the crop fields (Table 5.2). The number of weed species whose seeds were present in soil was always lower than the number of weed species present in the flora. The highest number of weeds (18) was represented in the soil seed bank of the maize field on tilled terraces while the least (13) in the mustard crop field under similar practice of cultivation. The number of weed species represented in soil seed bank was generally higher in the crop fields where sowing was done after tilling the land compared to the fields where it was done by dibbling (Table 5.2).

Seeding period of weeds

The time of seed formation for different weed species varied, but slightly, in different crop fields (Table 5.2). Most of the weeds shed their seeds during wet summer season (June to September), while a good number of them produced seeds during winter months. *Ageratum conyzoides* produced seeds twice in a year. *Ageratum haustonianum*, *Ambrosia artemisiifolia*, *Bidens pilosa*, *Borreria hispida*, *Brachiaria villosa*, *Commelina benghalensis*, *Drymaria cordata*, *Eleusine indica*, *Emelia sonchifolia*, *Eupatorium adenophorum*, *Eupatorium riparium*, *Fimbristylis complanata*, *Galinsoga ciliata*, *Galinsoga parviflora*, *Hypochaeris radicata*, *Lantana camara*, *Mimosa pudica*, *Polygonum* sp., *Poulzozia bennetians*, *Richardsonia piolosa*, *Setaria glauca* and *Setaria pallide-fusca* produced seeds only once in a year. *Drymaria cordata*, *Eragrostis*

Table 5.2 - List of weeds represented in the weed flora and/or soil seed bank together with their peak growth and seeding periods in the crop fields under terrace cultivation at ICAR farm, Barapani during 1989-91.

Weed species	Life form	Crop fields								Peak growth period	Seeding period
		Maize		Mustard		Linseed		Paddy			
		WF	SB	WF	SB	WF	SB	WF	SB		
Ageratum conyzoides L.	A	+	+	+	+	+	+	+	+	Jul	Jun, Jan
Ageratum haustonianum Mill.	A	+	+	+	+	+	+	+	+	Jun	Jun
Ambrosia artemisiifolia Linn.	A	+	+	-	-	-	-	-	-	Oct	Nov
Arundinella benghalensis (Spreng) Druce	P	+	+	+	+	+	+	+	+	Sep	Oct
Bidens pilosa L.	A	+	+	+	+	+	+	+	+	Aug	Feb, Sep
Borreria hispida (L.) Schum	A	+	+	+	+	+	+	+	+	Jun	Jul
Brachiaria villosa (Lamk) A. Camus	A	+	+	+	+	+	+	+	+	Jul	Aug
Commelina benghalensis	A	+	-	-	-	-	-	+	+	Mar	Apr
Drymaria cordata	A	+	+	-	-	-	-	+	+	Jun	*
Eragrostis unioloides	A	+	+	-	-	-	-	-	-	Aug	*
Eleusine indica Gaertn	A	+	+	+	+	+	+	+	+	Oct	Nov
Emelia sonchifolia DC	A	+	+	+	+	+	+	+	+	Mar	Apr
Eupatorium adenophorum Spreng	P	+	+	+	-	-	-	-	-	Mar	Apr
Eupatorium odoratum L.	P	-	-	-	-	+	+	+	+	May	Jun
Eupatorium riparium	P	-	-	-	-	-	+	+	+	May	May
Fimbriszlis complanata Benth.	A	+	-	+	-	-	-	-	-	Sep	Oct
Galinsoga ciliata (Rafin) Blake	A	+	+	+	+	+	+	+	+	Jun	Jul

Table 5.2 (Contd.)

Weed species	Life form	Crop fields								Peak growth period	Seeding period
		Maize		Mustard		Linseed		Paddy			
		WF	SB	WF	SB	WF	SB	WF	SB		
Galinsoga parviflora Cav.	A	+	+	+	+	+	+	+	+	Aug	Sep
Hypochaeris radicata	A	+	-	-	-	-	+	-	-	Jul	*
Imperata cylindrica Beauv.	P	+	+	-	-	-	-	+	+	Jul	*
Isachne albens	P	-	-	-	-	+	-	-	-	Aug	*
Lantana camara	P	+	+	-	-	+	+	+	+	Mar	Apr
Lindernia sp.	A	-	-	+	-	-	-	-	-	Jul	*
Mimosa pudica L.	P	+	+	-	-	+	+	-	-	Feb	Feb
Oxalis corniculata	P	-	-	-	-	-	-	+	-	Aug	*
Paspalum distichum	P	+	-	+	-	-	-	-	-	Sep	*
Plygonum sp.	A	-	-	-	-	+	+	-	-	Feb	Feb
Poulzolzig bennettiana	P	-	-	+	+	-	-	-	-	Jun	Jul
Richardsonia piolosa	A	+	+	+	+	+	+	+	+	Jun	Jul
Spilanthes paniculata DC.	A	+	+	+	+	+	+	+	+	Jun	Jul
Setaria glauca Beauv.	A	+	+	+	+	+	+	+	+	Sep	Oct
Setaria pallide-fusca (Schumach) Stapf & C.E. Hubb	A	-	-	-	-	-	-	+	+	Feb	Feb

WF - weed flora; SB - soil seed bank; Asterisk indicates absence of seeding during the study period; + species present; - species absent.

unioloides, Isachne albens, Lindernia sp., Oxalis corniculata and Paspalum distichum, however, did not produce seeds in any of the crop fields during the study period. The species Commelina benghalensis produced seeds in the paddy field only, although it occurred in the maize field as well.

Out of the thirty-two weed species, the seeds of twenty four weeds were present in the soil seed bank. The six species viz. Fimbristylis complanata, Hypochaeris radicata, Isachne albens, Lindernia sp., Oxalis corniculata and Paspalum distichum were restricted only to the weed flora of the crop fields (Table 5.2).

Most of the weed species attained their peak growth during rainy season, a few of them viz., E. sonchifolia, E. adenophorum during spring, while Polygonum sp. and S. pallide-fusca showed peak growth during winter season (Table 5.2). The number of annual weeds was 3-4 times greater than that of perennial weeds.

Seasonal fluctuation in soil seed bank

The seed population of different species varied markedly in different seasons. Ageratum spp. showed two distinct peaks; one during summer and another during winter season. The size of seed population gradually declined after each peak. However, it peaked only once in all the crop fields where dibbling was practiced. *A. benghalensis* showed only one peak in all the crop fields except in mustard field on tilled terraces where two peaks were observed (Fig. 5.1). In between the two peaks, the seed density was observed to be low. *B. pilosa* and *B. hispida* peaked only once during the wet summer season in most crop fields. However, in the maize field on tilled terraces, *B. pilosa* showed one more peak during the winter season. *E. indica* and *E. sonchifolia* peaked during spring in all the crop fields (Fig. 5.2) while *Galinsoga* spp. and *R. piolosa* peaked during wet summer season (Fig. 5.3). *Galinsoga* spp. showed a very low seed population in soil during March to May but from June onwards there was a sudden increase in seed population density which peaked during rainy season after which it gradually declined. *Richardsonia piolosa*, on the other hand, showed several peaks during wet summer season in the tilled terraces. *Setaria* spp. peaked twice in the crop fields where sowing was done after tilling and only once in the crop fields where dibbling was practiced. *S. paniculata* peaked once (in wet summer season) and showed a gradual decline in soil seed bank after the peak (Fig. 5.4). In the tilled terrace fields, however, it showed two peaks, one, during rainy season and the other, during winter. The unidentified seed population did not show any clear-cut trend in both time and space; different peaks were observed at different times in different crop fields. The soil seed

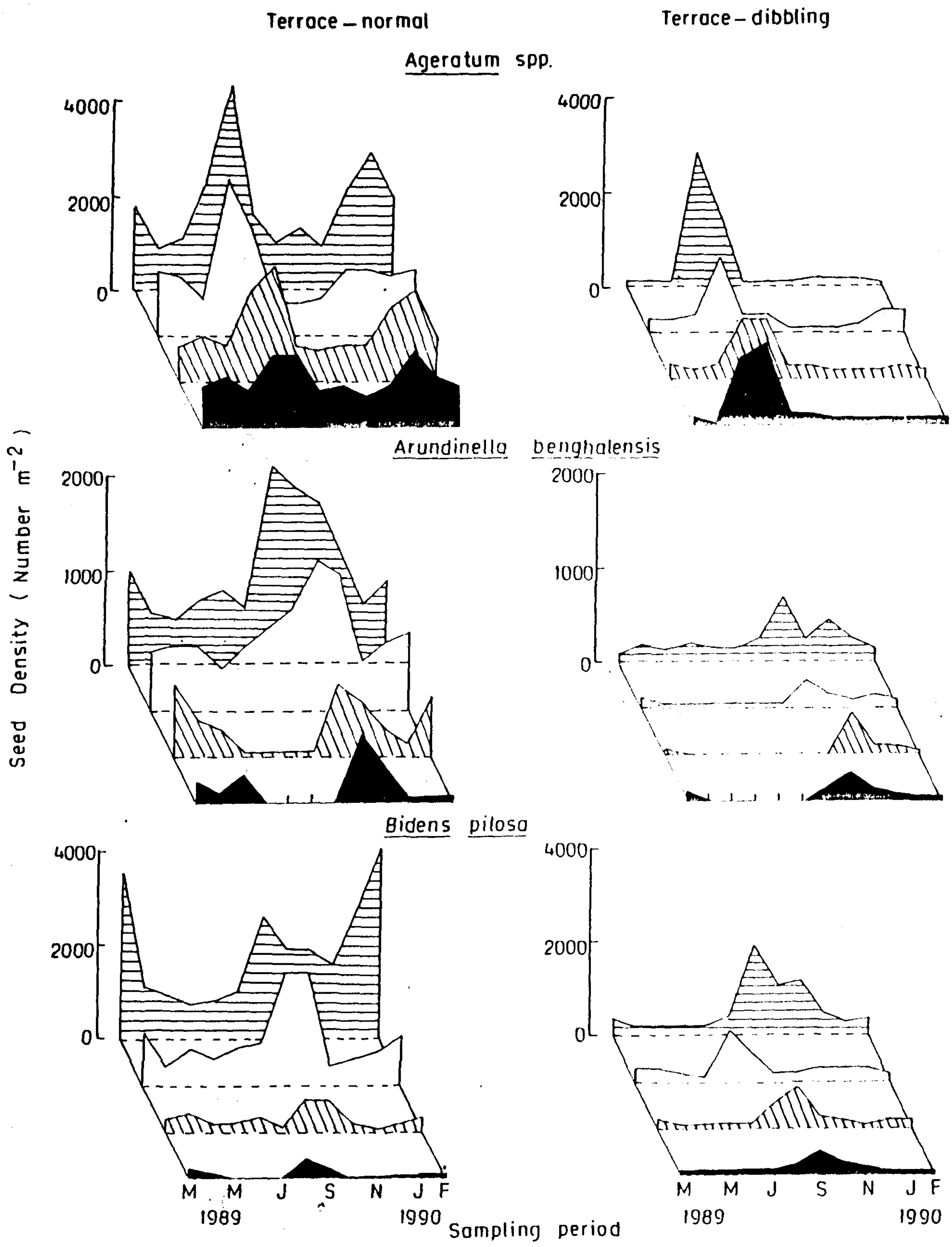


Fig. 5.1. Seasonal variation in soil seed bank of *Ageratum* spp, *A. benghalensis* and *B. pilosa* in four different crop fields under two types of terrace cultivation, viz., 'terrace-normal' and 'terrace-dibbling' ▤, maize; ☐, paddy; ▨, mustard; ■, linseed crop field.

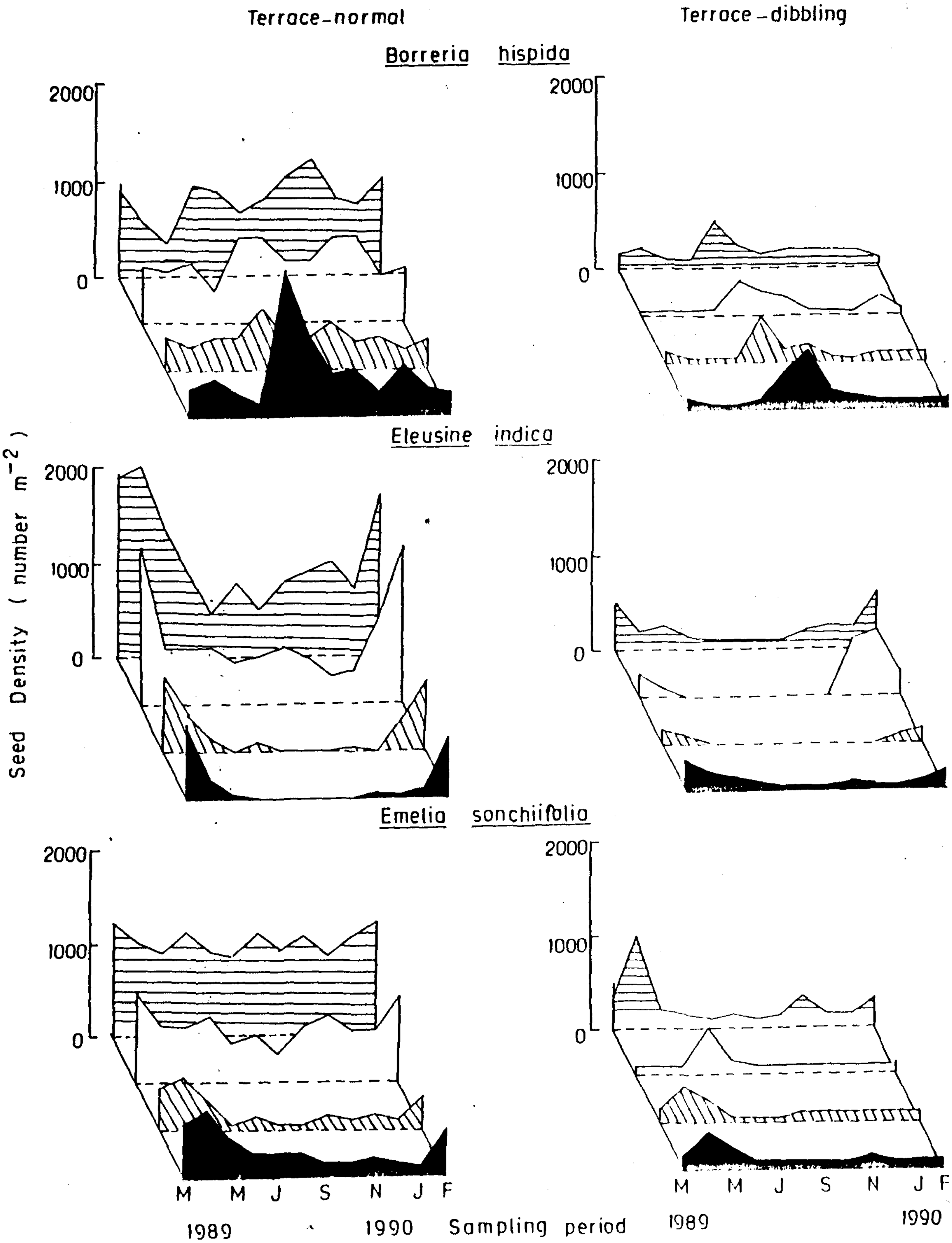


Fig. 5.2. Seasonal variation in soil seed bank of B. hispida, E. indica and E. sonchifolia in four different crop fields under two types of terrace cultivation viz., 'terrace-normal' and 'terrace-dibbling' category. Key as in Fig. 5.1.

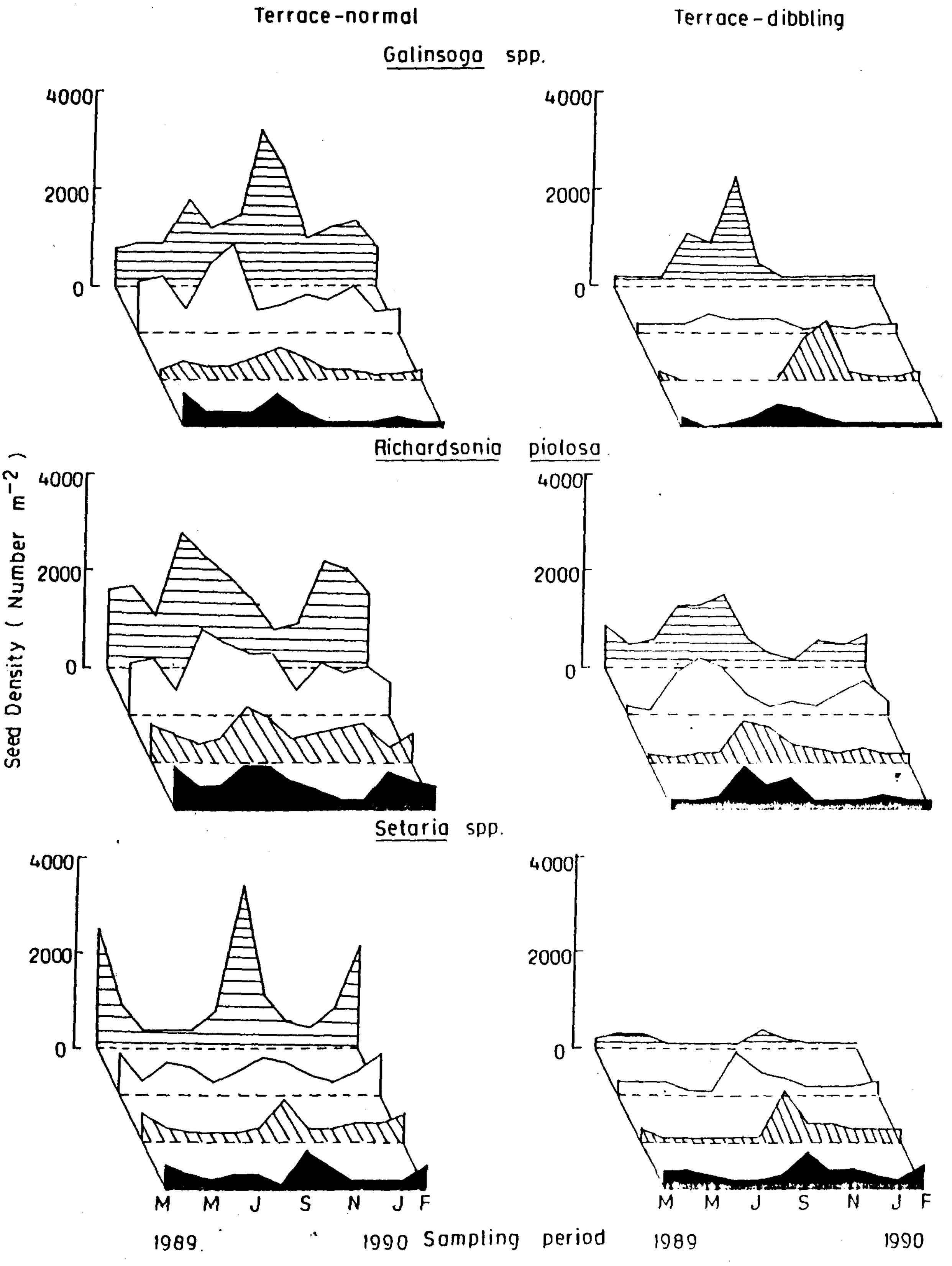


Fig. 5.3. Seasonal variation in soil seed bank of Galinsoga spp., R. piolosa and Setaria spp. in four different crop fields under two types of terrace cultivation viz., 'terrace-normal' and 'terrace-dibbling' category. Key as in Fig. 5.1.

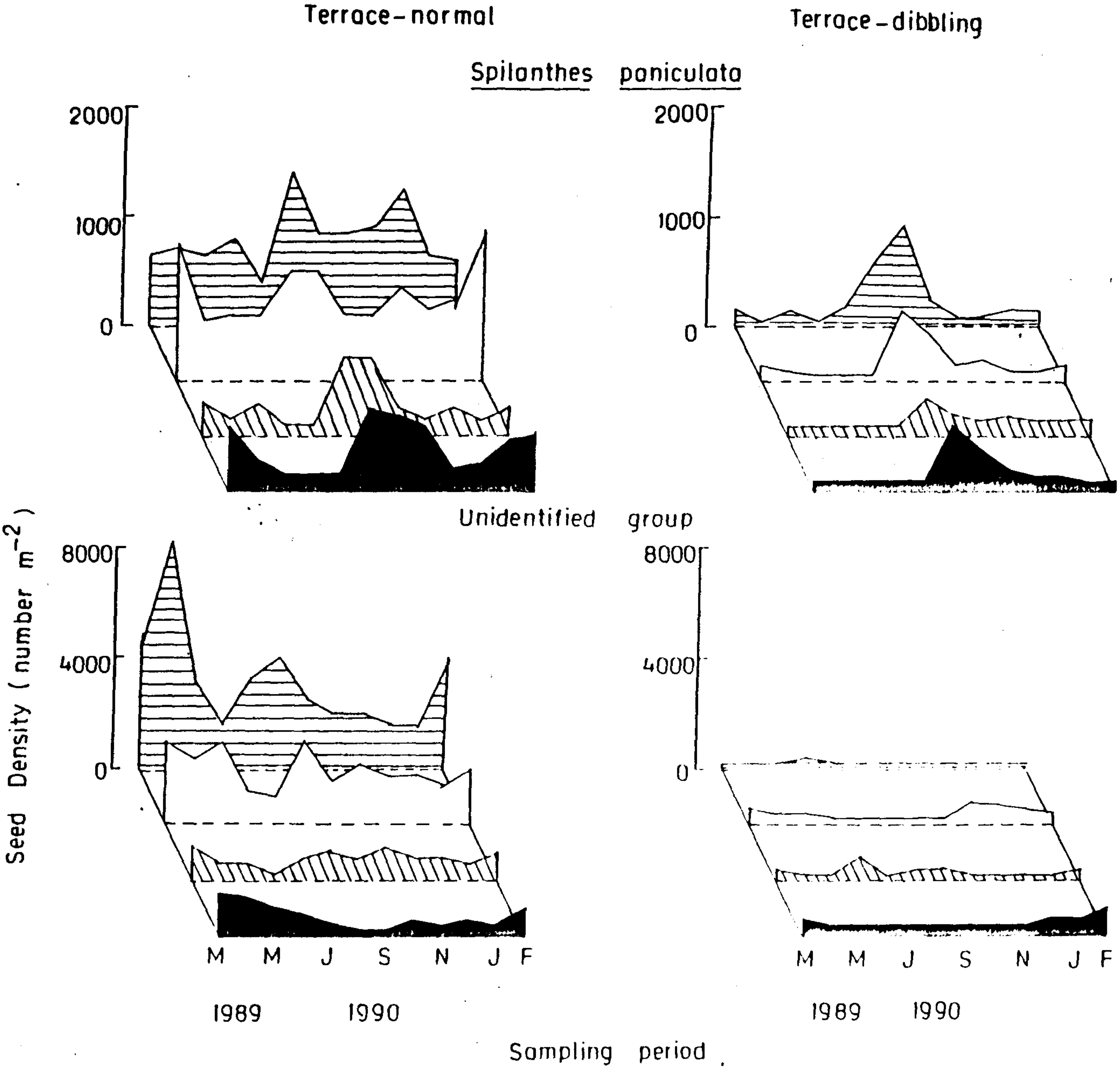


Fig. 5.4. Seasonal variation in soil seed bank of S. paniculata and unidentified group in four different crop fields under two types of terrace cultivation viz., 'terrace-normal' and 'terrace-dibbling' category.

bank showed more or less a similar dynamics in all the crop fields where sowing was done by dibbling, but it showed marked variation from one crop field to the other where the terraces were tilled (Fig. 5.5).

The size of the weed seed bank in soil was always larger in the crop fields where tilling preceded the crop sowing compared to the fields where seed sowing was done by dibbling. The weed seed density in soil was highest in the maize field, followed by paddy and mustard, while it was lowest in the linseed field (Table 5.3).

The trend of seasonal fluctuation in soil seed bank during 1990-91 was more or less similar to that observed during 1989-90.

Based on the seed population density in soil, Ageratum sp. were the most important in the mustard and linseed crop fields, R. piolosa in the maize and paddy fields where crop seeds were sown by dibbling, while the unidentified group secured the first rank in the maize and paddy fields on tilled terraces. The seed population density of different weed species in various crop fields varied so much that it was not possible to single out any weed species as the most dominant one (Fig. 5.6).

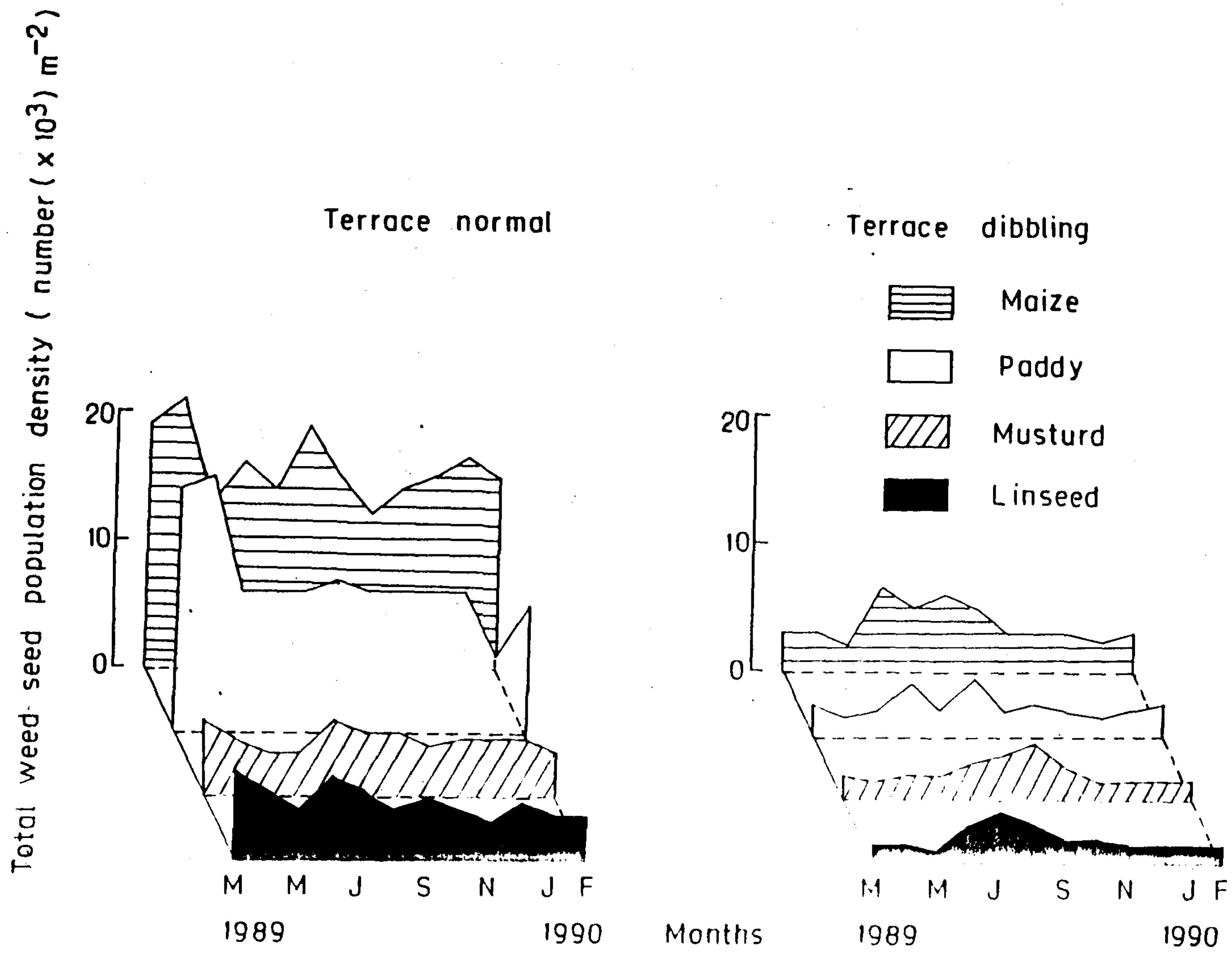


Fig. 5.5. Seasonal variation in soil seed bank of all weeds in four different crop fields under two types of terrace cultivation viz., 'terrace-normal' and 'terrace-dibbling' category.

Table 5.3 - Mean weed seed density (number m^{-2}) in soil down to 20 cm depth in different crop fields under terrace cultivation at ICAR farm, Barapani.

Crop field	Seed density	
	Terrace-normal	Terrace-dibbling
Maize	18,434±1,977	3,757±246
Mustard	13,477±1,637	2,926±326
Linseed	12,650±1,443	2,758±265
Paddy	16,243±2,292	3,542±315

± S.e.m. The values in the table are pooled means over a period of two years.

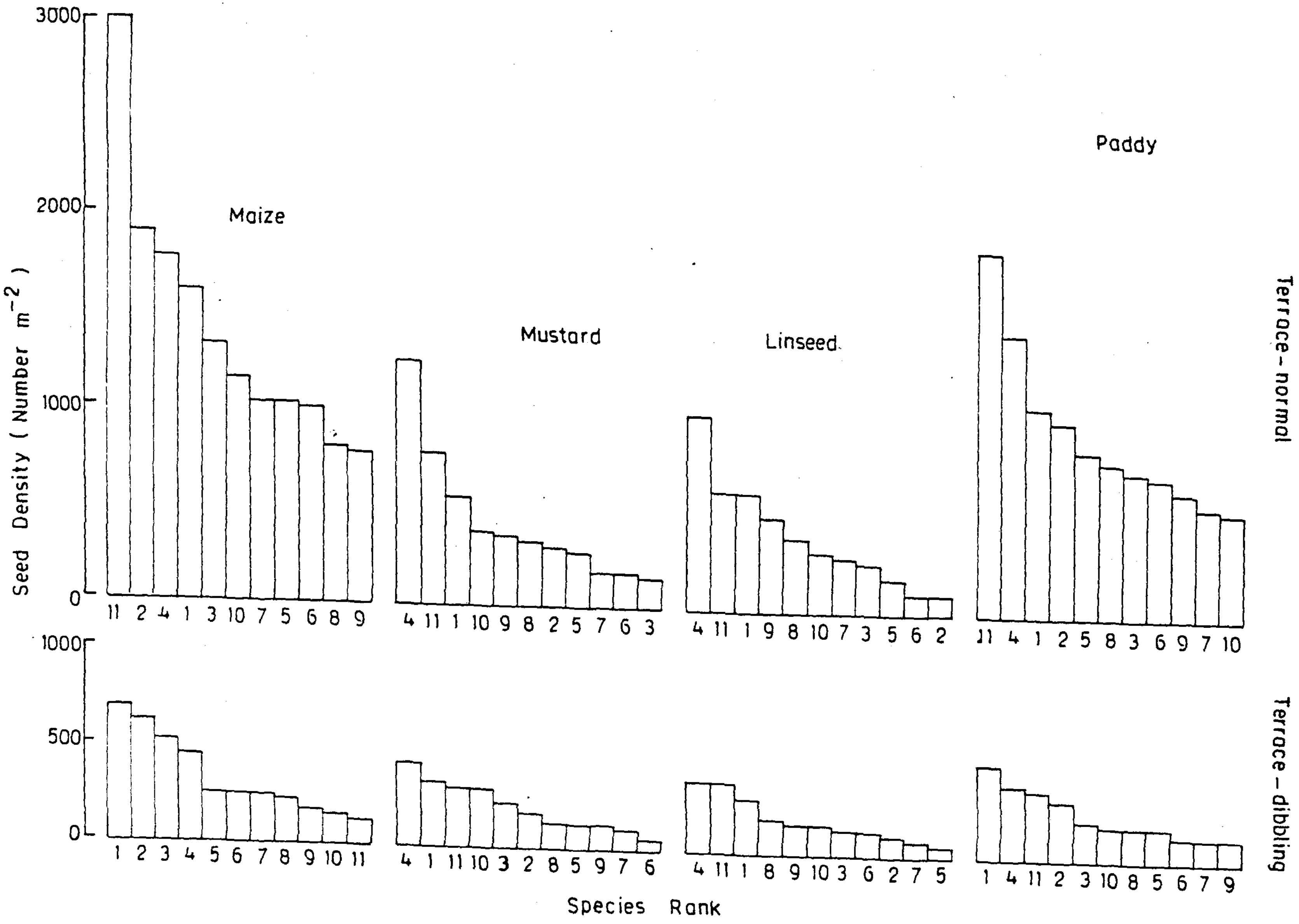


Fig. 5.6. Ranking of the species according to their seed density in the soil seed bank of different crop fields under two types of terrace cultivation viz., 'terrace-normal' and 'terrace-dibbling' cultivation. 1, R. piolosa; 2, B. pilosa; 3, Galinsoga spp.; 4, Ageratum spp; 5, A. benghalensis; 6, E. indica; 7, E. sonchifolia; 8, S. paniculata; 9, B. hispida; 10, S. glauca; 11, Unidentified group.

Ratio of seedlings to viable seeds

The ratio of weed seedlings to total viable weed seeds at 0-20 cm soil depth revealed a significant difference ($P<0.01$) between the cultivation types (Table 5.5). The value obtained during cropping varied significantly ($P<0.05$) from that obtained during fallow period in situations where crop sowing was done after tilling the land (Table 5.4), while the differences were insignificant where dibbling was adopted for sowing. The percentage of the viable seeds that emerged as seedlings was highest in linseed field while it was lowest in the maize field. The ratio was always higher during the cropping periods than during the intervening fallow periods (Table 5.4).

DISCUSSION

The data revealed that species composition of the weed flora differs from the species composition of the soil seed bank. Even the composition of the weed flora was also different from field to field. This could be attributed to several factors such as the difference in agricultural operations, crop canopy, crop density, crop architecture, competitive ability of the crops, soil characteristics, variation in microclimatic conditions and irrigation aspects (Fryer & Makepeace, 1977; Froud-Williams & Chancellor, 1987; Bridga-

Table 5.4 - Percentage of viable seeds that emerged as seedlings during cropping and fallow periods in different crop fields from 0-20 cm soil layer under terrace cultivation at ICAR Farm, Barapani.

Crop field	Terrace-normal		Terrace-dibbling	
	Cropping period	Fallow period	Cropping period	Fallow period
Maize	8.0±0.8	8.0±0.8	7.3±0.3	7.3±0.3
Mustard	12.5±1.2	8.6±1.0	9.6±0.6	9.2±0.4
Linseed	13.5±1.4	9.3±0.9	9.8±1.1	9.0±0.8
Paddy	12.0±1.3	10.0±1.1	8.4±0.4	8.2±0.4

± S.e.m, n=6.

Table 5.5 - Analysis of variance of the data on percentage of viable seeds that emerged as seedlings from 0-20 cm soil layer during cropping and fallow periods in different crop fields under terrace cultivation at ICAR farm, Barapani.

Source of variation	df	Ms	F
Type of cultivation	1	57.64	16.29**
Crop	3	9.55	2.70
Cropping period/Fallow period	1	19.18	5.42*
Cultivation type x crop	3	1.81	0.51
Cultivation type x Cropping period/ Fallow period	1	4.08	1.15
Crop x Cropping period/Fallow period	3	7.30	2.06
Cultivation type x Crop x Cropping period/Fallow period	3	3.29	0.93
Error	32	3.54	-

** Significant at $P < 0.01$, * Significant at $P < 0.05$.

mohan & Brathwaite, 1989; Saavedra et al., 1990). Crop cycle also greatly influences the behaviour of weeds (Barralis, 1972). Saavedra et al. (1989) have suggested that the types of crop grown is important in influencing the dynamics of weed communities. Highest number of weeds observed to grow in the maize fields in the present study was attributed to its long cycle and slow growth of the crop during the early stages, while the lowest number of species in linseed field was perhaps, due to its short cycle and rapid growth and to effective hoeing practices in this field.

The species composition of the soil seed bank depends on many factors such as seed input, seed output (loss) and the changes that take place in soil-seed environment during burial. In the present study, only a small number of weed species could be identified from the soil seed bank upto generic level, while majority of them could not be identified and were kept under unidentified group. There was a striking similarity between the species composition of the soil seed bank and weed flora, which depicts that weed seed bank in soil and weed flora composition are intimately linked. However, a few weeds (e.g. E. riparium, M. pudica and Polygonum sp.) though present in the soil seed bank of certain crop fields, were absent from the weed flora of the respective fields. Such weeds which appear in the soil seed bank but not in the weed flora probably produce seeds that are long-lived but dormant as argued by Robinowitz (1981) and Robinowitz et al. (1980).

Weed seed population in soil was generally largest after the seed rain depicting that seed rain is the most important source of weed seed input to the crop fields. The contribution of seed rain to the soil seed bank depends upon the seed production by the plants and the prevailing environmental factors which influence seed input into the crop fields. In the terrace fields where crop sowing was done by dibbling, the soil seed bank was much smaller compared to the fields where sowing was done after tilling the land. It appears that in the former type of terrace fields, the weed seeds were mostly present on the soil surface and could not reach the deeper soil layers and thus, were more vulnerable to losses through run-off water compared to the other type of terrace fields.

The size of the buried viable seed populations at Upper Shillong and Barapani (Table 5.7) were comparable with the available data from other tropical and sub-tropical areas (Table 5.6 and 5.7). However, the buried seed population in the 'Jhum' fields at Upper Shillong was much larger compared to that in the 'jhum' fields at Byrnihat reported by Saxena (1981).

Table 5.6 - Range of seed population (seed density m^{-2}) in soil seed bank of different crop fields located in the temperate region.

Location	Crop/Arable soil	Total seed population	Viable seed population	Author(s)
Woburn	Barley	31000-358000	-	Brenchley & Warington (1930)
Rothamsted	Wheat	3600-296000	-	-do-
Wellesbourne	Arable	22900	-	Roberts (1958)
Hampshire	-do-	52000	-	Roberts (1963)
WArwickshire	-do-	38000	-	-do-
Yorkshire	-do-	15000	-	-do-
Great Britain	-do-	-	1600-86000	Roberts & Strokes (1966)
Denmark	-do-	-	4000-80000	Jensen (1969)
Denmark	-do-	-	600-496000	-do-
English Midland	-do-	-	1800-67000	Lockett & Roberts (1976)
British Honduras	-do-	-	7623	Kellman (1974)
Warwick, U.K.	Vegetable crop	-	1270-65580	Roberts & Ricketts (1974)
WRO, Oxford, England	Arable	-	6600	Howe & Chancellor (1983)
-do-	-do-	-	5700	-do-
Sussex, England	-do-	-	6770	Graham & Hutchings (1988)
South Perth, Australia	Wheat/Lupin	134-13539	14-8145	Chaem (1988)

Table 5.6 (Contd.)

Location	Crop/Arable soil	Total seed population	Viable seed population	Author(s)
South Perth, Australia	Lupin/Wheat	59-2707	17-1896	Chaem (1988)
Darwin, Australia	Arable	1898-12000	475-1680	Lonsdale et al. (1988)
Wyoming, USA	Zea mays - Sugarbeet - Pint beans	2060-14094	571-2928	Ball & Miller (1989)

Table 5.7 - Available data on viable seed population (seed density m^{-2}) in tropical agricultural soils.

Location	Crop field	Depth of sampling (cm)	Viable buried seed population	Author(s)
Belize	Pasture and cropped field	0.0-4.2	6497	Miege & Tehoume (1963)
Senegal	Cropped field	Intermediate	6350	-do-
Philippines	Lowland rice	0-15	80,000	Vega & Sierra (1970)
Belize	Cropped field	0-4.2	7600	Kellman (1974)
Malaysia	Cropped field	-	70-630	Wee (1974)
Java	Rice	0-10	20,000	Hayashi *et al.* (1978)
Belize	Maize	0-10	9800	Kellman (1978)
Byrnihat (Meghalaya)	4 yr Jhum cycle cropped field	0-5	87-213	Saxena (1981)
-do-	6 yr Jhum cycle cropped field	0-5	68-173	-do-
-do-	10 yr Jhum cycle cropped field	0-5	37-85	-do-
-do-	20 yr Jhum cycle cropped field	0-5	38-97	-do-

Table 5.7 (Contd.)

Location	Crop field	Depth of sampling (cm)	Viable buried seed population	Author(s)
Shillong (Meghalaya)	Crop fields under Jhum cultivation	0-20	4322-40234	Present study
-do-	Crop fields under terrace cultivation at CPRS farm.	0-20	394-32048	-do-
-do-	Crop fields under terrace cultivation at ICAR farm.	0-20	625-12898	-do-

The seasonal changes in the soil seed bank seems to be related to the prevailing environmental conditions. The decline in the soil seed bank during the wet summer season indicates that a larger fraction of the seed population germinated during this period owing to favourable temperature and moisture regimes. On the contrary, low soil temperature and inadequate moisture regime during the winter months prevented emergence of weeds to a greater extent whereby the soil seed bank was large during this period even though the weed seed input was low. This view finds uspport from the works of Roberts & Feast (1970) and Montegut (1975). Stoller & Wax (1973) and Vincent & Cavers (1978) reported that sufficient rainfall can cause the germination of weed seeds buried at different soil depths. Roberts & Potter (1980) concluded that the time of year at which the soil is disturbed, also affects the species composition of the weed flora as the seeds present in deeper layers of soil get chance to come on the surface where they get favourable conditions for germination.

The physical condition of the surface soil also affects the emergence of weed seedlings. Significantly ($P<0.01$) greater number of seedlings emerging during the cropping period could be ascribed to the favourable conditions induced by soil tillage and hoeing practices during cropping, as also reported by Bubler & Oplinger (1990). The land lying fallow for long periods, when cultivated, gave rise to large population of weed seedlings confirming that cultivation brings many of the deeply buried seeds to surface layers of the soil and exposed them to light (Wesson & Wareing, 1969a; 1969b) or to greater diurnal fluctuation of temperature (Stoller & Wax, 1973; Thompson et al. 1977) which helped them in overcoming dormancy. Thus the crop fields where disturbance was more intensive, the ratios of seedlings to viable seeds were greater. Holm (1972) suggested that when buried seeds are brought near the surface soil by cultivation or by other means, they lose volatile inhibitors contained in them and germinate. The smaller number of weed seedlings emerging from the buried viable seed bank during fallow periods, as observed in the present study, could be ascribed to the reasons mentioned above. The data indicates that the canopy cover of a crop also regulates the emergence of weeds. The greater the canopy cover, least is the emergence and opposite becomes true when canopy cover is less.

CHAPTER VI

Source of weed seed input to the crop fields and composition of soil weed seed bank and weed flora under 'Jhum' and terrace cultivation.

INTRODUCTION

Weed seeds enter into the crop fields through seed rain, wind, birds, contaminated crop seeds, manure, irrigation water, machinery and farm tools (Skroach & Dana, 1965; Tripathi, 1965; Kelley & Bruns, 1975; Dastgheib, 1989) and influence the size and composition of the soil seed bank. Despite the fact that farmyard manure (FYM) and contaminated crop seeds are considered as the important sources of weed seed input in the crop fields (Klingman & Ashton, 1982), no serious attempt has been made to collect quantitative data on this aspect.

The farmyard manure is the major agricultural input in the labour-intensive shifting agriculture, commonly known as 'jhum' in the tribal dominated state of Meghalaya, india. The crop fields under jhum cultivation are heavily infested by a large variety of weed species, while the crop fields under terrace cultivation are less infested by weeds. In order to understand the role of farmyard manure application and use of contaminated crop seeds as sources of weed infestation, the species composition and density of buried weed seed population were determined before and after the application of FYM, and weed seeds present in the contaminated crop seeds was also quantified. Besides, an attempt has been made to examine the relationship between buried weed seed population and weed flora.

MATERIALS AND METHODS

The study was carried out during 1989-90 in the crop fields under terrace cultivation at ICAR farm at Barapani and at Central Potato Research Station (CPRS) and in the jhum fields at Upper Shillong. The jhum fields were lying fallow for four years before they were brought again under cultivation, while the terrace fields were continuously cultivated during the last eight years with regular use of herbicides, chemical fertilizers and farmyard manure.

The cropping pattern in the area involves cultivation of rainfed summer (March-August) and autumn (September - February) vegetables, cereals and oil seed crops. The crop rotation at the ICAR farm included maize, groundnut and paddy in the summer season and linseed, radish, mustard and dwarf bean in the autumn. At other two sites; potato crop was rotated with cabbage and mixed crops (cabbage + radish) in the autumn season, while during summer season only potato was grown. FYM was applied during summer season to all the crop fields under jhum cultivation, and during both summer and rainy seasons to all the crop fields under terrace cultivation at a rate of 10 tonnes ha^{-1}.

Weed seed production was determined by laying 7 permanent quadrats (50 x 50 m) in cabbage fields under both 'jhum' and terrace cultivation at Upper Shillong and maize fields in both 'terrace-normal' and 'terrace-dibbling' fields at ICAR farm, Barapani during October 1988 to February 1991. All the plants which emerged and matured in these quadrats were harvested. Number of plants in each quadrat, number of fruits per plant and number of seeds per fruit were determined to calculate the seed production by each of the weeds jpresent in the plots.

Twenty soil cores (5.727 cm diameter) down to 20 cm depth were randomly collected from eight different crop fields viz., linseed, maize, mustard and paddy at ICAR farm, maize and potato at CPRS farm and maize and potato under jhum cultivation, before FYM application and at the end of cropping season. The samples collected from each field were mixed, air-dried and passed through 2 mm metallic mesh sieve to remove stones, large roots and litter particles adhering to the soil. Three sub-samples each weighing 100 g of soil were drawn from the mixed soil sample and weed seeds were recovered following the method described by Roberts & Ricketts (1979). The viability of the recovered seeds was tested by using tetrazolium salt (Malone, 1967).

Weed seed populations in the seed samples of linseed

(Linum usitatissiumum L.), maize (Zea mays L.), mustard (Brassica juncea L.) (Czernj & Cosson), paddy (Oryza sativa L.) and potato (Solanum tuberosum L.) were determined by taking 10 samples each of 500 g seeds of each crop. The weed seeds were separated and identified with the help of pre-identified seeds and/or Seed Identification Manual (Martin & Barkley, 1961). The weed seeds were sorted out into viable and non-viable fractions after testing their viability.

Ten samples (500 g each) of the FYM were collected in the polythene bags. These were carefully washed and sieved in the laboratory through a tier of five mesh sieves having pore diameters of 2.0, 1.5, 1.0, 0.7 and 0.5 mm, keeping 2.0 mm mesh sieve on the top and 0.5 mm sieve at the bottom. The recovered seeds were sorted out with the help of a magnifying lens and their viability was tested. The species composition of the weed flora and their density were determined in different crop fields by using quadrat method (Misra, 1968).

RESULTS

Buried weed seed population

The buried weed seed population even before the application of FYM contained a high proportion of viable seeds in different crop fields (Table 6.1). It also varied in both

Table 6.1 - Viable and non-viable buried weed seed population (number (x10^8) ha^{-1} ± Sem) in different crop fields under terrace and Jhum cultivation prior to FYM application (A) and after crop harvesting (B).

Crop field	Viable		Non-Viable	
	A	B	A	B
Terrace Cultivation:				
ICAR Farm:				
Linseed	0.3±0.1 (60)	0.3±0.1 (63)	0.2±0.0	0.2±0.0
Maize	0.7±0.2 (70)	0.7±0.1 (67)	0.3±0.0	0.4±0.0
Mustard	0.3±0.1 (60)	0.3±0.0 (60)	0.2±0.1	0.2±0.0
Paddy	0.7±0.1 (70)	0.7±0.1 (69)	0.3±0.0	0.3±0.0
CPRS Farm:				
Maize	0.8±0.2 (62)	0.8±0.2 (57)	0.5±0.0	0.6±0.0
Potato	0.8±0.0 (67)	0.8±0.0 (63)	0.4±0.1	0.5±0.0
Jhum Cultivation:				
Maize	1.2±0.3 (75)	1.3±0.4 (81)	0.4±0.1	0.3±0.0
Potato	1.6±0.3 (80)	1.6±0.7 (84)	0.4±0.0	0.3±0.0

Values in parentheses represent the percentages of total buried weed seed population.

'jhum' and terrace fields. The number of viable seeds in linseed and mustard fields under terrace cultivation was very low (3 x 10^7 ha^{-1}) compared to potato field under 'jhum' cultivation (16 x 10^7 ha^{-1}). The viable buried seed population in the maize field under jhum cultivation was larger ($P<0.05$) than that under terrace cultivation. The number of non-viable weed seeds, however, was higher in the former. Similar was the case when the potato of 'jhum' cultivation was compared with the potato of CPRS farm. Even under the same type of cultivation, the size of buried weed seed population varied markedly in different crop fields. In general, the total buried weed seed population was much larger in the 'jhum' fields compared to terrace fields. There was no significant difference in the buried seed population when the data obtained before FYM application was compared with that obtained after the crop harvest.

Weed seed input through seed rain

There was a great variation in the seed output between the four important weed species. It also varied significantly ($P< 0.05$) with the type of cultivation. Spergula arvensis and Polygonum alatum produced a significantly ($P<0.05$) greater number of seeds in 'jhum', while Galinsoga ciliata and Ambrosia artemisiifolia showed a reverse trend. Seed population of S. arvensis ranged from 123000 to 1670000 with a mean value

Table 6.2 - Components of fecundity and seed production in four important weeds during 1988-89 and 1989-90 in 'Jhum' and terrace fields at Upper Shillong.

Species	Month/Year	No. of fertile plants m^{-2}		No. of fruits $plant^{-1}$		No. of seeds $fruit^{-1}$		Seed production m^{-2} (x 1000)	
		Jhum	Terrace	Jhum	Terrace	Jhum	Terrace	Jhum	Terrace
S. arvensis	November '88	25±3	53±7	464±183	672±144	24±0.3	24±0.3	278±5	854±9
	May '89	104±23	79±6	576±183	576±183	25±0.3	24±0.3	1498±34	1092±26
	August '89	116±14	-	600±183	-	24±0.3	-	1670±28	-
	November '89	16±2	7±2	866±107	732±132	24±0.3	24±0.3	333±9	123±11
	May '90	52±3	36±3	911±107	808±98	24±0.3	24±0.3	1136±16	598±18
	August '90	69±7	42±5	968±132	692±132	25±0.3	24±0.3	1670±52	698±22
G. ciliata	June '89	23±2	19±2	22±6	23±3	28±4	28±2	14±7	19±30
	November '89	29±3	38±5	22±4	25±4	28±5	29±6	20±7	29±20
	June '90	26±3	21±2	22±2	22±2	28±4	28±4	16±3	13±2
P. alatum	February '89	115±3	37±5	36±2	36±1	19±3	21±3	82±3	31±2
	February '90	78±4	39±3	36±2	36±2	20±2	21±2	56±2	29±2
A. artemisiifolia									
	November '89	8±1	14±1	126±4	91±6	16±0.3	16±1.0	15±2	20±2

± S.e.m.; -, absence of seed setting.

Table 6.3 - Component fecundity and seed production in three important weeds during 1989-90 and 1990-91 in terrace field at ICAR farm, Barapani.

Species	Month/Year	No. of fertile plant m^{-2}	No. of fruits $plant^{-1}$	No. of seeds $fruit^{-1}$	Seed production m^{-2} (x 1000)
R. piolosa	July '89	11±1	266±13	22±0.3	64±11
	July '90	8±1	192±11	23±0.3	35± 4
B. pilosa	September '89	8±2	88±6	36±0.3	24± 2
	February '90	3±1	92±4	35±0.3	9± 2
	September '90	6±1	78±3	35±0.2	16± 3
	February '91	7±1	88±3	36±0.3	22± 4
G. ciliata	June '89	12±2	22±2	28±1	7± 1
	November '89	18±2	22±2	28±2	11± 2
	June '90	21±3	22±2	28±2	13± 1
	November '90	13±2	23±2	28±1	8± 1

± S.e.m.,

Table 6.4 - Total weed seed production (number m^{-2} x 1000) during 1988-89 and 1989-90 in 'Jhum' and terrace fields at Upper Shillong and during 1989-90 and 1990-91 in terrace field at ICAR farm, Barapani.

	Upper Shillong		Barapani
Year	'Jhum'	Terrace	Terrace
1988-89	3405±112	1636±98	-
1989-90	2812±128	1018±62	1023±18*
1990-91	-	-	998±7*

± S.e.m., * represents the pooled means of both categories of terrace cultivation.

of 914636 ± 11289 seeds m^{-2}. The average number of fruits per plant was also quite high (715 ± 17). There was not much variation in the number of seeds per fruit due to the method of cultivation (Table 6.2). The maximum number of fertile plants of *S. arvensis* was observed in the 'jhum' field during August 1989, followed by May 1989. *S. arvensis* showed three phases of seed formation, while *G. ciliata* produced seeds twice in a year and *P. alatum* and *A. artemisiifolia* only once in a year. Number of fruits per plant and number of seeds per fruit of *G. ciliata* did not show much variation between the plants. In case of *A. artemisiifolia*, number of fertile plants was greater in the terrace field (14) than in the jhum field (8). On the contrary, number of fruits per plant was greater in jhum field (126) than in the terrace (91). However, the total seed production was significantly higher in the 'jhum' field compared to terrace field. Seed production during 1988-89 was higher than during 1989-90 (Table 6.4). At ICAR farm, Barapani, too, the total weed seed output was significantly ($P<0.05$) higher during 1989-90 than in the following year (Table 6.4).

Weed seed input through FYM and contaminated crop seeds

Seeds of twenty-seven species were extracted from the samples of FYM. The extracted seeds mostly belonged to the members of grass family such as *Setaria glauca*, *Digitaria* *adscendens*. *Arundinella benghalensis* and *Imperata cylindrica*. Paddy seeds were also found in manure samples in large numbers (Table 6.5). The FYM applied to different farms varied with respect to the number of weed species and weed seed population. *S. arvensis*, *Brachiaria villosa*, and *P. alatum* were recorded in the CPRS farm, while *Ageratum* spp. was restricted only to the crop fields at ICAR farm (Table 6.5). The estimated input of seeds of different species to the crop fields through FYM ranged from 92,000 ha^{-1} in *Borreria hispida* to 1,944,000 seeds ha^{-1} in *Setaria* spp., out of which about 64% were viable. The number of viable seeds of different weed species that entered into the crop fields through FYM was very large compared to those which entered through contaminated vrop seeds.

Seeds of thirteen weed species were reocrded from the crop seed samples. Of these, *Bidens pilosa* and *S. glauca* were present in all the crops except potato. Seeds of *Galinsoga* spp. were also present in the seed samples of all the crops except maize (Table 5.6). Linseed was contaminated by more number (8) of weed species than other crop seed samples. Maize and potato contained seeds of 2 weed species. Linseed was observed to be highly contaminated with mustard and vice-versa (Table 6.6). The soil particles adhering to the potato tubers contained a large number of seeds of *S. arvensis* and *G. ciliata*.

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Table 6.5 - **Estimated input (number $ha^{-1} \times 10^{3}$) of viable and non-viable weed seeds through FYM to different crop fields under terrace and Jhum cultivation.**

Type of cultivation	Weed species	Viable seeds	N[illegible]iable s[illegible]
Terrace cultivation:			
ICAR Farm:	*Ageratum* spp.	812±15.3	352±61
	Ambrosia artemisiifolia	16±3.7	5.6±0.5
	Arundinella benghalensis	262±28	268±72.3
	Borreria hispida	52±22.3	40±13.3
	Fimbristylis sp.	96±22.5	72±13.3
	Eragrostis sp.	80±15.8	48±15.5
	Galinsoga spp.	56±8.8	28±10.4
	Imperata cylindrica	356±62.7	196±27
	Oryza sativa	900±148.4	472±50.5
	Richardsonia piolosa	60±14.9	32±13.1
	Setaria glauca	748±11.9	356±38.9
	Spilanthes paniculata	52±6.4	26±4.2
	Unidentified weeds	192±40.8	152±36.3
CPRS Farm:	*Ambrosia artemisiifolia*	76±17.3	28±8.5
	Brachiaria villosa	204±21	96±12.2
	Digitaria adscendens	52±16.4	48±11.6
	Galinsoga spp.	232±19.6	72±15.5
	Oryza sativa	656±49.8	480±45
	Polygonum alatum	104±13.6	56±12.2

Table 6.5 (Contd.)

Type of cultivation	Weed species	Viable seeds	Non-viable seeds
	Setaria spp.	1336±139.7	608±92.1
	Spergula arvensis	122±44.5	140±32.2
	Unidentified weeds	112±20.5	96±14.8
'Jhum' cultivation:	*Ambrosia artemisiifolia*	24±7.8	20±1.3
	Brachiaria villosa	32±15.8	18±3.4
	Digitaria adscendens	72±47	16±2.9
	Galinsoga spp.	14±2.6	12±1.7
	Polygonum alatum	52±5.8	36±10.7
	Pycreus latispicatus	92±14.1	72±24.4
	Setaria spp.	28±9.7	12±1.9
	Spergula arvensis	84±17.3	84±11.1
	Unidentified weeds	20±5.8	6±0.2

± S.e.m.; n=10.

Table 6.6 - Estimated input (number ha^{-1} ± S.e.m.; n=10) of viable and non-viable weed seeds to different crop fields through contaminated crop seeds.

Crop seed	Contaminated weed	Viable seeds	Non-viable seeds
Terrace cultivation:			
ICAR Farm:			
Linseed	*Brassica juncea*	810±39	165±24
	Bidens pilosa	54±13	30±10
	Galinsoga spp.	18±5	27±5
	Oryza sativa	141±23	81±14
	Setaria glauca	138±27	30±9
	Zea mays	48±9	42±16
	Unidentified weeds	63±8	33±9
Maize	*Bidens pilosa*	42±11	32±6
	Setaria glauca	80±13	46±9
Mustard	*Bidens pilosa*	54±2	30±10
	Galinsoga spp.	22±6	18±5
	Setaria glauca	72±12	24±4
	Linum usitatissimum	54±7	28±7
	Unidentified weeds	32±6	16±6
Paddy	*Ageratum* spp.	180±72	84±26
	Bidens pilosa	444±80	132±38

Table 6.6 (Contd.)

Crop seed	Contaminant weed	Viable seeds	Non-viable seeds
	Brassica juncea	600±76	144±39
	Galinsoga spp.	120±57	168±51
	Setaria glauca	444±44	240±40
	Unidentified weeds	206±53	108±33
CPRS Farm:			
Maize	Setaria glauca	40±6	20±3
	Spergula arvensis	12±2	4±1
*Potato	Galinsoga spp.	2000±1229	1200±854
	Spergula arvensis	3200±1665	800±533
'Jhum' cultivation:			
Maize	Setaria glauca	20±3	20±3
	Spergula arvensis	4±1	4±1
*Potato	Galinsoga spp.	800±759	400±379
	Spergula arvensis	1200±854	400±379

*Weed seed present in the soil particles adhering around the potato tubers.

Composition and density of weed flora

A total of sixteen weed species was recorded from eight different crop fields during peak growth period, out of which *G. ciliata* and *S. glauca* were present in all the fields. The crop fields at ICAR farm was infested with greater number of weed species than those at the CPRS farm and in jhum fields. The weed flora at ICAR farm was also markedly different from those of CPRS farm and jhum fields. However, the weed flora did not show much variation in the different crop fields located at a given altitude or under a particular type of cultivation (Table 6.7).

The peak density of various weeds varied with the crop fields and it was significantly ($P<0.05$) different between jhum and terrace fields. The estimated peak density ranged from 10,000 plants ha^{-1} in *Ageratum conyzoides* to 10,164,000 plants ha^{-1} in *Ageratum conyzoides* to 10,164,000 planta ha^{-1} in *S. arvensis*. The two common species *S. glauca* and *G. ciliata* showed higher density in maize (ICAR) and potato (CPRS) fields, respectively. *P. alatum* showed greater density (6,960,000) in potato field under jhum cultivation. In linseed crop field *B. hispida* and *Spilanthes paniculata* were most frequent weed species followed by *S. glauca*, while in all other crop fields at ICAR farm, *A. haustonianum* was the most frequent species followed by *S. glauca* (Table 6.7). Although relatively fewer

Table 6.7 - Peak seedling density (plant x 10^5 ha^{-1} ± Sem, n=5) and buried viable weed seed population *(seed x 10^5 ha^{-1} ± Sem, n=3; given in parentheses) of different weeds in different crop fields under Jhum and terrace cultivation.

	Terrace cultivation						Jhum cultivation	
	ICAR Farm				CPRS Farm			
Weed species	Linseed	Maize	Mustard	Paddy	Maize	Potato	Maize	Potato
Ageratum conyzoides	0.1±0.0	3.0±0.1	6.3±0.1	0.2±0.0	-	-	-	-
Ageratum haustonianum	3.0±0.1 (25.6±0.0)	34.1±0.4 (371.0±4.8)	12.2±0.6 (52.3±0.0)	8.2±0.1 (56.4±1.3)	-	-	-	-
Ambrosia artemissiifolia	-	0.2±0.0 (2.0±0.0)	-	-	2.6±0.6 (16.5±0.8)	2.1±0.8 (16.1±1.6)	1.8±0.6 (7.8±0.8)	1.5±0.2 (6.5±0.8)
Arundinella benghalensis	0.7±0.1 (6.0±0.8)	7.0±0.1 (86.1±3.4)	4.1±0.3 (39.7±0.0)	1.9±0.2 (10.2±0.0)	-	-	-	-
Bidens pilosa	2.1±0.1 (22.7±0.1)	3.2±0.4 (34.6±0.8)	0.4±0.1 (3.9±0.4)	1.2±0.4 (87.6±1.4)	-	-	-	-
Borreria hispida	4.2±0.2 (50.3±1.6)	2.2±0.4 (31.5±1.6)	0.2±0.0 (1.6±0.3)	0.2±0.0 (0.7±0.1)	-	-	-	-
Emilia sonchifolia	1.8±0.1 (12.6±1.2)	1.7±0.1 (12.4±0.6)	0.2±0.01 (1.4±0.2)	0.1±0.0 (0.8±0.0)	-	-	-	-
Digitaria adscendens	-	-	-	-	1.8±0.0 (9.0±0.4)	0.8±0.0 (4.0±0.0)	0.6±0.0 (4.0±0.0)	0.8±0.0 (8.2±0.0)
Galinsoga ciliata	2.3±0.4 (28.5±0.6)	10.2±2.1 (135.4±6.8)	3.2±0.2 (5.9±0.8)	3.8±0.6 (26.2±1.2)	8.2±2.3 (134.0±6.8)	14.8±1.6 (199.8±12.5)	5.4±0.2 (76.5±3.6)	8.0±1.2 (82.9±6.5)

Contd.

Table 6.7 (Contd.)

	Terrace Cultivation						Jhum cultivation	
	ICAR Farm				CPRS Farm			
Weed species	Linseed	Maize	Mustard	Paddy	Maize	Potato	Maize	Potato
Imperata cylindrica	-	0.3±0.1 (2.2±0.4)	0.4±0.1 (3.5±1.2)	0.1±0.0 (0.5±0.0)	-	-	-	-
Polygonum alatum	-	-	-	-	3.8±0.8 (25.0±1.2)	24.4±2.3 (158.6±12.5)	13.8±3.4 (147.4±5.8)	69.6±3.9 (484.1±10.8)
Pycreus latispicatus	-	-	-	-	0.2±0.0 (0.6±0.0)	0.1±0.0 (0.5±0.0)	0.1±0.0 (0.6±0.0)	0.1±0.0 (0.8±0.0)
Richardsonia pilosa	2.7±0.1 (31.2±0.8)	2.3±0.2 (18.1±1.2)	4.8±1.2 (47.3±3.9)	5.6±0.6 (19.4±0.8)	-	-	-	-
Setaria glauca	3.6±0.1 (44.6±1.2)	8.2±1.0 (79.1±2.2)	7.0±0.6 (70.6±4.3)	7.8±0.3 (33.9±1.6)	0.7±0.1 (6.0±0.6)	0.5±0.1 (3.3±0.4)	2.8±0.6 (10.9±0.8)	2.0±0.02 (10.5±0.6)
Spergula arvensis	-	-	-	-	28.4±2.6 (357.8±13.2)	62.1±17.4 (804.0±18.6)	32.8±6.7 (459.0±13.0)	66.1±13.2 (1016.4±16.2)
Spilanthes paniculata	4.2±0.1 (38.6±3.2)	1.0±0.1 (9.6±0.6)	2.0±0.3 (18.6±1.4)	4.8±0.1 (39.9±3.2)	-	-	-	-
Unidentified weeds	9.2±0.1 (39.9±4.4)	17.6±1.8 (51.6±3.2)	8.3±0.2 (55.2±3.8)	26.4±0.8 (424.3±18.7)	13.6±0.4 (247.1±16.6)	2.8±0.4 (27.6±8.3)	4.2±0.8 (488.4±22.7)	3.2±0.6 (31.9±5.2)

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* Determined at the time of peak seedling population in the crop field.

Population of *Ageratum conyzoides* and *Ageratum haustonianum* were considered together.

\- Indicates species absence.

weed species were present in the CPRS and jhum fields, the total weed density in these fields was much greater than in the ICAR crop fields which had more weed species than CPRS farm and jhum fields.

DISCUSSION

Weeds generally have a high seed output (Salisbury, 1942; Harper, 1957), which helps them in successful colonization (Salisbury, 1978). The luxuriant growth of the weeds and greater number of fertile plants surviving to maturity contributed to the soil seed bank through seed rain.

The viable seed population in soil was strongly related to the past history of the crop fields and method of cultivation. The abandonment of the jhum field for four years before the commencement of cultivation was possibly, responsible for the luxuriant growth of weeds, and large input jof viable seeds into the soil seed bank. Conversely, continuous cultivation for the last eight years with regular use of herbicides and crop rotation in the terraces might have caused reduction in the viable weed seed population in soil.

Presence of large number of viable seeds of several weeds in the farmyard manure suggests that a large proportion of weed seeds which enter the digestive tract of the cattle during grazing, is passed out undamaged. Apart from the members of Poaceae, which are grazed by the cattle with relatively greter ease, presence of seeds of Galinsoga spp. in fairly large numbers, may be attributed to the effective dispersal of these species by wind from the surrounding areas and their deposition in the manure heaps. The seeds recovered from manure samples were mostly those which were present in the weed flora and soil seed bank of the particular crop field. Presence of B. villosa seeds in the soil seed bank and its absence in the surrounding weed flora suggests the infestation of this weed either through FYM or/and contaminated crop seeds. This assumption is also supported by the findings of Atkenson et al. (1934), Harmon & Keim (1934), Stocker et al. (1934) and Dastgheib (1989).

Although a good proportion of viable seeds was added to the crop fields through FYM and contaminated crop seeds, no significant increase was observed in the buried viable seed population at the end of cropping season, possibly due to the conversion of a good percentage of seeds into seedlings during the cropping period. The result suggests that an average of 9% of viable weed seed population was converted to seedlings in an annual cycle. This agrees with the results of Roberts & Dawkins (1967), Roberts (1958, 1981), Wilson et al. (1985)and Ball & Miller (1989). Seed loss could also be due to predation (Roberts, 1970) and surface run-off with sediments from the jhum fields on gentle hill slopes (Toky & Ramakrishnan, 1981).

The dissimilarity in species composition between maize crop fields located at different sites and a close similarity in species composition between jhum and CPRS fields reveal that weed flora, at least in the present study, was neither influenced by the method of cultivation nor by the type of crops. The climatic variations induced by altitude was perhaps more important in determining the weed community composition as is evident from a greater number of weed species found at lower elevation (952 m asl). The restricted distribution of S. arvensis and P. alatum to the crop fields of CPRS farm and in the jhum fields located at higher elevation (1825 m asl) also seems to be related to prevailing climatic conditions.

The application of FYM increased the total viable seed population in soil and caused a higher degree of weed infestation in the crop fields as is evident from significant positive correlations between the viable seed population in soil and the population density of weed seedlings in the crop fields (Fig. 6.1). As observed in the present investigation, greater number of seedlings emerged from the viable seed population in soils of terrace fields, but the total

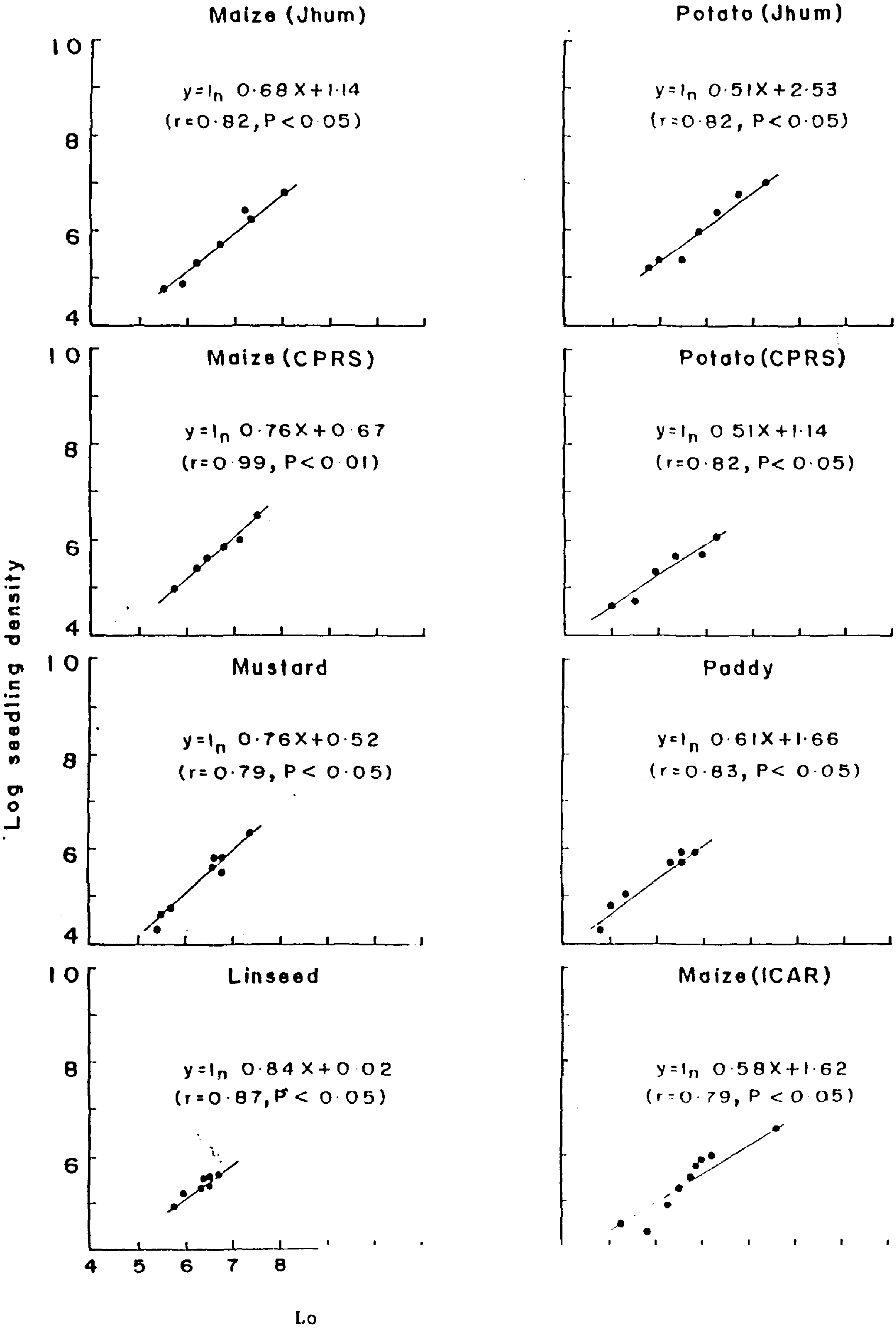

Fig. 6.1. Coefficient of
seed population
and their seedl
under 'Jhum' and

weed density was higher in the jhum than in the terrace fields. This was mainly due to greater proportion of viable seed population in the soil seed bank of jhum fields (Table 5.6). Roberts & Dawkins (1967) reported that in frequently cultivated soils, viable weed seed population decreases more rapidly than in the undisturbed or less disturbed soils. Our findings also suggest that relatively less disturbed jhum fields had larger proportion of viable seeds in soil than the more disturbed terrace fields due to frequent tilling and hoeing. As seen from Table 6.8, terrace cultivation resulted in loss of large number of viable seed population (0.3×10^8 seeds ha^{-1} in ICAR and 0.2×10^8 viable seeds ha^{-1} in CPRS) while jhum cultivation results in a gain of 0.6×10^8 viable seeds ha^{-1}. This was due to greater weed seed input into the jhum field through seed rain during the cropping season owing to minimal weeding operation. The loss in the terrace field could be attributed to greater seedling emergence and lower seed input through seed rain (Misra et al. 1992).

During an annual cycle there was a net gain of 2% in the viable buried weed seed population in terrace fields compared to 5% in jhum fields (Table 6.8). About 26% of the existing weed seeds in soil was attributed to FYM application, while the contaminated crop seeds contributed only 0.01%. Although FYM considerably improves soil condition by changing

Table 6.8 - Average populations (number ha^{-1} ± S.e.m.) of viable and non-viable weed seeds, total seed input through seed rain, FYM and contaminated crop seeds and total seedling emergence in terrace and 'Jhum' fields during March 1989 to February 1990.

Parameter	Terrace Cultivation				Jhum Cultivation	
	ICAR Farm		CPRS Farm			
	Viable	Non-viable	Viable	Non-viable	Viable	Non-viable
Buried weed seed population before FYM application (x10^8) (a)	0.50±0.05	0.45±0.03	0.8±0.04	0.45±0.03	1.25±0.3	0.55±0.05
Seed input through seed rain (x10^8)	88±7.8	14±2.2	122±9.8	41±3.2	285±11.2	56±4.6
Seed input through FYM (x10^3)	3682±111	2038±93	2894±58	1624±103	418±16	276±13
Seed input through contaminated crop seeds	906±30	3370±30	2626±144	1012±103	1012±72	412±30
Total buried seed population (x10^8)	885±33	146±3	228±30	415±7	2851±82	566±23
Seedling emergence (x10^5)	58.5±3.0	-	83.4±2.2	-	106.4±3.2	
	(10.83)		(10.04)		(8.51)	
Buried seed population after crop harvesting (x10^8) (b)	0.51±0.04	0.26±0.01	0.81±0.02	0.55±0.1	1.31±0.3	0.3±0.03
Net gain/loss in soil seed bank (x10^8)	+0.01	+0.11	±0.01	-0.19	+0.06	-0.25
(b) - (a)	(+2)	(+22.2)	(+1.3)	(-42.2)	(+4.8)	(-45.5)

Values in parentheses are percentages of the viable buried seed population.

its physical and chemical properties, it also contributes substantially to the buried seed population and acts as a major source of weed infestation in the crop fields. The weed infestation through crop seeds is less alarming in this region, yet the contaminated crop seeds must be made free from weed seeds before sowing in order to minimize the severity of weed infestation.

CHAPTER VII

Fate of buried seed population of four annual weeds in potato fields under 'Jhum' and terrace cultivation.

INTRODUCTION

Buried seeds of annual weeds show a cyclic change in their dormancy behaviour (Baskin & Baskin, 1985) which is regulated by a number of soil conditions such as light (Black, 1969), temperature (Mukherjee *et al*., 1980; Baskin & Baskin, 1984), moisture (Schafter & Chilcote, 1970), oxygen supply (Russel, 1961; Wesson & Wareing, 1967), pH (Ellenberg, 1950), CO_2 level (Popay & Roberts, 1970) and soil texture (Hay, 1962). The objective of this study was to examine the effects of some of these factors on the behaviour of buried seed population of four annual weed species viz., *S. arvensis* L., *G. ciliata* (Rafin) Blake, *P. alatum* Ham. and *A. artemisiifolia* in potato crop fields under two contrasting types of cultivation widely practiced in Meghalaya.

MATERIALS AND METHODS

Twenty soil cores (5.727 cm diameter x 20 cm depth) were collected from each crop field at monthly intervals between October 1988 to September 1990. These were brought to the laboratory and cut horizontally into four soil layers corresponding to four different soil depths and were processed as described in Chapter IV of the thesis. From the pooled soil sample corresponding to each depth, 6 replicates of 100 g soil samples each were analysed for each of the two crop fields. Three replicates were used for determining the total viable buried seed (Vt) following the method outlined by Roberts & Ricketts (1979). The viability was determined by using 0.1% tetrazolium salt (Malone, 1967). The other three replicates were spread uniformly in plastic petri dishes (10.5 x 1.5 cm), watered and kept in a seed germinator at an alternating temperature of 30 and 7° C (12 hrs at each temperature) maintaining a 12 h photoperiod. Seedlings emerging in the petri dishes were identified and counted daily. After the cessation of germination, soil was again assessed for the remaining viable seeds in the sample. The number of seedlings was considered equivalent to the number of seeds in the state of enforced-dormancy (ED) at the time of recovery, while ungerminated viable seeds were grouped into induced-dormant (ID) fraction. The degenerated and empty seeds were put into the category of dead (D) seeds. The germinable (G) fraction was estimated by subtracting the number of seeds under enforced and induced dormancy from the total viable seeds in soil. At each sampling date soil temperature, soil moisture, pH and CO_2 evolution were determined at different soil depths. CO_2 evolution was measured according to Macfadyen (1970).

Correlation analysis was carried out to see how the different fractions of the buried seed population are related to the ecological parameters of the soil seed environment. F test was applied to test the significance of variations in the above parameters due to the method of cultivation.

RESULTS

Spatial and temporal variation in soil conditions

Soil temperature and moisture were higher in the surface layer declining gradually with increasing soil depth (Table 7.1). Soil moisture and soil temperature in both 'jhum' and terrace fields decreased during winter season and increased during rainy season (Fig. 7.1 and 7.2, Table 7.1). Soil temperature and CO_2 evolution were relatively higher in the 'jhum' field compared to the terrace field, while the soil moisture was higher in the latter. CO_2 evolution in both the fields increased with increasing soil depth and was always higher during winter season compared to other seasons (Fig. 7.3 and Table 7.1). Soil temperature and moisture and CO_2 evolution showed relatively higher value during 1989-90 than during 1988-89. pH did not show any seasonality through depth and year.

Vertical distribution of seeds in soil

The germinable seed population of all the four weeds

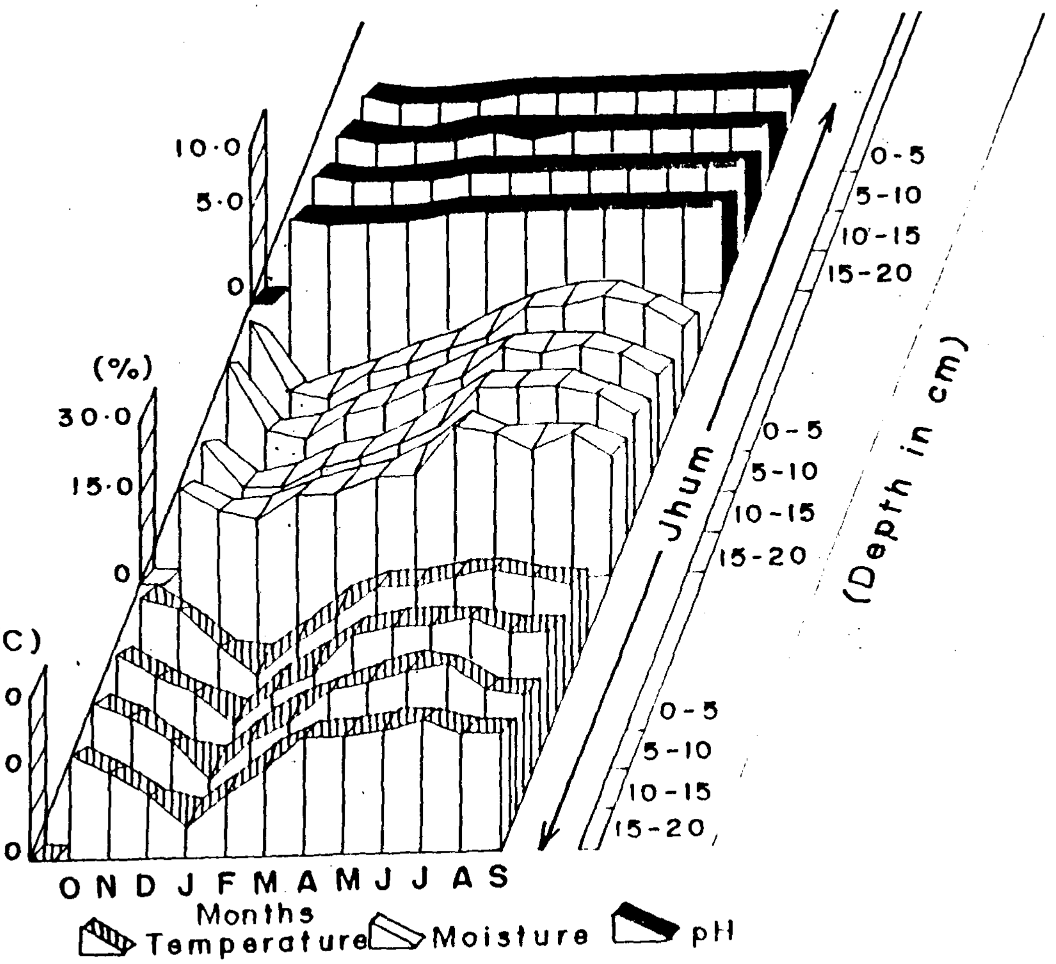

Fig. 7.1. Monthly variation in soil temperature, moisture and pH at four different soil depths in potato field under 'Jhum' cultivation at Upper Shillong during October 1988 to September 1989.

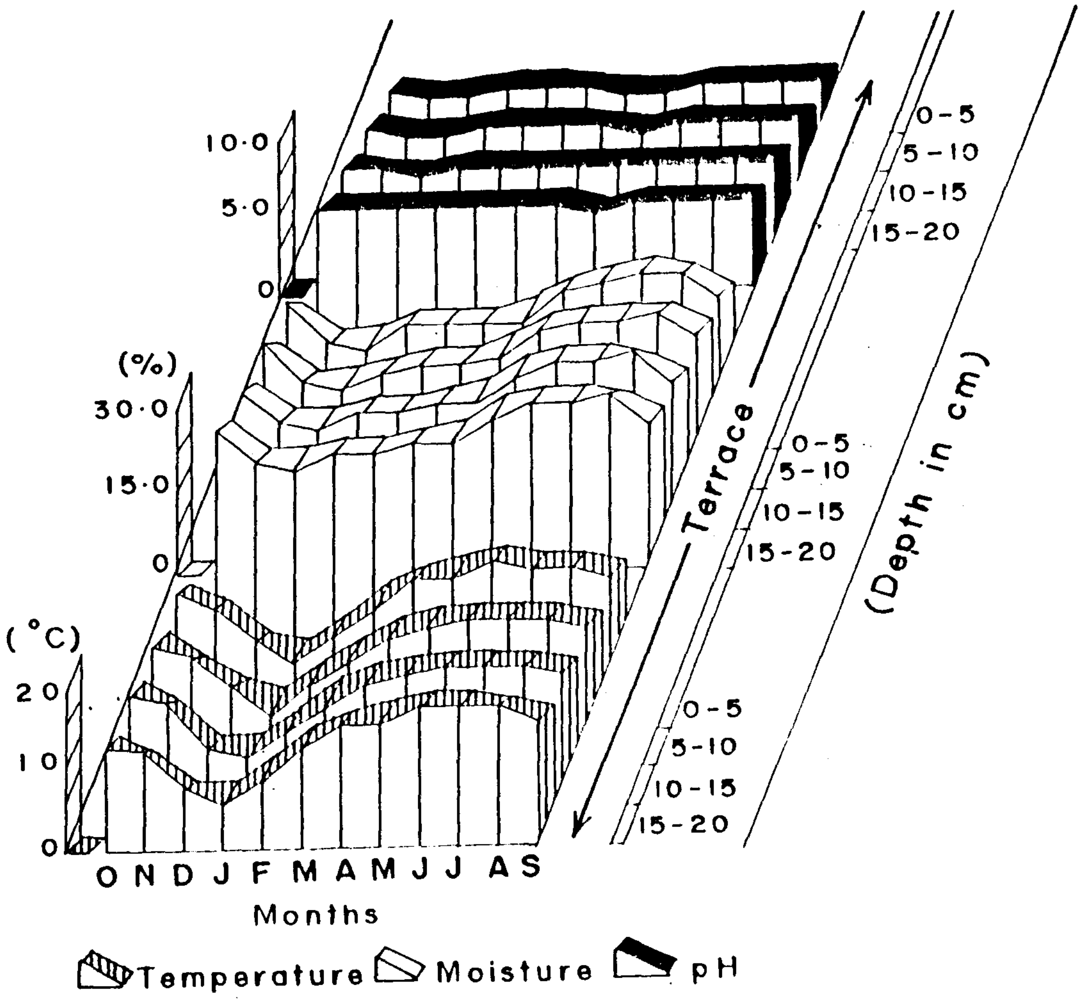

Fig. 7.2. Monthly variation in soil temperature, moisture and pH at four different soil depths in potato field under terrace cultivation at Upper Shillong during October 1988 to September 1989.

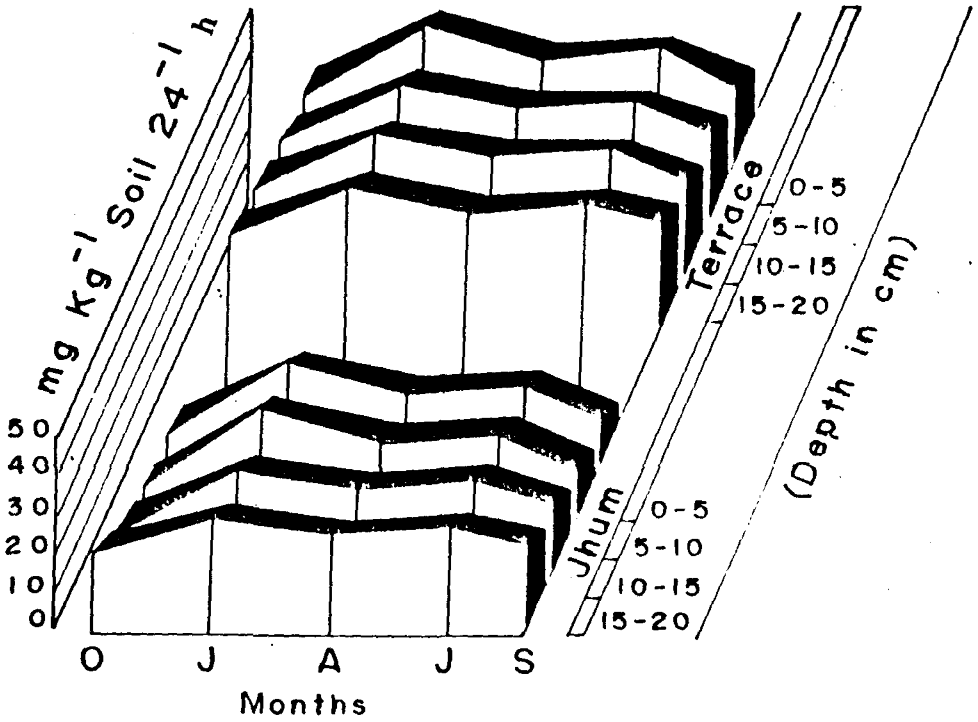

Fig. 7.3. Monthly variation in CO_2 evolution rate at four different soil depths in potato fields under 'Jhum' and terrace cultivation at Upper Shillong during October 1988 to September 1989.

Table 7.1 - Seasonal variation in soil temperature, soil moisture, pH and CO_2 evolution at different soil depths in 'Jhum' and terrace fields at Upper Shillong during October 1989 to September 1990.

Season	Depth (cm)	'Jhum'				Terrace			
		Temperature (°C)	Moisture (%)	pH	CO_2 evolution (mg kg^{-1} 24h^{-1})	Temperature (°C)	Moisture (%)	pH	CO_2 evolution (mg kg^{-1} 24h^{-1})
Winter	0-5	9.4	15.8	5.3	36.2	10.2	19.8	5.5	32.4
	5-10	8.2	18.4	5.4	38.8	8.6	22.6	5.4	34.2
	10-15	6.0	14.9	5.3	40.6	6.2	18.0	5.5	36.3
	15-20	5.4	16.7	5.5	48.0	5.8	19.6	5.5	40.4
Spring	0-5	19.6	20.8	5.6	32.0	20.0	24.2	5.5	28.0
	5-10	18.8	21.0	5.7	34.0	19.2	23.8	5.5	30.0
	10-15	16.4	20.4	5.5	38.8	17.0	24.0	5.4	31.2
	15-20	14.2	20.2	5.6	37.2	14.6	23.4	5.5	33.2
Rainy	0-5	21.4	26.8	5.5	34.2	21.2	30.2	5.6	32.0
	5-10	20.8	28.4	5.5	36.0	20.2	32.4	5.5	32.2
	10-15	18.2	28.7	5.6	38.2	18.0	32.6	5.5	34.4
	15-20	17.0	24.9	5.5	41.2	17.6	28.0	5.5	36.4
Autumn	0-5	18.2	23.4	5.7	23.0	18.4	25.2	5.3	21.0
	5-10	16.8	24.2	5.5	25.0	17.0	26.0	5.4	23.0
	10-15	14.4	24.6	5.5	26.4	14.8	24.8	5.4	23.8
	15-20	13.0	24.2	5.5	28.0	13.6	26.6	5.5	24.4

declined with increasing soil depth in both 'jhum' and terrace fields (Fig. 7.4 to 7.8); their number being greater in the latter. The proportion of seeds under enforced dormancy, however, increased with depth down to 15 cm, and beyond this depth it declined (Fig. 7.4 to 7.8). The population of seeds that were in the state of induced-dormancy gradually increased with increasing soil depth, however, difference due to depths was significant ($P < 0.01$) only in the case of P. alatum and A. artemisiifolia (Fig. 7.7 and 7.8). The proportion of non-viable seeds was also higher in lower layers of soil than in the surface layers in both 'jhum' and terrace fields.

Seasonal variation in soil seed bank

The number of germinable seeds showed three peaks (in October, April and July) in S. arvensis, two (in November and June) in G. ciliata and only one (in June) in P. alatum and A. artemisiifolia. This trend was broadly similar in both types of crop fields and in both years of study. S. arvensis seeds which were in the state of enforced dormancy did not show marked seasonal variation in the 'jhum' field, but in the terrace field, their proportion was higher during winter months (Fig. 7.4). In other three species the population of seeds under enforced dormancy was larger during rainy season in both the crop fields. The number of seeds of S. arvensis under enforced dormancy during 1989-90 showed a

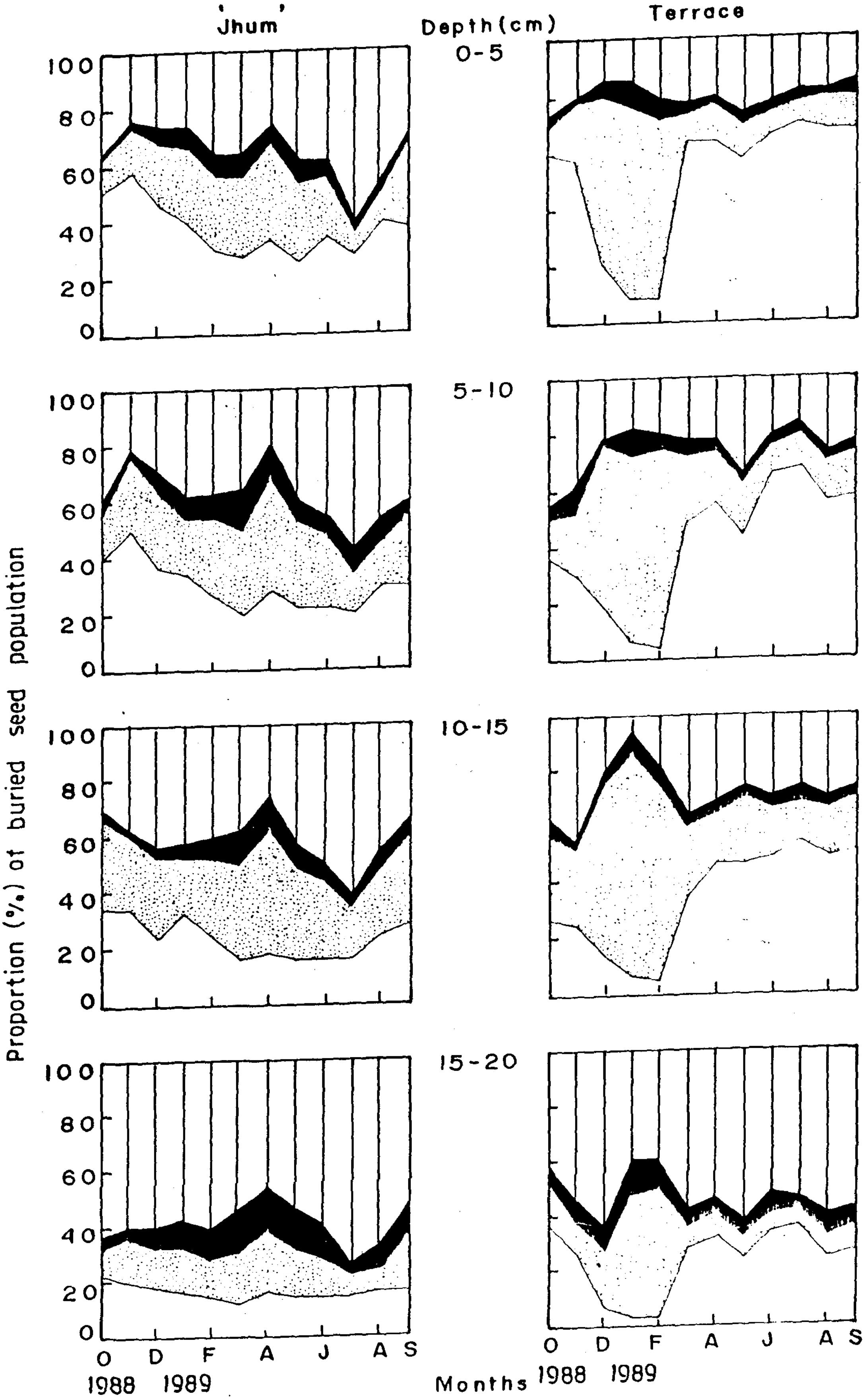

Fig. 7.4. Monthly variation in the proportion of different fractions of buried seed population of *S. arvensis* in potato field under 'Jhum' and terrace cultivation during October 1988 to September 1989. ☐, germinable; ░, enforced-dormant; ■, induced-dormant; ▥, dead fraction of the buried seed population.

Table 7.2 - **Seasonal variation in the proportion of different fractions of the buried seed population of *S. arvensis* at different soil depths in 'Jhum' and terrace fields at Upper Shillong during October 1989 to September 1990.**

Season	Depth (cm)	'Jhum'				Terrace			
		G	ED	ID	D	G	ED	ID	D
Winter	0-5	47.5	23.5	5.6	23.3	27.2	53.0	5.7	13.9
	5-10	40.7	26.3	4.9	28.0	23.2	55.8	3.5	17.3
	10-15	32.6	26.2	4.6	36.6	20.4	62.4	3.6	13.5
	15-20	20.3	16.0	7.3	56.3	13.2	33.8	8.6	44.3
Spring	0-5	34.1	32.2	11.3	22.3	67.1	12.9	2.7	17.3
	5-10	27.9	35.7	11.7	24.6	55.8	19.8	3.2	21.7
	10-15	21.1	39.7	10.7	28.5	44.5	24.4	3.0	28.4
	15-20	18.9	19.1	11.9	57.5	32.9	8.9	6.8	49.4
Rainy	0-5	36.8	21.7	7.4	40.8	69.2	11.4	3.6	15.1
	5-10	28.3	23.6	8.3	42.3	62.3	14.9	2.7	21.1
	10-15	24.6	27.9	8.3	41.7	52.9	19.6	3.4	24.1
Autumn	0-5	56.0	13.3	0.9	29.7	64.0	11.2	3.0	21.8
	5-10	43.5	16.4	2.5	37.5	40.4	14.3	3.6	21.6
	10-15	37.5	33.6	3.0	24.8	29.4	30.3	4.9	15.4
	15-20	25.7	11.0	3.0	60.3	40.5	16.4	5.2	37.8

G - germinable, ED - enforced-dormant, ID - induced-dormant, and D - dead fraction of buried seed population.

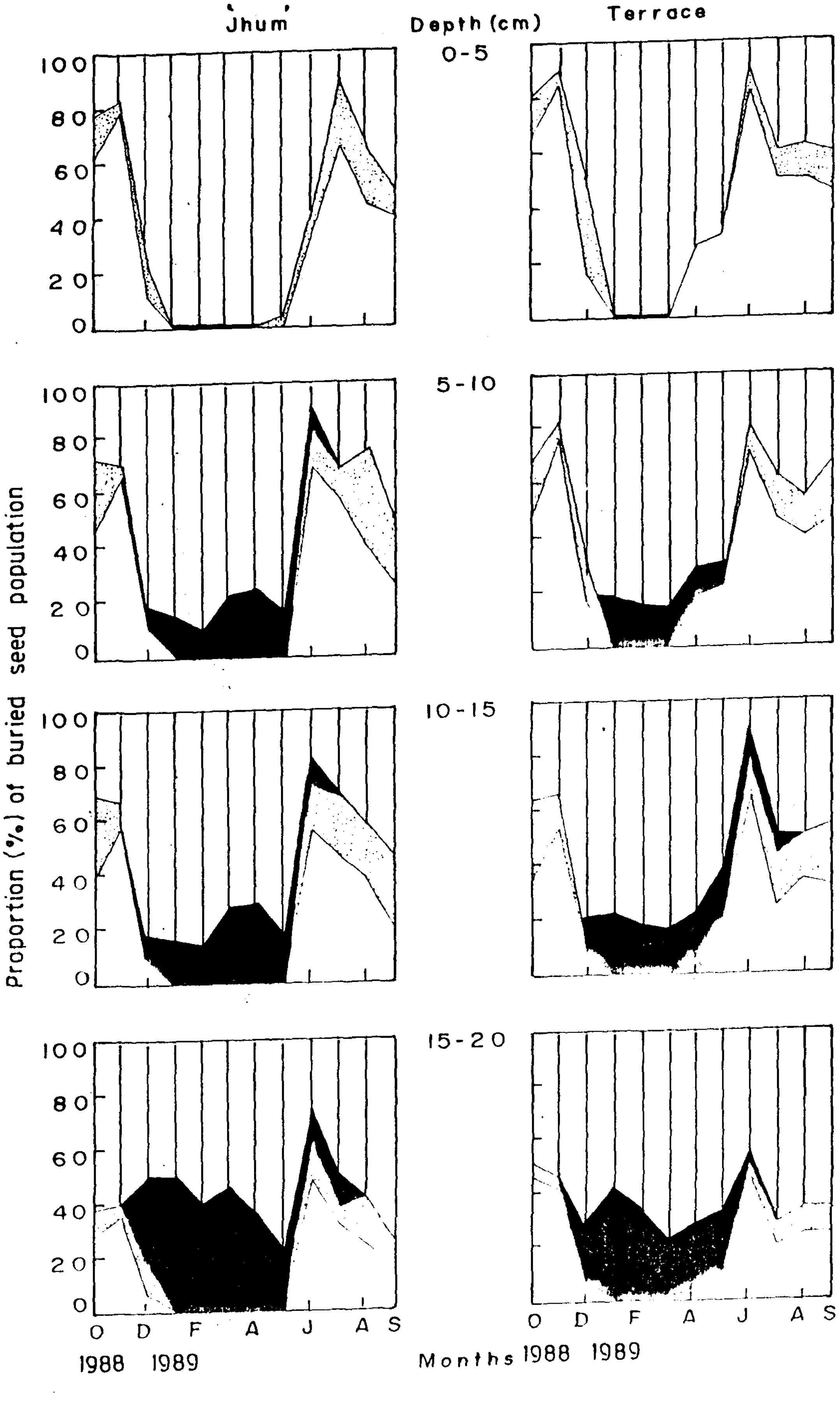

Fig. 7.5. Monthly variation in the proportion of different fractions of buried seed population of G. ciliata in potato field under 'Jhum' and terrace cultivation during October 1988 to September 1989. Key as in Fig. 7.4.

Table 7.3 - Seasonal variation in the proportion of different fractions of the buried seed population of *G. ciliata* at different soil depths in potato crop fields under 'Jhum' and terrace cultivation at Upper Shillong during October 1989 to September 1990.

Season	Depth (cm)	'Jhum' G	'Jhum' ED	'Jhum' ID	'Jhum' D	Terrace G	Terrace ED	Terrace ID	Terrace D
Winter	0-5	23.8	0.8	1.2	74.1	26.3	9.6	1.2	62.9
	5-10	19.7	0.8	8.6	70.9	24.4	4.2	11.5	59.8
	10-15	17.4	2.6	10.8	69.2	16.5	3.2	14.6	65.7
	15-20	11.8	1.7	32.5	51.9	12.7	6.8	26.0	54.5
Spring	0-5	-	-	1.4	98.6	14.4	-	1.1	84.5
	5-10	-	-	23.9	76.1	10.3	-	9.5	80.1
	10-15	-	-	29.5	70.4	4.4	-	1.8	77.6
	15-20	-	-	42.5	57.5	3.1	-	23.5	68.5
Rainy	0-5	46.7	10.7	1.1	41.5	52.5	8.8	1.0	36.2
	5-10	39.2	15.5	7.2	37.9	45.4	11.8	1.0	41.8
	10-15	33.0	21.7	8.6	36.7	36.1	13.8	4.5	45.6
	15-20	24.9	9.9	10.6	54.6	25.8	4.8	6.2	63.2
Autumn	0-5	59.5	32.8	1.2	16.4	66.8	16.3	-	16.9
	5-10	42.3	36.4	1.3	20.0	48.2	19.4	-	32.3
	10-15	37.6	41.3	1.4	19.6	37.6	28.5	-	33.9
	15-20	21.5	7.3	1.4	69.8	46.3	5.9	-	47.7

G - germinable, ED - enforced dormant, ID - induced dormant, and D - dead fractions of the buried seed population.

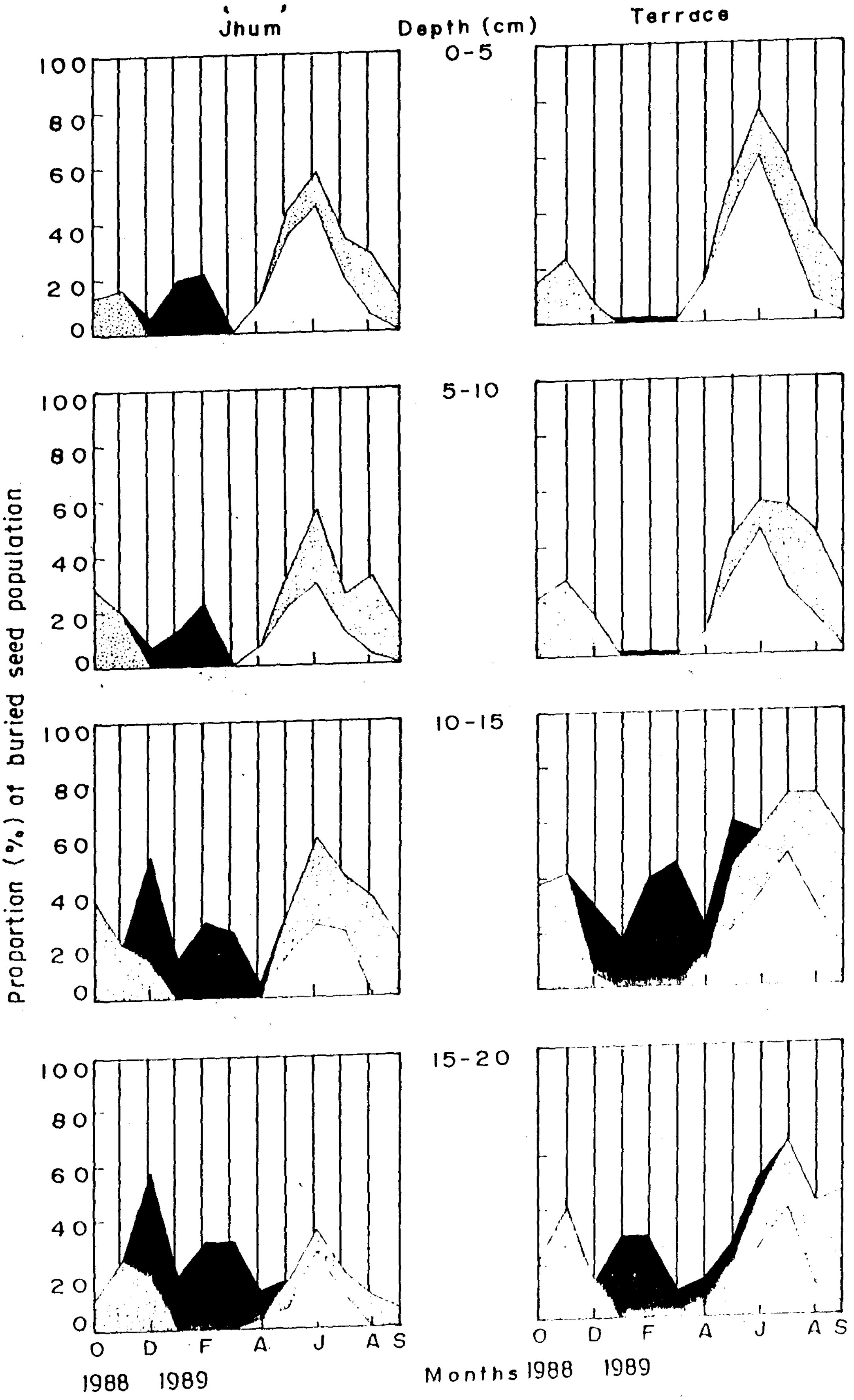

Fig. 7.6. Monthly variation in the proportion of different fractions of buried seed population of P. alatum in potato field under 'Jhum' and terrace cultivation during October 1988 to September 1989. Key as in Fig. 7.4.

Table 7.4 - Seasonal variation in the proportion of different fractions of the buried seed population of *P. alatum* at different soil depths in potato fields under 'Jhum' and terrace cultivation at Upper Shillong during October 1989 to September 1990.

Season	Depth (cm)	'Jhum'				Terrace			
		G	ED	ID	D	G	ED	ID	D
Winter	0-5	-	3.8	8.2	37.9	-	7.8	2.3	90.1
	5-10	-	4.9	6.9	88.20	-	11.2	2.1	88.5
	10-15	-	8.5	21.9	69.7	-	9.5	16.5	73.9
	15-20	-	11.3	24.8	63.9	-	13.8	17.3	68.9
Spring	0-5	7.7	-	13.3	79.1	8.8	-	2.2	89.1
	5-10	5.5	-	17.9	86.6	5.7	-	2.2	92.0
	10-15	2.0	-	14.7	81.3	6.8	-	35.6	57.6
	15-20	12.5	8.9	-	79.3	20.8	25.0	3.3	52.1
Rainy	0-5	24.1	13.1	-	62.8	31.6	18.6	2.0	47.8
	5-10	16.7	18.6	-	66.1	24.5	22.0	2.0	51.5
	10-15	15.4	21.0	-	59.7	32.0	29.2	5.8	36.8
	15-20	12.5	8.9	-	79.3	20.8	25.0	3.3	52.1
Autumn	0-5	-	13.6	-	86.4	-	16.8	-	83.2
	5-10	-	29.5	-	71.5	-	21.6	-	28.4
	10-15	-	36.6	-	63.4	-	28.6	-	71.4
	15-20	-	11.3	-	88.2	-	21.8	-	78.4

G - germinable, ED - enforced dormant, ID - induced dormant and D - dead fractions of the buried seed population.

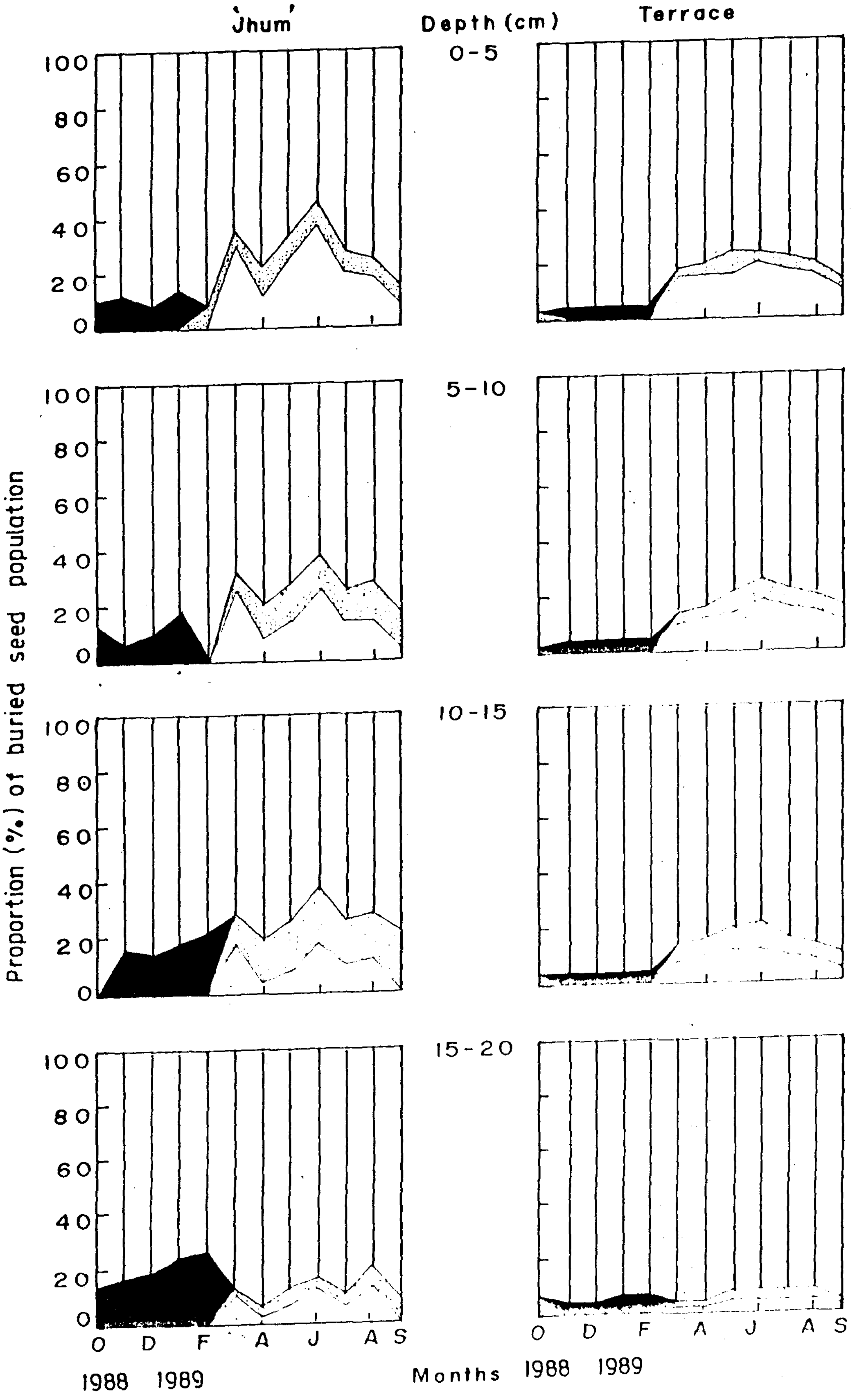

Fig. 7.7. Monthly variation in the proportion of different fractions of buried seed population of *A. artemisiifolia* in potato field under 'Jhum' and terrace cultivation during October 1988 to September 1989. Key as in Fig. 7.4.

Table 7.5 - Seasonal variation in the proportion of different fractions of the buried seed population of *A. artemisiifolia* at four different soil depths in potato fields under 'Jhum' and terrace cultivation at Upper Shillong during October 1989 to September 1990.

Season	Depth (cm)	'Jhum'				Terrace			
		G	ED	ID	D	G	ED	ID	D
Winter	0-5	-	-	12.9	87.1	-	-	7.4	92.6
	5-10	-	-	13.7	86.3	-	-	10.6	89.4
	10-15	-	-	20.1	79.9	-	-	11.0	9.0
	15-20	-	-	22.6	77.4	-	-	14.4	85.6
Spring	0-5	17.3	5.0	-	77.7	41.0	6.8	-	52.1
	5-10	15.2	9.0	-	75.8	31.9	8.8	-	59.2
	10-15	11.4	12.9	-	75.7	23.6	13.8	-	62.6
	15-20	7.3	2.5	-	90.2	20.5	4.4	-	75.1
Rainy	0-5	23.6	9.9	-	66.5	42.4	12.5	-	45.1
	5-10	16.3	12.7	-	70.9	37.6	16.0	-	46.3
	10-15	11.4	18.4	-	70.1	28.2	20.6	-	51.2
	15-20	9.4	5.7	-	84.9	18.6	80.0	-	73.4
Autumn	0-5	-	-	-	100.0	-	5.9	-	94.0
	5-10	-	-	-	100.0	-	6.1	-	93.9
	10-15	-	-	-	100.0	-	11.1	-	88.9
	15-20	-	-	-	84.7	-	13.6	-	86.4

G - germinable, ED - enforced dormant, ID - induced dormant and D - dead fractions of the buried seed population.

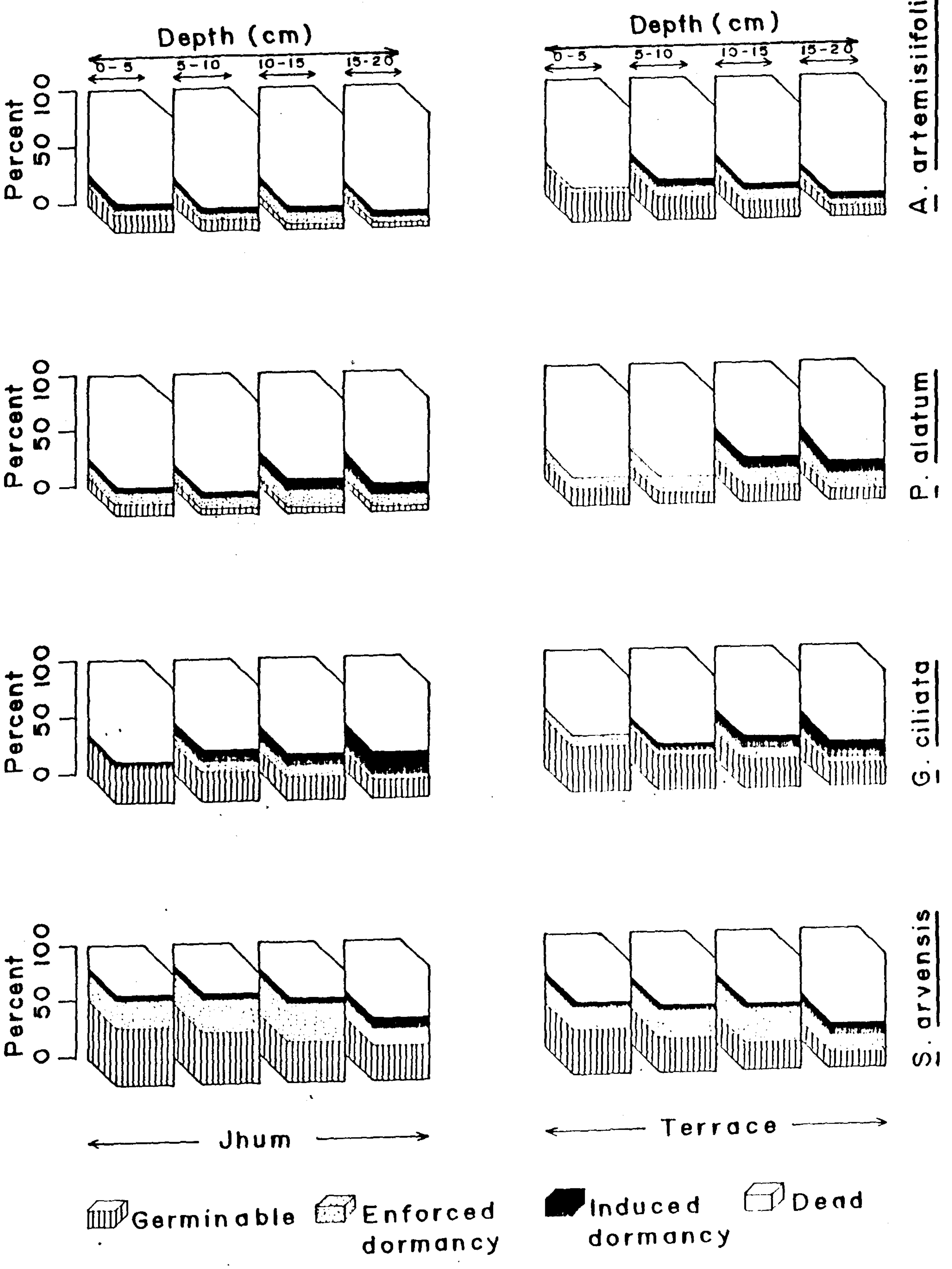

Fig. 7.8. Proportion of the different fractions of buried seed population of four different weed species in potato field under 'Jhum' and terrace cultivation during October 1988 to September 1989. Key as in Fig. 7.4.

Table 7.6 - Proportion of the different fractions of the buried seed population of four different weed species in potato fields under Jhum and terrace cultivation during October 1989 to September 1990.

Species	Depth (cm)	'Jhum'				Terrace			
		G	ED	ID	D	G	ED	ID	D
S. arvensis	0-5	54.7	25.5	4.1	15.6	41.5	23.4	6.0	29.1
	5-10	48.0	29.3	3.1	19.6	33.6	25.9	6.2	34.2
	10-15	40.4	35.6	3.5	20.5	27.8	29.8	6.0	36.4
	15-20	27.2	27.8	7.0	48.0	19.8	15.8	8.8	55.6
G. ciliata	0-5	32.9	6.4	1.9	59.5	38.6	8.2	1.1	52.0
	5-10	26.9	8.9	9.4	54.7	32.8	7.9	5.9	53.3
	10-15	23.1	12.5	11.5	53.0	24.4	9.2	9.8	56.6
	15-20	16.9	5.3	22.4	54.5	19.3	2.8	15.3	52.6
P. alatum	0-5	11.8	7.9	5.9	74.4	15.5	11.7	2.1	70.7
	5-10	8.1	11.7	5.9	73.9	1.2	14.7	2.1	71.2
	10-15	7.6	16.2	11.1	65.1	15.3	17.7	14.0	53.0
	15-20	6.3	8.4	13.0	72.7	10.1	16.8	10.9	62.2
A. artemisiifolia	0-5	14.6	5.0	5.6	74.8	25.3	6.8	3.8	64.0
	5-10	10.8	6.8	5.9	76.6	51.8	8.6	4.9	64.6
	10-15	7.9	9.8	7.0	74.3	16.5	11.8	5.0	66.7
	15-20	6.2	2.8	9.9	81.1	14.0	5.2	6.1	74.7

G - germinable, ED - enforced dormant, ID - induced dormant and D - dead fractions of the buried seed population.

significant ($P<0.05$) increase during rainy and autumn seasons over the corresponding values observed during 1988-89. Seeds of S. arvensis under induced dormancy were recorded throughout the year, while in other species, they were restricted only to winter months. Seed mortality was almost constant throughout the year in S. arvensis, while the other species suffered greater mortality during winter season compared to other seasons (Fig. 7.4 to 7.7).

The proportion of germinable seeds was greater compared to other fractions in soil weed bank (Table 7.6 and 7.8). This was true for all the species in both crop fields and in both years.

Relationship between soil condition and different fractions of the buried weed seed population

The relationship between various soil parameters and different fractions of the buried weed seed population is summarised in Table 7.7. Soil temperature and moisture were positively correlated (Table 7.7) with the germinable fraction of the soil seed bank. Soil temperature showed a positive correlation with the seed population under enforced dormancy in the case of all weeds except S. arvensis. Soil pH had no effect on the germinable seed population of weed species in the 'jhum' field, while it showed a very little effect on the germinable buried seed population of weeds

Table 7.7 - **Correlation coefficient value (r) between the different fractions of the buried seed population with various soil parameters in four weed species under 'Jhum' and terrace cultivation during October 1988 to September 1990.**

Parameters		'Jhum'				Terrace				n
		G	ED	ID	D	G	ED	ID	D	
Soil temperature	Sa	-0.315*	-0.151	0.043	0.286	0.88***	-0.872***	-0.561	0.394	24
	Gc	0.484*	0.463*	0.248	-0.619**	0.606**	0.388	-0.671***	-0.354	24
	Pa	0.534*	0.481*	-0.563**	-0.412*	0.624**	0.59**	-0.243	-0.69***	24
	Aa	0.524*	0.757***	-0.804***	-0.476*	0.762***	0.796***	-0.718***	-0.756***	24
Soil moisture	Sa	-0.392	-0.361	-0.262	0.453	0.65[illegible]***	-0.653***	-0.296	0.229	24
	Gc	0.316	0.504	-0.186	-0.371	0.398	0.423	-0.338	-0.292	24
	Pa	0.603**	0.576**	-0.452*	-0.575**	0.744***	0.449*	-0.084	-0.637***	24
	Aa	0.602**	0.689***	-0.756***	-0 338	0.743***	0.811***	0.752***	-0.772***	24
Soil pH	Sa	0.15	-0.518**	-0.321	-0.263	0.455*	-0.424*	-0.111	0.219	24
	Gc	0.085	0.56**	-0.256	-0.306	0.264	0.478*	-0.309	-0.265	24
	Pa	-0.137	0.3	0.144	0.16	0.229	0.323	-0.17	-0.246	24
	Aa	0.115	0.497*	-0.541**	0.106	0.061	0.262	-0.451	-0.061	24
Soil CO_2 evolution	Sa	-0.364	-0.443	0.426	0.245	-0.104	-0.547*	0.352	0.42	12
	Gc	-0.345	-0.877**	0.815**	0.38	-0.348	-0.631*	0.688*	0.637*	12
	Pa	0.4	-0 701*	0.693**	0.37	0.287	-0.463	0.634*	-0.028	12
	Aa	0.371	-0.185	0.563*	0.451	0.064	-0.505	0.697*	0.104	12

Sa, Gc, Pa, Aa correspond to *S. arvensis*, *G. ciliata*, *P. alatum*, and *A. artemisiifolia*, respectively. *, **, *** significant at P = 0.05, 0.01, 0.001 respectively.

in terrace field. CO_2 evolution was strongly related with the induced dormant fraction of the soil seed bank (Table 7.7).

DISCUSSION

The climatic conditions which regulated germination of weed seeds in soil by altering temperature and moisture conditions in soil-seed environment seem to have played a key role in bringing about seasonal variation in viable seed population in soil. Suppression of germination due to low soil temperature and moisture seems to be the chief cause of accumulation of large number of viable seeds in soil during winter months. Conversely, higher temperature and moisture during rainy season which favoured seedling emergence in large numbers, were responsible for reduction of viable seeds in soil. However, different germination peaks for different species could be attributed to their specific germination requirements. In this respect S. arvensis had a wider ecological amplitude than G. ciliata, P. alatum and A. artemisiifolia.

Seeds of all weed species showed better germination during rainy season and then entered into the state of enforced dormancy during late part of this season. As winter season approached, many of them become induced dormant. In all the species except S. arvensis, seeds held in enforced dormancy during rainy season encountered such conditions during winter season which caused induced dormancy to develop.

Lack of light and low temperature at deeper layers of soil prevented germination by enforcing a higher proportion of seeds to enter into dormant state (Wesson and Wareing, 1967; Black, 1969). This seems to be true in the present study as well, since when the soil samples from the deeper depths were kept under favourable conditions in an incubator, the dormant seeds started germinating. The higher concentration of CO_2 at 15-20 cm soil depth possibly converted some of the enforced-dormant seeds into induced-dormant state, as indicated by a lower proportion of seeds under enforced dormancy at this soil depth. Low soil moisture content during winter months, perhaps, was responsible for degenerating a greater proportion of the viable seeds in soil. This view finds support from the works of Schafter & Chilcote (1970).

Restricted gas exchange during the time when seeds are buried in soil, plays an important role in inducing dormancy. Higher CO_2 evolution in soil during winter season might have prevented the germination of many seeds and induced them into dormancy. Lower proportion of induced-dormant seeds observed in the terrace fields compared to 'jhum' field could also be related to lower rate of CO_2 evolution in the former field than in the latter. This may be attributed to greater soil disturbance in the terrace field due to frequent tillage and hoeing. Conversely, less soil disturbance in the 'jhum' field might be responsible for inducing a larger proportion of seeds under induced-dormant state in deeper soil layers. Significantly higher ($P < 0.05$) proportion of viable seeds in less disturbed 'jhum' field than the more disturbed terrace field indicates that disturbance plays an important role in regulating the size of viable weed seed population in soil. The larger proportion of viable seeds at deeper layers in the terrace field compared to 'jhum' field may be attributed to greater depth of ploughing and higher frequency under terrace cultivation.

It is evident from Table 7.7 that the interaction of soil moisture and temperature maximized the germinability of the buried seed population as these factors reflect a compromise between the ecology and physiology of the buried seed population. The fate of buried seeds does not seem to be influenced by the soil pH but the factors such as CO_2 evolution, soil temperature and soil moisture do exert considerable influence. Among these factors, soil moisture regime affects the germination of buried weed seeds most, and its deficiency imposes enforced dormancy on the buried seeds.

CHAPTER VIII

Effect of weeding frequency on buried weed seed population and its distribution at different depths of soil.

INTRODUCTION

The distribution of weed seeds in soil is an important determinant in the understanding of their population dynamics. The position of these seeds within the soil is likely to influence their emergence and future weed infestation (Kropac, 1966). Seedlings of many weeds have been observed to emerge from the seeds lying at a depth of 0-20 cm (Holroy, 1964; Cousen & Moss, 1990) and such weeds can be successful colonizers (Kozolowski, 1972) and cause considerable loss in agriculture. Cropping practices such as time and method of planting crop type, crop density, crop species and varieties are known to have influence on soil seed bank by regulating the changes in overall level of weed infestation (Fryer & Makepeace, 1977) and in the relative abundance of seed producing species. Although many of the studies in agricultural soils of temperate zones have included the determination of the number of seeds present at different depths of soil (Kropac, 1966; Fekete, 1975; Roberts, 1981), little attention has been paid to the estimation of seed population in tropical soils. Moreover, none of the study has compared the effect of weeding frequency, weed control practices, crop rotation and cultural techniques on the distribution of weed seeds in the arable soil of sub-tropical region of India.

This chapter deals with the effect of weeding frequency on the distribution of buried seed population of four dominant weeds viz., A. artemisiifolia, G. ciliata, P. alatum and S. arvensis as well as total weeds in four different crop fields where potato, radish, cabbage and mixed crops (cabbage-radish) were raised by 'Jhum' and terrace cultivation at Upper Shillong in the state of Meghalaya.

MATERIALS AND METHODS

Weed seed population at different depths of soil was analysed by the procedure described in Chapter IV. The soil sampling frequency and intensity were also same as mentioned in Chapter IV. The seed separation from the samples were made according to Robers & Ricketts (1979) and seed viability was tested by the method suggested by Malone (1967).

In order to study the effect of weeding frequency on viable as well as total soil seed bank, a 4 x 4 m plot was marked in each of the four above mentioned crop fields under 'Jhum' and terrace cultivation and weeding was done at 15 days interval until September 1990. The buried seed population of this plot referred to as the "frequently weeded plot" was compared with the rest of the field where normal weeding opration (2-3 times during a 3-4 month cropping season) was done. The normally weeded fields have been referred to in this thesis as 'less frequently weeded fields'. Change in seed population during 2-year period in frequently weeded fields was computed by subtracting the initial seed population data from the corresponding data recorded at the end of the study.

In the above mentioned crop fields, rainfed potato, radish, cabbage and cabbage + radish (mixed) were rotated with potato and cabbage as secondary and tertiary crops respectively. This cropping pattern was similar under both types of cultivation, but the cultural operations differed markedly in the two (Table 8.1).

RESULTS

Total buried seed population

Total (viable + dead) seed population of *A. artemisiiflora* peaked during winter and showed a depletion with time (Fig. 8.1). *G. ciliata* showed two peaks, one during winter and another during rainy season. In between the two peaks, seed population was very low (Fig. 8.2). *P. alatum* peaked during winter. It also showed another peak during rainy season but only in the terrace field where the mixed cropping was done (Fig. 8.3). *S. arvensis* peaked thrice i.e., in winter,

Table 8.1 - **The agronomic practices followed in 'Jhum' and terrace fields at the study sites.**

Cultural operation	'Jhum'	Terrace
Cultivation method	Hand spading	Hoeing
Plough design	Mid board plough	Thin board plough
Skill of operation	Manual	Mechanical
Depth of ploughing/ Soil inversion	0-15 (cm)	0-20 (cm)
Weeding operation	Manual hand weeding twice in a cropping season.	Manual hand weeding and mechanical weeding thrice in a cropping season.
Application of farmyard manure	10 tonnes ha^{-1} only during summer season crop.	10 tonnes ha^{-1} at the beginning of each summer and rainy season crops.
Application of chemical fertilizer	Nil	N-60 kg; P-80 kg; K-40kg ha^{-1} at the beginning of each summer and rainy season crops.
Herbicide application	Nil	Spread at seedling and vegetative growth stages of crop plants.
Harvest operation	Manual (hand spading) down to 15-25 cm depth in root crops and potato.	Manual (hoeing) down to 15-20 cm depth in root crops and potato.

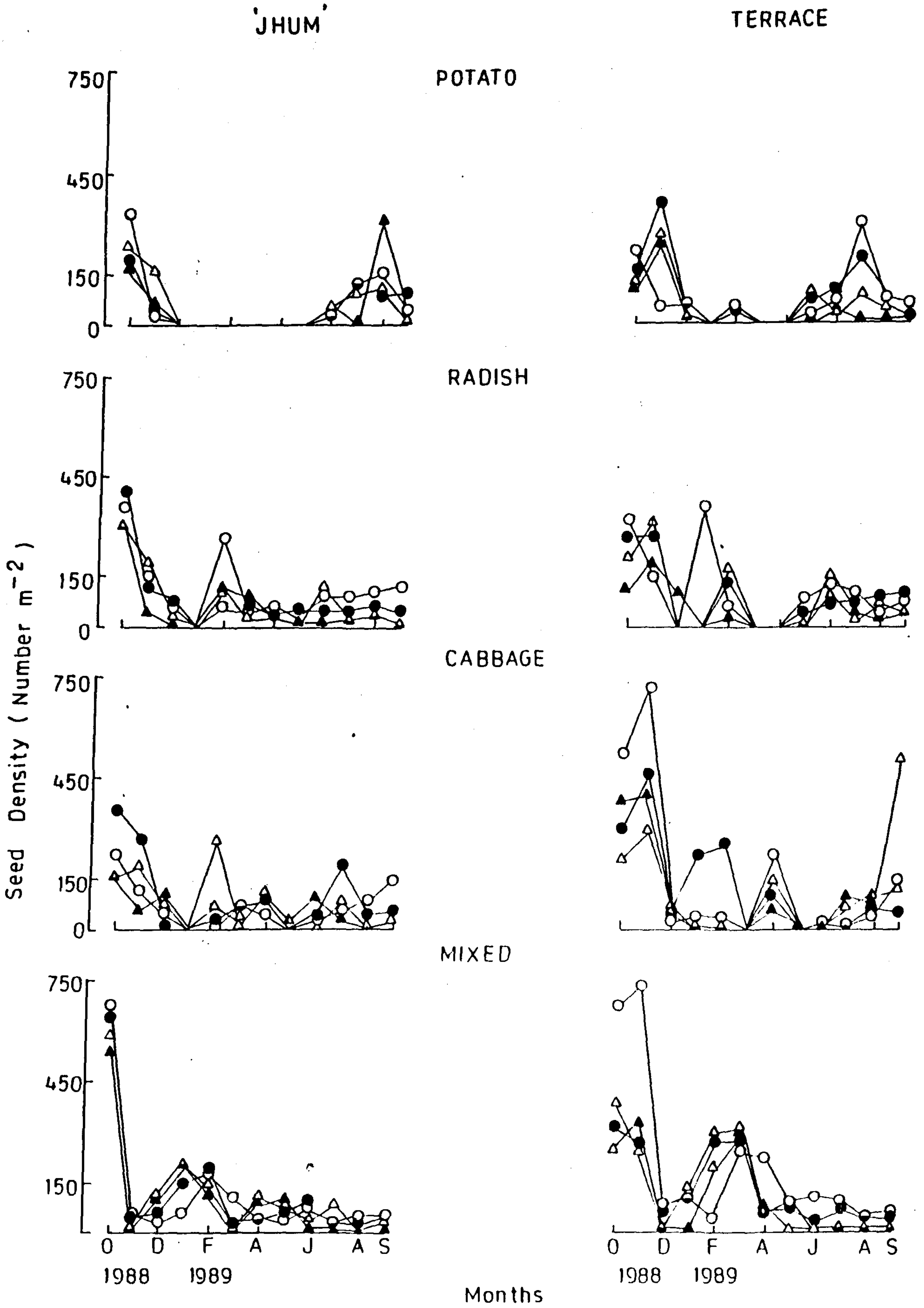

Fig. 8.1. Monthly variation in the total (viable + non-viable) buried seed population of *A. artemisiifolia* at four different soil depths under 'Jhum' and terrace cultivation during October 1988 to September 1989, O, 0-5; ●, 5-10; △, 10-15; ▲, 15-20 cm soil depths.

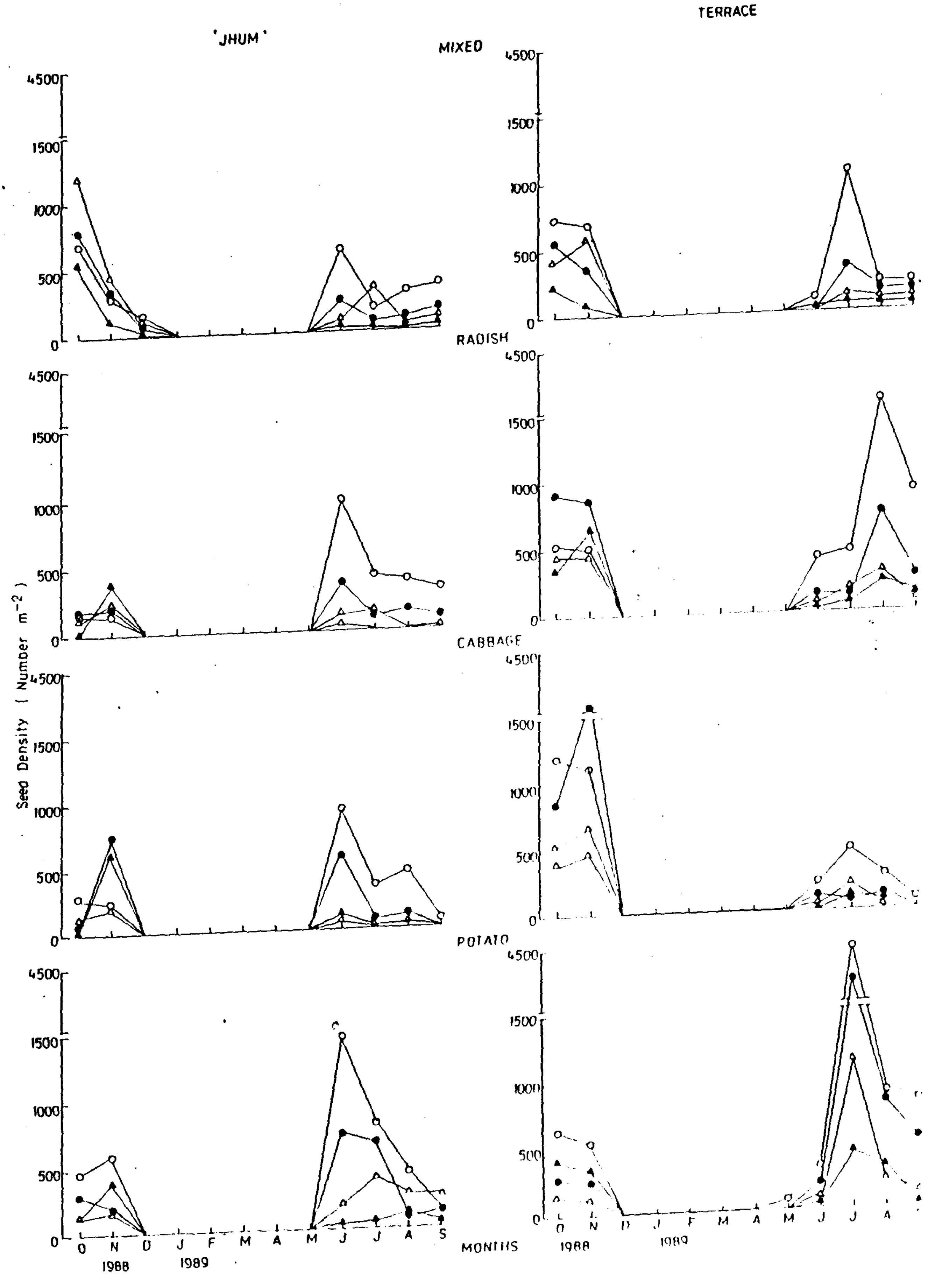

Fig. 8.2. Monthly variation in the total (viable + non-viable) buried seed population of G. ciliata at four different soil depths under 'Jhum' and terrace cultivation during October 1988 to September 1989. Key as in Fig. 8.1.

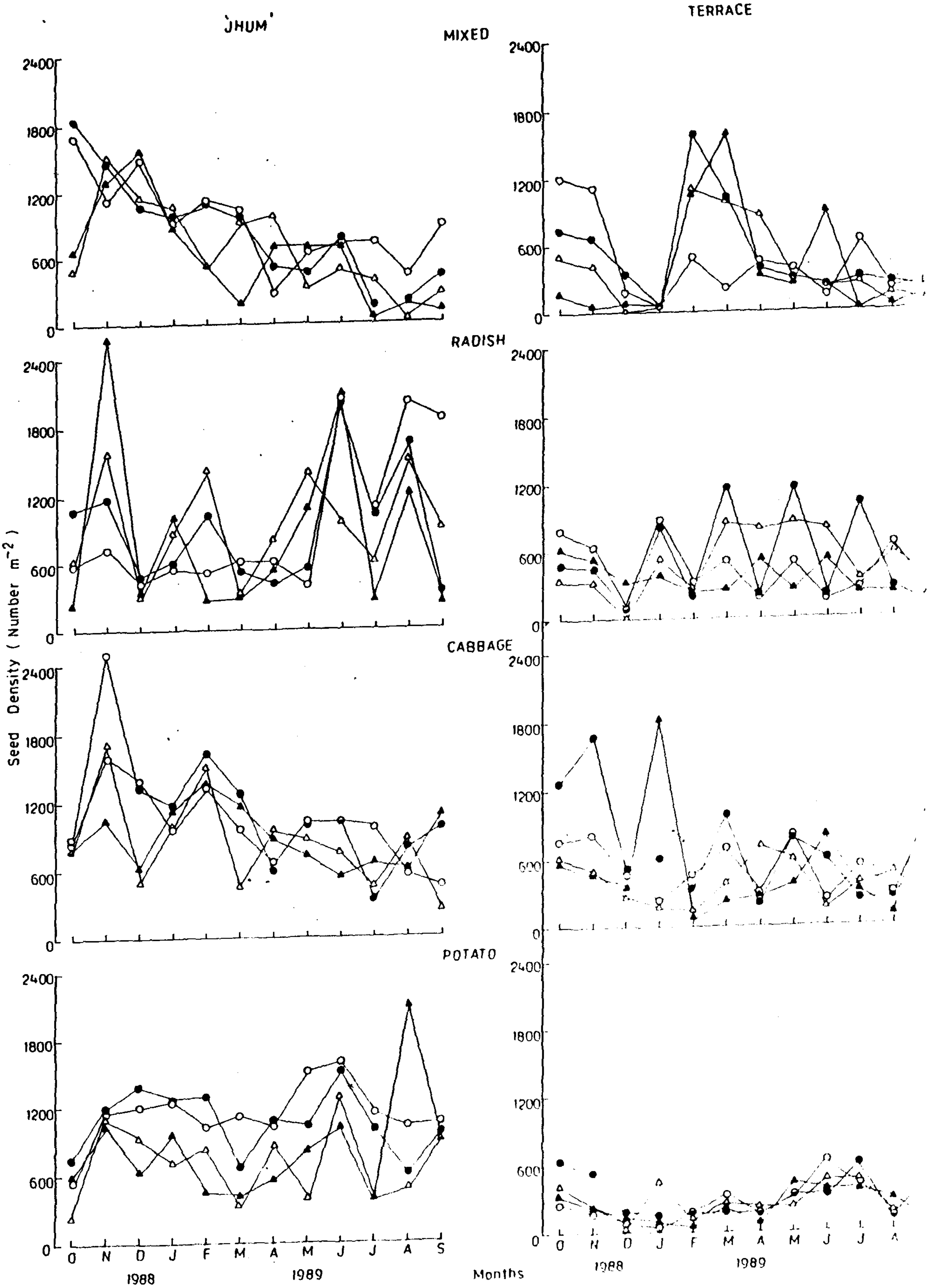

Fig. 8.3. Monthly variation in the total (viable + non-viable) buried seed population of *P. alatum* at four different soil depths under 'Jhum' and terrace cultivation during October 1988 to September 1989. Key as in Fig. 8.1.

spring and rainy seasons (Fig. 8.4). The weed seed population density of all the species showed two peaks in all the monoculture fields under both types of cultivation. It showed two peaks, but in mixed culture under 'Jhum' cultivation, it peaked only once (Fig. 8.5).

There was a distinct variation in the total buried seed population along depth and time. This was true for all the four weeds. All of them exhibited a gradual decline in their seed population through depth. But this was not true during February-March and September-October. The weed seed population varied markedly with the type of cultivation. The seed populations of S. arvensis and P. alatum were significantly ($P < 0.05$) larger in the crop fields under 'Jhum' cultivation than under terrace cultivation, while the opposite was true for G. ciliata and A. artemisiifolia. The total seed population density was, however, always greater in the 'Jhum' fields than in the terrace fields.

Total mean weed seed population density declined significantly ($P < 0.05$) with increase in soil depth (Fig. 8.6a) as was also true for the seed populations of G. ciliata and S. arvensis. Seed population of P. alatum declined with depth in radish and cabbage + radish mixed fields under 'Jhum' cultivation, but in other crop fields, it did not show any depth-related trend (Fig. 8.6a). Seed population of A. artemi-

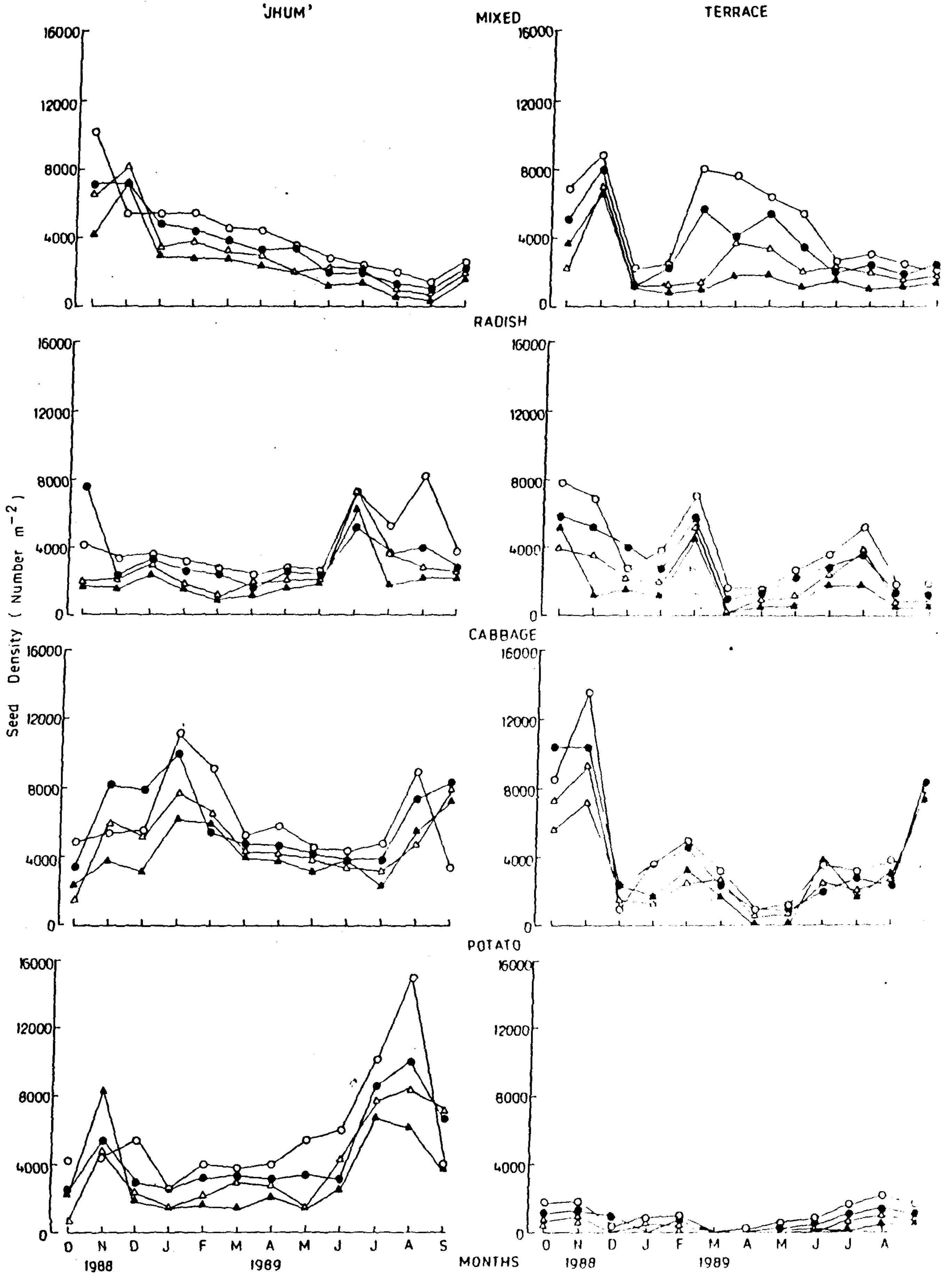

Fig. 8.4. Monthly variation in the total (viable + non-viable) buried seed population of S. arvensis at four different soil depths under 'Jhum' and terrace cultivation during October 1988 to September 1989. Key as in Fig. 8.1.

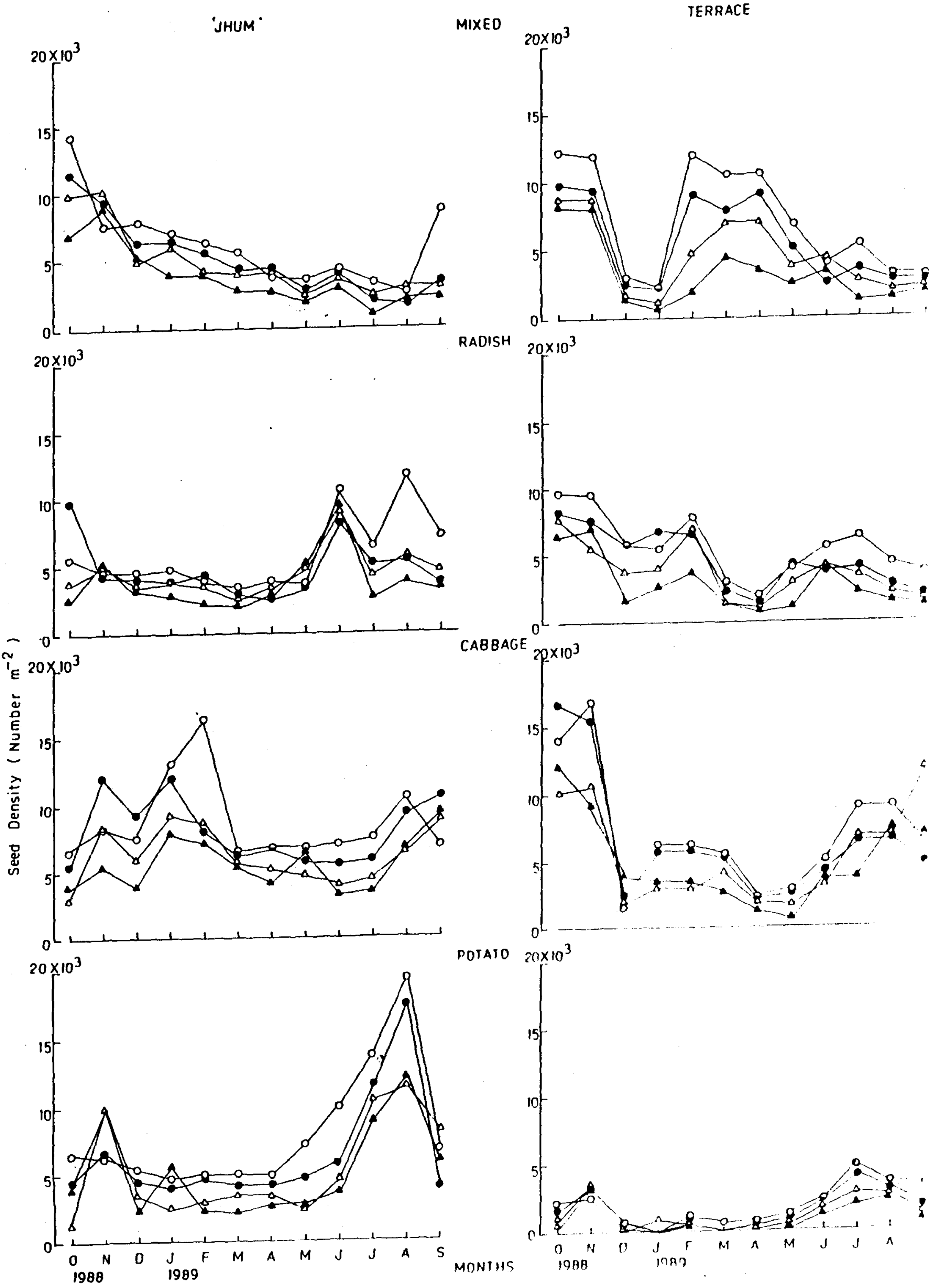

Fig. 8.5. Monthly variation in the total (viable + non-viable) buried seed population of all the weeds at four different soil depths under 'Jhum' and terrace cultivation during October 1988 to September 1989. Key as in Fig. 8.1.

siifolia declined with depth in potato field under 'Jhum' cultivation, while in other crop fields no definite trend was noticed (Fig. 8.6b). Seed population of *A. artemisiifolia*, *P. alatum* and *S. arvensis* was influenced significantly ($P<0.05$) by soil depth, crop type and cultivation method. In case of *G. ciliata*, on the other hand, only the effect of cultivation method was significant ($P<0.05$).

Viable buried seed population

Proportion of the viable seeds showed a significant ($P<0.05$) increase through depth. It also varied with the type of crops and was significantly ($P<0.05$) higher in the crop fields under 'Jhum' cultivation than those under terrace cultivation. This was true for all the four dominant weeds as well as for the total weeds (Fig. 8.6a and 8.6b). During the second year, the soil seed bank showed slight increase in its viable seed population in all the crop fields under both 'jhum' and terrace cultivation, however, the total soil seed bank did not show any significant difference between the two years (Fig. 8.7).

Effect of weeding frequency on buried seed population

Weeding frequently the viable seed population significantly ($P<0.05$). At the beginning of the study all the crop fields under 'Jhum' cultivation had a significantly ($P<0.05$) larger population of viable seeds compared to those under

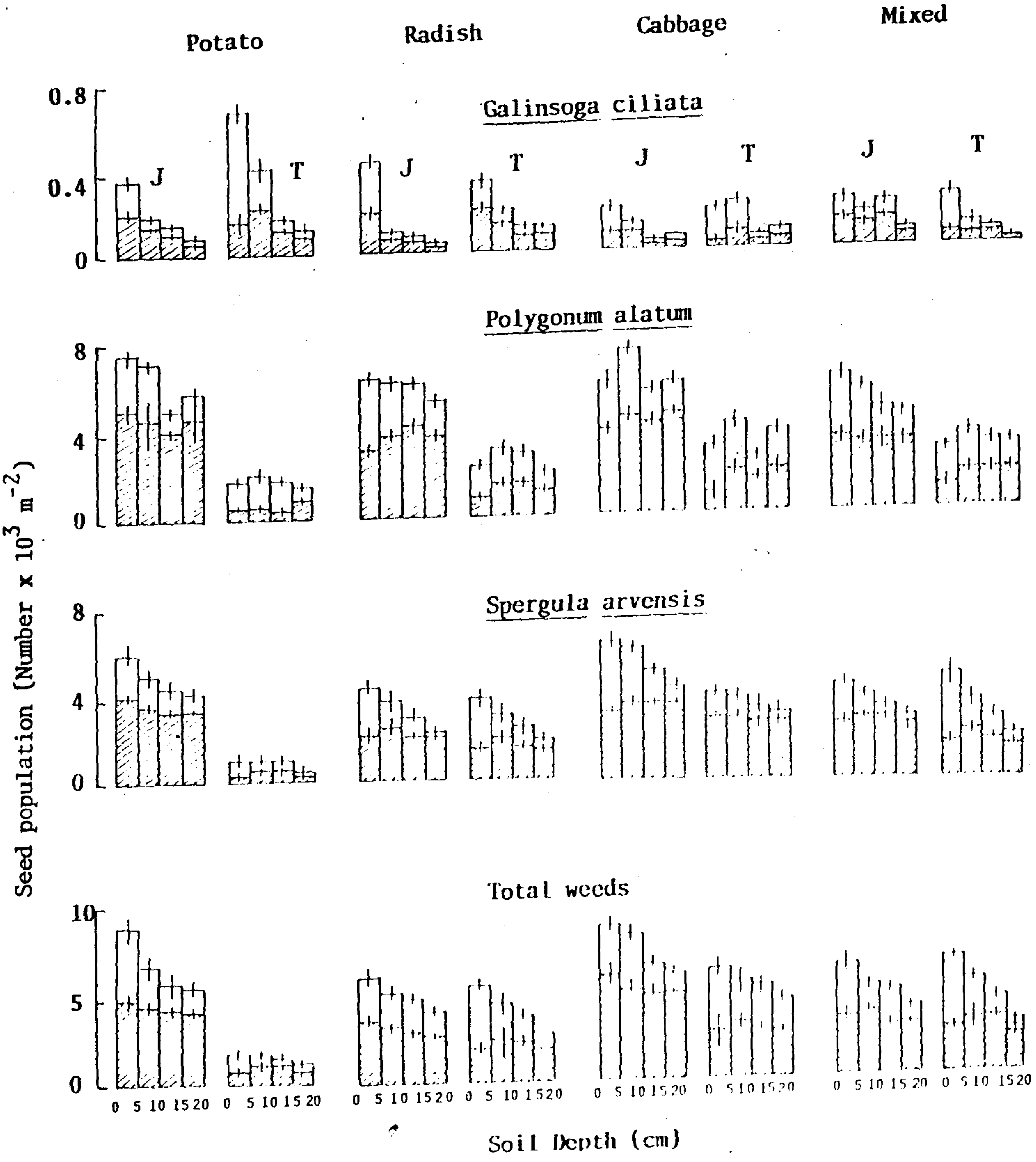

Fig. 8.6a. Vertical distribution of buried seed population of three dominant weeds as well as total weeds in four different crop fields under 'Jhum' and terrace cultivation. The values represent the pooled means over the year 1988-89. J, Jhum; T, Terrace cultivation. [ ], viable seeds; I represents the standard error of means, n=12.

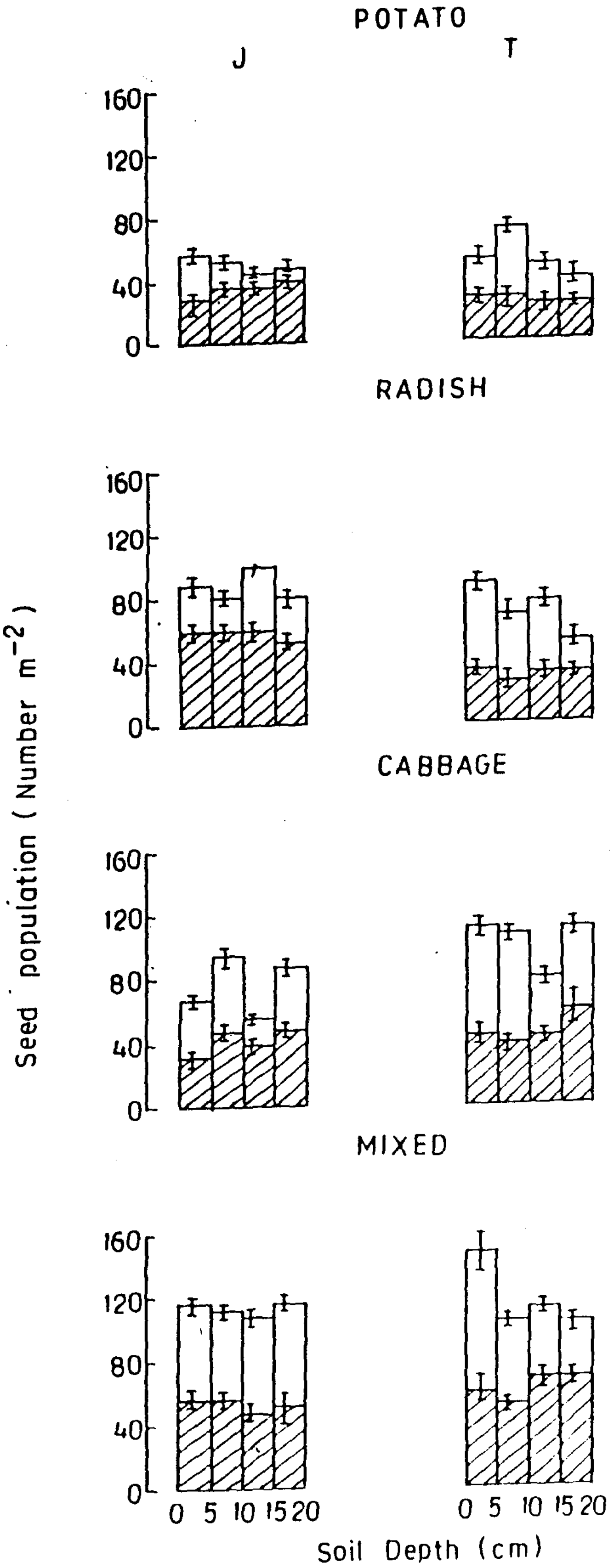

Fig.8.6b. Vertical distribution of buried seed population of A. *artemisiifolia* in four different crop fields under 'Jhum' and terrrace cultivation. Key as in Fig. 8.6a.

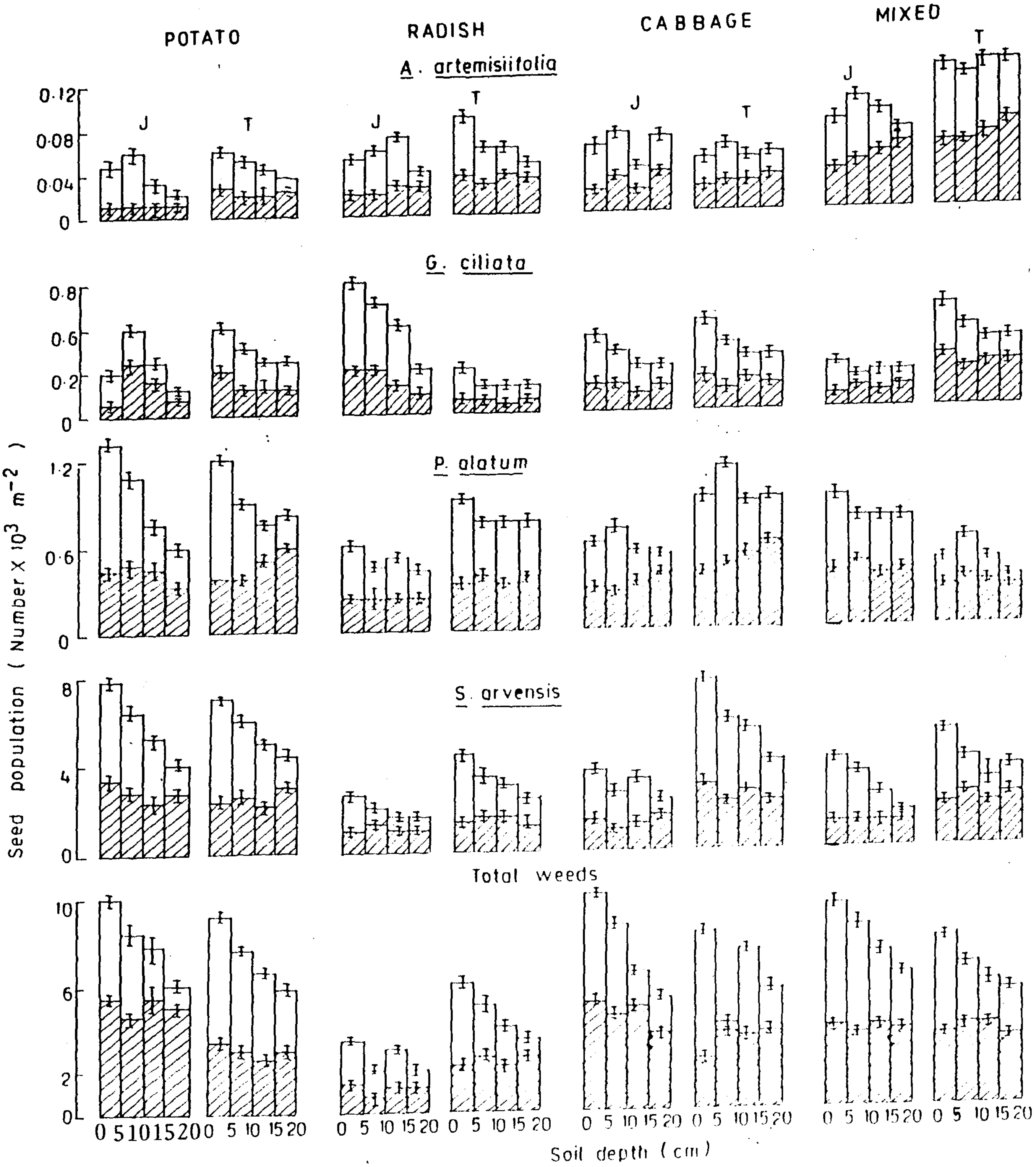

Fig. 8.7. Vertical distribution of buried seed population of four dominant weeds as well as total weeds in four different crop fields 'Jhum' and terrace cultivation. The value represents the pooled means over the year 1989-90. Key as in Fig. 8.6. Please note the change in scale.

terrace cultivation. Among different crop fields maximum number of viable seeds was recorded in the mixed culture and the minimum in the potato field regardless of the type of cultivation. The loss of viable weed seeds from the less frequently weeded fields of potato and radish was more in the terrace (3.6 to 5.8%) than in the 'Jhum' fields (1.2 to 1.9%). Under similar weeding condition, cabbage and cabbage + radish (mixed) fields under 'Jhum' cultivation showed an increase of 1.8 and 4.9%, respectively in viable seed population which were higher than the values (1.4 and 4.0% respectively) recorded in the same fields under terrace cultivation. During second year, the less fequently weeded fields showed increase in viable seed population which ranged from 2.35% in mixed crop field to 8.7% in radish field under terrace cultivation (Table 8.3). The frequently weeded plots always showed a greater reduction in viable seed population than the less frequently weeded fields. This reduction was greater during the second year ('Jhum' - 34%, terrace - 46%) compared to the first year ('Jhum' - 26%, terrace - 32%).

The total buried seed population declined considerably at the end of 1988-89 in the crop fields where normal weeding was done except potato and cabbage fields which registered an increase in soil seed bank. At the end of the second year (1989-90) the total buried seed population increased in the

Table 8.2 - Decrease/increase in number of viable seeds (%) of four dominant weed species and total weeds* in 20 cm soil layer over 1-yr period in different crop fields under 'Jhum' cultivation during 1989-90.

Species	Frequently weeded plot				Less frequently weeded crop fields			
	Potato	Radish	Cabbage	Mixed (Cabbage-Radish)	Potato	Radish	Cabbage	Mixed (Cabbage-radish)
During 1988-89								
S. arvensis	-36.7	-38.0	-30.1	-32.5	+1.4	-3.5	+4.6	+4.4
G. ciliata	-34.0	-37.1	-28.5	-30.7	+4.2	-1.7	+2.2	+1.3
P. alatum	-16.5	-18.7	-14.4	-15.6	-2.4	-6.9	-4.1	-2.7
A. artemisiifolia	-17.9	-18.2	-16.0	-16.2	-1.3	-5.4	-1.3	-4.4
Total weeds	-25.4	-28.0	-24.2	-26.4	-1.9	-1.2	+1.8	+4.9
During 1989-90								
S. arvensis	-40.6	-43.8	-36.6	-34.6	-4.7	+3.5	+12.4	-1.0
G. ciliata	-34.3	-39.7	-32.3	-32.6	-5.3	+1.7	+8.6	+3.2
P. alatum	-19.6	-22.7	-19.4	-21.9	-3.9	-3.2	-2.2	-2.2
A. artemisiifolia	-20.5	-21.2	-17.1	-19.2	-0.8	-1.4	-1.3	-0.1
Total weeds	-33.8	-35.6	-32.0	-34.0	+4.0	+4.2	+7.4	+2.7

* Includes four dominant weeds plus all other weeds present in the soil seed bank. + and - indicate increase and decrease in viable buried seed population respectively.

Table 8.3 - Decrease/increase in number of viable seeds (%) of four dominant weed species and total weeds* in 20 cm soil layer over 1-yr period in frequently weeded plots and less frequently weeded crop fields under terrace cultivation during 1988-90.

Species	Frequently weeded plots				Less frequently weeded crop fields			
	Potato	Radish	Cabbage	Mixed (Cabbage-radish)	Potato	Radish	Cabbage	Mixed (Cabbage-radish)
During 1988-89								
S. arvensis	-38.6	-38.4	-32.2	-33.3	-7.2	-4.0	+3.8	+4.9
G. ciliata	-37.8	-39.4	-32.3	-34.7	-4.3	-3.7	+2.1	+2.7
P. alatum	-21.2	-25.4	-17.0	-13.8	-3.5	-2.9	+1.3	+3.4
A. artemisiifolia	-27.4	-29.8	-19.3	-17.4	-4.0	-3.3	+1.0	+2.3
Total weeds	-18.0	-38.2	-35.8	-36.0	-5.8	-3.6	+1.4	+4.0
During 1989-90								
S. arvensis	-46.2	-52.8	-43.7	-47.6	+3.4	+7.2	+7.5	+4.7
G. ciliata	-42.1	-46.7	-41.6	-40.1	+2.3	+1.3	+4.6	+3.2
P. alatum	-26.7	-38.8	-23.4	-25.1	+1.9	+4.6	+7.0	+2.3
A. artemisiifolia	-32.9	-39.8	-28.7	-31.3	+4.3	+2.1	+2.2	+1.9
Total weeds	-32.0	-51.8	-49.6	-48.8	+3.2	+8.7	+5.3	+2.4

* Includes four dominant weeds plus all other weeds present in the soil seed bank. + and - indicate increase and decrease in viable buried seed population respectively.

less frequently weeded fields. In the frequently weeded plots, the viable buried seed population declined steadily over the year in both 'Jhum' and terrace fields (Fig. 8.8).

Effect of weeding frequency on buried seed population of individual weed species

All the weed species responded to frequent weeding by reducing their viable seed population to a considerable extent. The seed population of all the species decreased most in the radish field and least in the cabbage field under jboth 'Jhum' and terrace cultivation. The reduction in viable seed population of various weeds was more during 1989-90 than during 1988-89 (Tables 8.4 and 8.5). *S. arvensis* suffered a greater loss in its viable seed population than other species in the frequently weeded plots.

Under low frequency of weeding, the individual species showed differential response. *A. artemisiifolia* and *P. alatum* responded to low frequency of weeding by reducing their viable seed population to a considerable extent in all the crop fields in both years, while the other two weeds viz., *S. arvensis* and *G. ciliata* did not show any decrease in their viable seed population (Table 8.2).

DISCUSSION

The seasonal changes in the density of buried weed

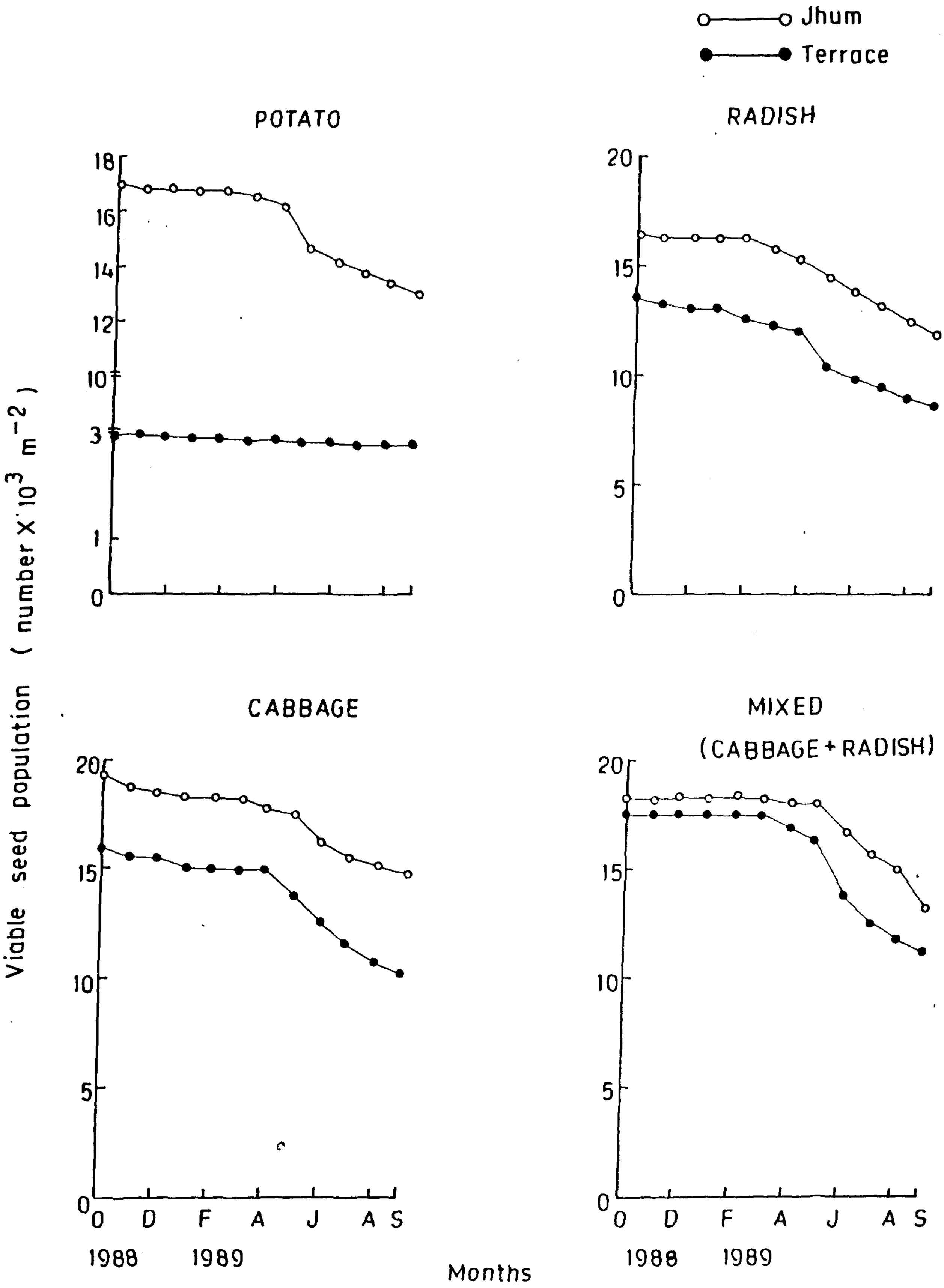

Fig. 8.8. The change in viable buried seed population (number m^{-2} down to 20 cm soil depths) with time in four different crop fields under 'Jhum' and terrace cultivation during October 1988 to September 1989.

Table 8.4 - Change (gain/loss) in the number of viable and total (viable + dead) buried weed seed population down to 20 cm depth in different crop fields under 'Jhum' and terrace cultivation over one year period (October 1989 to September 1990).

Method of cultivation and name of the crops grown	Seed Population in October 1988		Change in viable buried weed seed population		Change in total buried weed seed population	
	Total	Viable	LFW	FW	LFW	FW
Jhum						
Potato	26470±1528	14112±662	-1.9±0.1	-25.4±1.0	+ 9.8±0.3	-28.4±0.9
Radish	21399±926	16691±1008	-1.2±0.1	-28.0±1.2	-14.9±0.7	-30.8±1.2
Cabbage	18920±812	15893±752	+1.8±0.1	-24.2±0.2	+16.1±0.9	-28.2±1.3
Cabbage + Radish	42819±4825	35112±1857	+4.9±0.6	-26.4±0.9	-12.3±0.7	-30.2±1.5
Mean	27402±4654	20452±4258	+3.5±0.2	-26.0±0.7	-0.3±0.1	-29.4±0.6
Terrace						
Potato	9807±747	6571±584	-5.8±0.4	-18.0±1.2	- 6.4±0.3	-20.5±0.8
Radish	19280±124	12532±992	-3.6±0.3	-38.2±0.2	-18.4±0.1	-40.2±1.3
Cabbage	16311±1021	12233±758	+1.4±0.2	-35.8±0.7	-15.7±0.7	-37.8±2.2
Cabbage + Radish	34707±3837	26642±1378	+4.0±0.4	-36.0±0.6	-14.7±0.7	-38.0±1.6
Mean	20026±4571	13995±3295	-4.0±0.4	-32.0±4.1	-13.8±2.3	-34.1±4.8

LFW - Less frequently weeded field; FW - Frequently weeded plot; ± S.e.m; + net gain and - net loss in weed seed population.

Table 8.5 - Change (gain/loss) in the number of viable and total (viable + dead) buried weed seed population down to 20 cm soil depth in different crop fields under 'Jhum' and terrace cultivation over one year period (October 1988 to September 1989).

Method of cultivation and namde of the crops grown	Seed population in October 1989		Change in viable buried weed seed population (%)		Change in total buried weed seed population (%)	
	Total	Viable	LFW	FW	LFW	FW
Jhum						
Potato	29072±1962	14938±750	+3.9±0.2	-33.8±2.7	+6.0±0.8	-36.8±3.2
Radish	18204±1508	13984±1320	+4.2±0.4	-35.6±3.4	+6.8±1.2	-39.4±2.8
Cabbage	21960±2069	18837±2104	+7.4±0.3	-32.0±1.7	+9.4±0.8	-37.5±4.6
Cabbage + Radish	37552±1494	32618±3369	+2.1±0.4	-34.0±2.2	+4.6±1.0	-39.3±2.8
Mean	26697±2497	20868±1596	+4.4±0.8	-33.9±1.8	+4.6±0.4	-38.3±3.3
Terrace						
Potato	9181±631	5620±430	+3.2±0.6	-32.0±3.2	+5.3±0.6	-48.2±2.8
Radish	15731±1322	9657±482	+8.7±1.2	-51.8±4.6	+10.0±1.8	-54.4±5.2
Cabbage	13747±1048	10504±801	+5.3±0.8	-49.6±3.8	+7.2±0.2	-53.2±4.6
Cabbage + Radish	29615±2315	23911±1255	+2.4±0.6	-48.8±4.2	+4.6±0.8	-50.8±4.4
Mean	17069±1330	11244±482	+4.9±0.4	-45.6±1.8	+6.8±1.4	-51.7±3.8

LFW - Less frequently weeded field; FW - Frequently weeded plot; ± S.e.m; + net gain and - net loss in weed seed population.

seed population are influenced by the input of seeds, germination of seeds and loss of seeds caused by various agencies determined by the prevailing environmental conditions. The low population density of weed seeds in all the crop fields during rainy season may be ascribed to germination of larger number of seeds caused by the prevailing favourable temperature and moisture condition. This is in agreement with the findings of Roberts & Feast (1970), Thompson & Grime (1979) and Roberts (1981).

The distribution of weed seeds at different soil depth was also dependent on the time during which the soil was disturbed. The weed seed population recovered from the soil samples collected from the crop fields before the preparation of land for cultivation showed a clear-cut decline with increasing soil depth. But during the time when the field was prepared for seed sowing, there was no depth-related trend in the distibution of weed seeds in soil. As expected, during land preparation and cultivation, weed seeds, in large numbers, are transported to the deeper layers of soil, while the seeds from the deeper layer whose number is usually much smaller are thrown to the surface layer. This disrupts the depth-related original trend in the distribution of weeds in soil. This conforms with views expressed by Chepil (1946) and Moss (1988).

Markedly high seed population of *S. arvensis*, *P. alatum* and total weeds in the 'Jhum' fields could be attributed to the long fallow period prior to the commencement of cultivation in 1988, which allowed abundant growth and reproduction of these as well as other weeds. This might have caused large input of seeds into soil seed bank. On the contrary, continuous cultivation for the last eight years with regular use of heribicides and crop rotation seems to be the probable cause of lower seed population density of most weeds in the terrace fields, except in the case of *G. ciliata* and *A. artemisiifolia* which showed higher buried seed density due to their abundant growth. These findings are comparable with those of Roberts (1962) who showed that the number of viable seeds decreased exponentially when the crop fields are subjected to frequent cultivation. Roberts & Dawkins (1967) also reported that the decrease was more rapid when the soil was cultivated rather than when allowed to remain undisturbed. They recorded 12% annual decrease in buried seed population in the undisturbed and uncropped soil and 30-36% decline when the disturbance was caused four times a year. According to Cavers (1983) and Ferner (1985) the major causes of depletion of seeds in soil are the death, predation and germination over the years. Most numerical studies of seed banks have also revealed that large number of seeds die without becoming established as seedlings due to disturbance in soil (Cavers, 1983). Over 1-year period, the 'Jhum' fields recorded a gain of about 4% in viable seed population, while the terrace fields showed a loss of 4% under similar weeding frequency. Also the extent of reduction in total weed seed population was less in the 'Jhum' than in the terrace fields. These differences may be ascribed to the suppression of germination of weed seeds in the former fields due to relatively low soil moisture and high CO_2 evolution rates (Sahoo et al. 1992). However, a larger input of seeds during the second year caused an increase in both viable as well as total soil seed bank in all the crop fields under 'Jhum' and terrace cultivation.

Presence of significantly ($P < 0.05$) higher proportion of viable seeds of the dominant weeds as well as total weeds in deeper soil layers under both types of cultivation may be related to a number of unfavourable climatic conditions for germination, especially low soil temperature (Chapter VII, Fig. 7.1), which prevent their germination by enforcing them into dormant state. Baskin & Baskin (1978) and Wesson & Wareing (1967) also reported that low temperature and lack of light in deeper soil layers prevent germination. A sharp decline (34% in 'jhum' and 46% in terrace fields) in viable seed population during the 2-yr period in the frequently weeded plots clearly showed that weeding frequency significantly influences weed seed population by causing reduction in weed seed input into the soil.

The results depict the important role played by the type of cultivation and frequency of weeding in regulating the density of viable seed population as well as vertical distribution of the total seed population in soil. The higher density of viable buried weed seed population in the 'jhum' fields compared to the crop fields under terrace cultivation explains the greater level of weed infestation observed under 'jhum' cultivation in Meghalaya (Saxena & Ramakrishnan, 1984). The depth-distribution pattern of seeds as observed in the present study (Fig. 8.6 and 8.7) indicates that the position of weed seeds in soil is regulated by the depth to which the soil is disturbed by cultivational operations.

CHAPTER IX

Effect of depth and duration of burial on seed viability and dormancy of few selected weeds.

INTRODUCTION

Numerous studies have been carried out in the temperate areas of the world to determine the longevity of weed seeds in soil (Dawson & Bruns, 1975; Egley & Chandler, 1978; Rampton & Ching, 1966; Zorner _et al_. 1984b). These studies have revealed that weed seeds can survive longer in viable condition in soil than in ordinary dry storage. Such long-lived seeds in soil cause weed infestation in due course of time when they get favourable condition in their soil-seed environment for germination and growth. Therefore, knowledge of the seed longevity in soil serves as a basis to the understanding and predicting future weed infestation and economic threshold (Conn & Farris, 1987). However, little information is available on the effect of burial on the longevity of weed seeds under Indian conditions. A study was, therefore, designed to determine the effect of depth and duration of burial on viability and dormancy of weed seeds.

MATERIALS AND METHODS

Matured seeds of six dominant weeds viz. _S. arvensis_, _G. ciliata_, _P. alatum_, _A. artemisiifolia_, _R. piolosa_ and _B. pilosa_ were collected on various dates (indicated in Table

9.1) from the plant populations growing at the two study sites. The seeds of these weeds were air-dried at room temperature for about 2 weeks, then cleaned and prepared for their burial. In view of differences in phenology of the various weeds the seed burial time was kept different for different species (Table 9.1) and was coincided with the time when they would have dispersed and buried on the ground naturally.

The burial experiment was conducted either at CPRS farm or at ICAR farm depending upon the occurrence of the concerned weed species in the weed flora of the study site.

100 air-dried seeds of each species were counted, mixed with finely sieved clay loam soil (pH 5.1-5.7) and placed in individual 5 x 5 cm mesh nylon bags having 50µ pore diameter. The bags were folded over at the top and sewn properly with a nylon thread. 144 of such seed packets were prepared for each species and these were buried at three depths viz., 2, 7 and 15 cm depths. At each soil depth, a group of 48 bags were kept at 12 separate places marked properly for sampling in an orderly manner on 12 separate dates. On each date, 4 seed packets were removed carefully from each depth of soil and were carried to the laboratory. The packets were then cut from the top and were washed carefully to recover the seeds. The recovered seeds were then transferred to petri dishes for germination and viability test. Out of

Table 9.1 - Dates of seed collection, viability test and burial of seeds of different weed species.

Species	Date of collection	Date on which viability was tested	Date of burial	Site of burial
Spergula arvensis	15.11.89	01.01.90	07.01.90	CPRS Farm
Galinsoga ciliata	15.11.89	01.01.90	07.01.90	CPRS Farm
Polygonum alatum	02.01.90	27.01.90	03.02.90	CPRS Farm
Ambrosia artemisiifolia	15.11.89	01.01.90	07.01.90	CPRS Farm
Richardsonia piolosa	07.07.89	10.09.89	15.09.89	ICAR Farm
Bidens pilosa	05.02.90	12.03.90	18.03.90	ICAR Farm

4 seed packets sampled on each sampling date from each soil depth, two (2 x 100 seeds) were used for determining viability (Vt) of seeds, while the remaining 2 were used for testing germinability of seeds and for detecting different types of dormancy associated with the seeds due to burial. The recovered seeds were examined individually and those which were empty or degenerated were separated and counted as dead, while the apparently healthy seeds were tested for their viability using 0.1% 2, 3, 5 triphenyl tetrazolium chloride. On the other hand, the healthy seeds from the 2nd set of 2 packets were sown in the petri dishes (10.5 x 1.5 cm) filled with a thin layer of very finely sieved soil from the experimental field (pH 5.1 to 5.7), watered and kept in a seed germinator at an alternating temperature of 30° and 7°C (12 hrs at each temperature), maintaining a 12 h photoperiod. As the seedlings emerged they were counted and removed. Seedling emergence was taken to be the equivalent of germination. Four weeks time was allowed for germination of the seeds. The ungerminated seeds in the petri dishes were again examined if they were still full. The empty seeds, if any, were added to the number of dead seeds already determined before keeping the seeds for germination. Those which were still full were subsequently tested for viability using 0.1% 2, 3, 5 triphenyl tetrazolium chloride. Based on their response to viability and germination test, the recovered seeds were divided into categories as follows:

(i) **Enforced-dormant (ED)** - The viable seeds that germinated on being exposed to favourable germination conditions, as existed in the seed germination.

(ii) **Induced-dormant (ID)** - The seeds which did not germinate even under favourable conditions obtaining in the seed germinator, were considered as 'induced-dormant'. This represented the ungerminated viable-dormant fraction of the buried weed seed population.

(iii) **Dead (D)** - The number of empty and degenerated seeds recovered from the sample in the beginning plus those which were subsequently detected as dead following germination and viability test.

(iv) **Germinable (G)** - This represented the seed population obtained by subtracting the number of seeds under enforced dormancy (ED) and induced dormancy (ID) from the total number of viable seeds (Vt).

In the present study, any loss due to predation was ignored. There may be some loss in number of viable seeds due to in situ germination during burial (Chapter X), which, however, has not been included in the present chapter.

Initial seed viability and germination percentages for different species were determined 4-5 days before burial.

For this purpose, four samples of 100 seeds each for each species were taken from the same seed lots that were meant for burial and their viability and germinability were found out.

RESULTS

Viability and dormancy of seeds at the time of burial

Species differed significantly ($P< 0.05$) with respect to their seed viability. Viability exceeded 60% in all the weed species except A. artemisiifolia (Table 9.2). Seed viability at the time of burial was maximum in G. ciliata (92%) and minimum in A. artemisiifolia (48%). The percentage of seeds that were readily germinable at the time of burial, was quite high (Table 9.2) in B. pilosa, but in the case of P. alatum and R. piolosa the percentage of dormant seeds was considerably high (54% in both species). In other species, the percentage of dormant seeds ranged between 36% in B. pilosa to 44% in S. arvensis at the time of burial.

Effect of depth and duration of burial on seed viability

Burial depth had a significant ($P< 0.05$) effect on seed viability in all the species. Viability of the seeds recovered from 15 cm depth was greater than those recovered from 2 cm depth (Table 9.3). Duration of burial had also a significant effect on seed viability. Seed viability declined

Table 9.2 - Percentage of weed seeds detected as viable and germinable at the time of burial.

Species	Percentage of viable seeds	Percentage of germinable seeds
Spergula arvensis	74±5	30±2
Galinsoga ciliata	92±5	52±3
Polygonum alatum	64±6	10±1
Ambrosia artemisiifolia	48±4	8±0
Richardsonia piolosa	66±4	12±1
Bidens pilosa	86±3	60±3

± S.e.m., n=4.

Table 9.3 - Loss of seed viability (%) in different weeds after 1-year of burial at different soil depths.

Species	Viability at the time of burial	Viability (%) after 1-year burial		
		Depth of burial (cm)		
		2	7	15
S. arvensis	74	46	48	50
G. ciliata	92	30	34	36
P. alatum	64	14	30	24
A. artemisiifolia	48	16	20	28
R. piolosa	66	44	50	56
B. pilosa	86	20	24	36

gradually with the increase in the duration of burial (Fig. 9.1-9.3). However, the species differed markedly ($P < 0.05$) with regard to the rate of decline in their seed viability. The rate of decline in seed viability was much slower in *A. artemisiifolia*, *S. arvensis* and *R. piolosa* than in *B. pilosa*, *G. ciliata* and *P. alatum*. The seeds buried in the surface soil layers lost viability more rapidly than those buried at greater depths.

Effect of depth and duration of burial on seed dormancy

Enforced-dormancy

Depth had a significant ($P<0.05$) effect on enforced-dormant seed population in all the species. The population of seeds under enforced-dormancy increased significantly with increase in soil depth. This was true in all the species except *R. piolosa*, in which the percentage of enforced-dormant seeds declined with soil depth (Fig. 9.3). Most of the species showed a low proportion of seeds under enforced-dormancy during winter season compared to other seasons (Fig. 9.1 to 9.3). The population of enforced-dormant seeds in *R. piolosa*, however, did not show any variation with the season indicating thereby that duration of burial does not alter the percentage of seed population under enforced-dormancy in this species (Fig. 9.3).

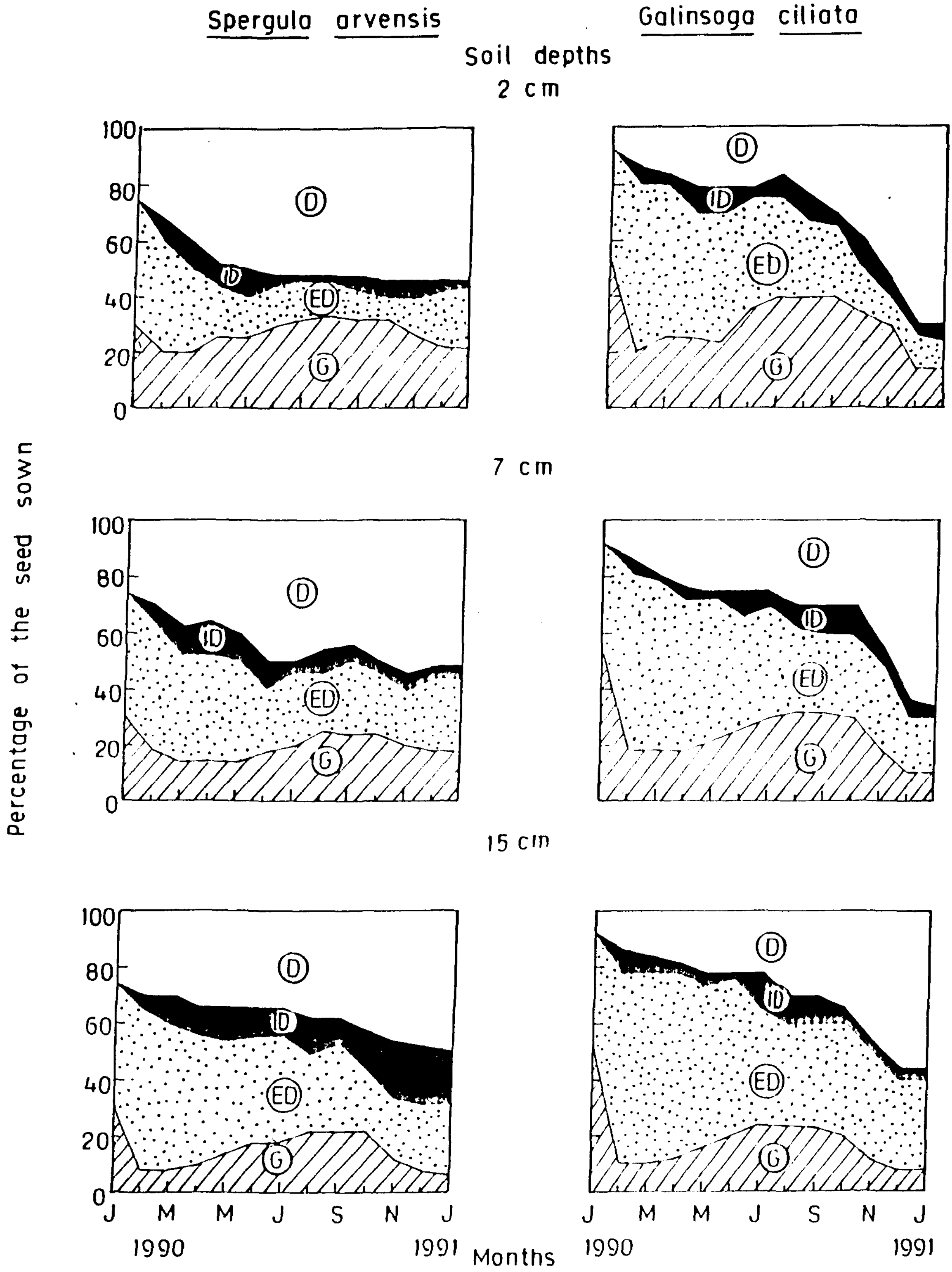

Fig. 9.1. Variation in the proportion of the different fractions of the dormant seed population of S. *arvensis* and G. *ciliata* with time. G, germinable; ED, seeds under enforced-dormancy; ID, seeds under induced-dormancy; D, fraction of the seed population that decayed.

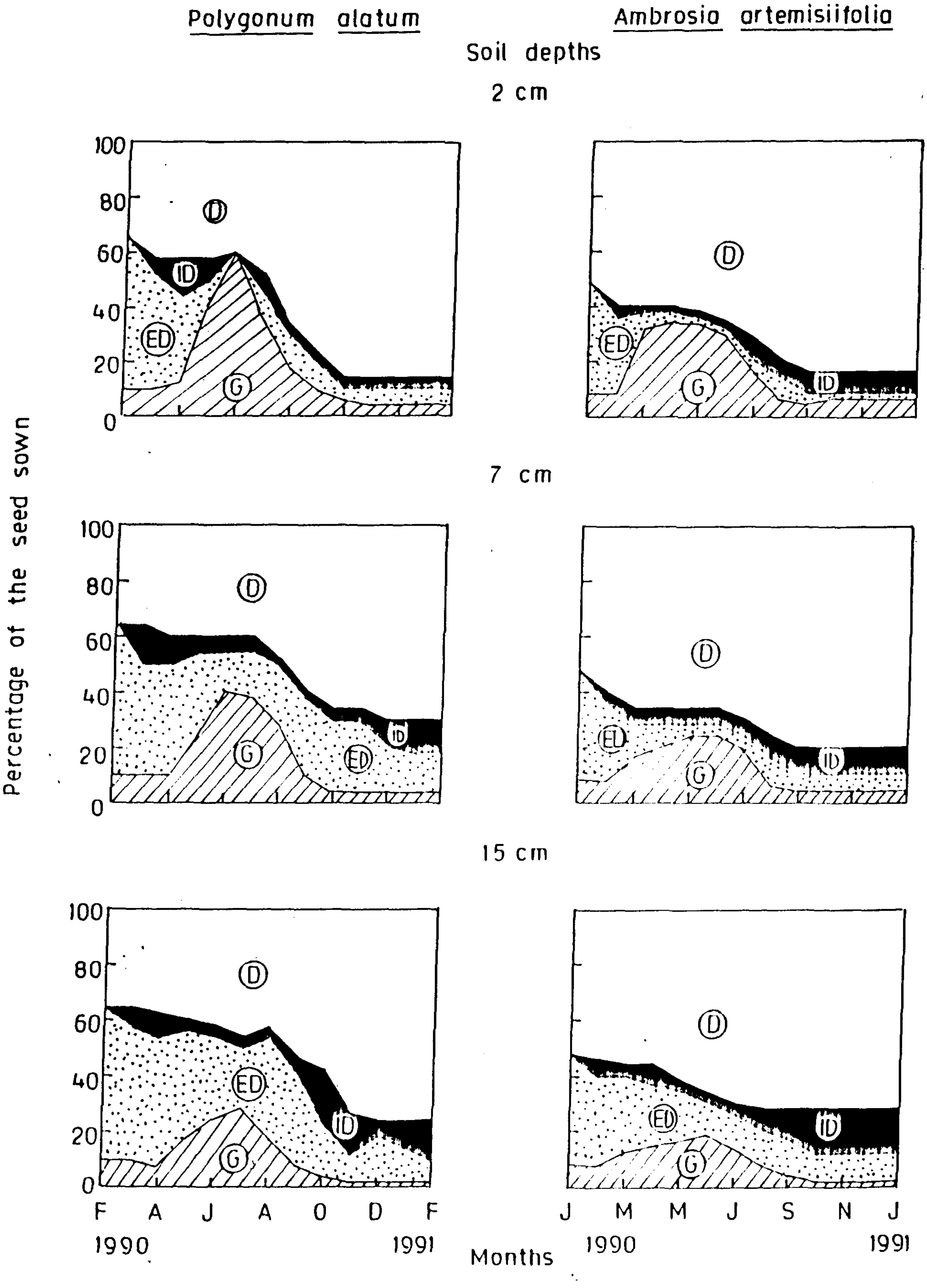

Fig. 9.2. Variation in the proportion of the different fractions of the dormant seed population of *P. alatum* and *A. artemisiifolia* with time. Key as in Fig. 9.1.

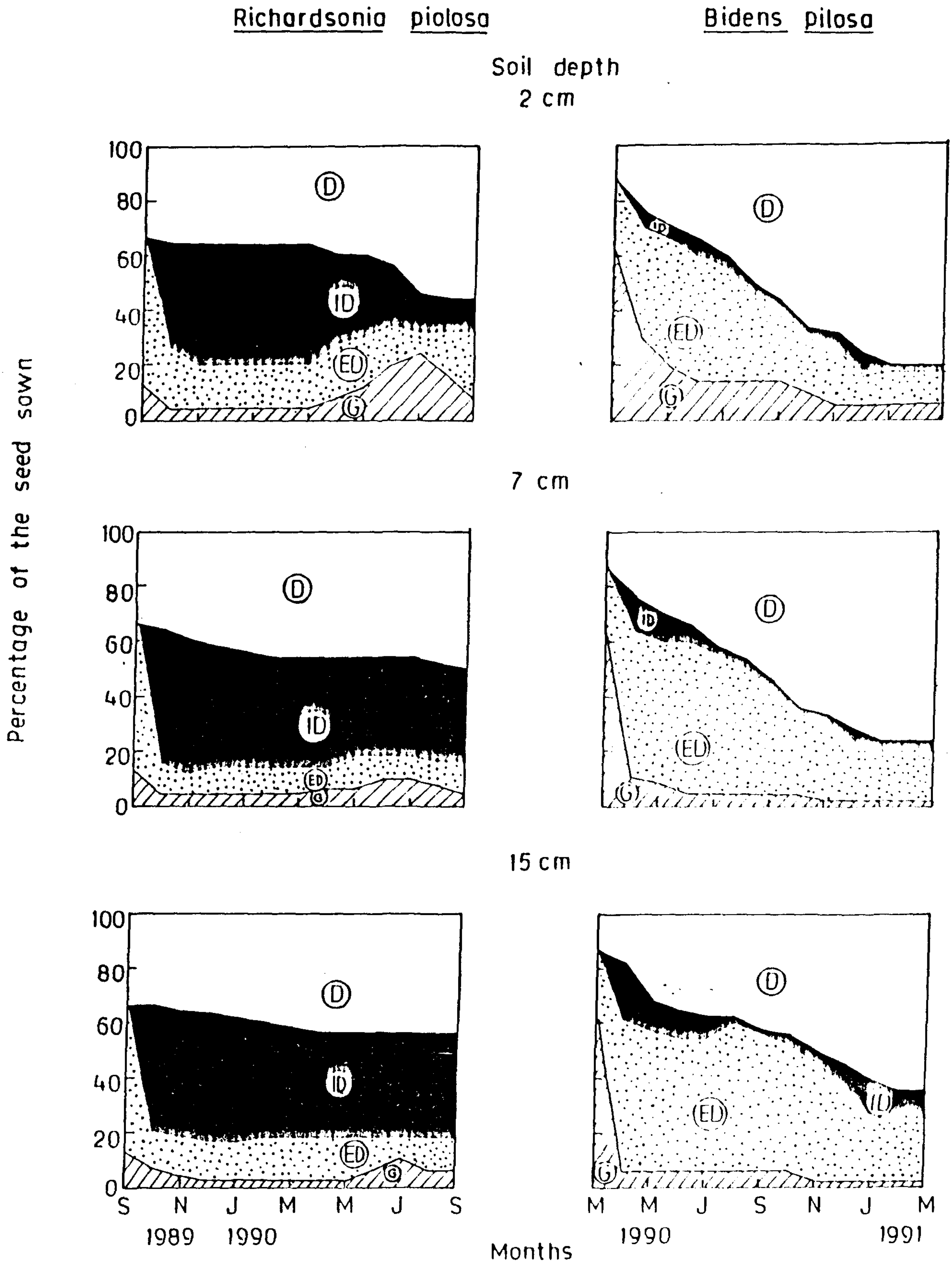

Fig. 9.3. Variation in the proportion of the different fractions of the dormant seed population of R. piolosa and B. pilosa with time. Key as in Fig. 9.1.

Induced-dormancy

Both depth and duration of burial had marked effect on the population of induced-dormant seeds. The seed population under induced-dormancy increased with the increase in soil depth. A significantly ($P<0.05$) higher percentages of seeds of S. arvensis, G. ciliata, P. alatum and A. artemisiifolia were observed to be under induced-dormancy during winter season compared to other seasons, while in other two species, the opposite was true (Fig. 9.3).

Germinable (non-dormant) seed population

Non-dormant seed population significantly ($P<0.01$) decreased with the increase in soil depth. After one month of burial, the percentage of germinable seed population declined in most weeds. P. alatum and A. artemisiifolia, however, did not show this trend (Fig. 9.2). Changes in non-dormant seed population were observed with increase in the duration time of seed burial. After six months of burial G. ciliata, S. arvensis, P. alatum and A. artemisiifolia showed increase in their non-dormant seed population in contrast to R. piolosa and B. pilosa which showed decrease in the germinable fraction of seed population after the same duration.

Changes in seed viability and dormancy after 1-year of burial

Seed viability in all weeds changed significantly

($P<0.05$) due to burial. After one year of burial the maximum reduction 66% in viable seed population at 2 cm soil depth was observed in the case of *B. pilosa*, while *R. piolosa* showed only 22% reduction. The viable seed population of *G. ciliata* and *P. alatum* also decreased considerably after 1-year burial; reduction in these two cases being greater than in *A. artemisiifolia* and *S. arvensis* (Table 9.3). The loss of viability was significantly ($P<0.01$) greater in the case of seeds buried at 2 cm depth than at greater depths (Table 9.3).

Burial caused significant ($P<0.01$) reduction in non-dormant or germinable seed population of weeds except in *P. alatum* and *A. artemisiifolia* (Table 9.5). After 1-year burial period, the germinable seed populations of *S. arvensis*, *G. ciliata*, *P. alatum* and *A. artemisiifolia* were significantly ($P<0.05$) lower compared to the corresponding values observed at the time of burial. The reduction in germinable fraction ranged from 3% in *S. arvensis* to 52% in *B. pilosa*. A higher proportion of initially non-dormant seed population of *S. arvensis*, *G. ciliata*, *B. pilosa* and *R. piolosa* became dormant after burial, while the opposite was true for *P. alatum* and *A. artemisiifolia* (Table 9.4).

Burial had a significant ($P<0.01$) effect in enforcing a greater proportion of the seed population to enter into dormancy at greater soil depths than at shallow depths. In

Table 9.4 - The fraction of populations of buried weed seeds that germinated (G), acquired enforced dormancy (ED), acquired induced dormancy (ID) and decayed (D), the living fraction in the soil (L) = (ID + ED) and the total seeds recovered (S)* from three different soil depths.

Species	2 cm depth						7 cm depth						15 cm depth					
	G	ED	ID	L	D	S	G	ED	ID	L	D	S	G	ED	ID	L	D	S
S. arvensis	27.1	20.9	5.2	26.1	46.8	100	20.3	30.0	6.6	36.6	43.1	100	14.9	36.3	11.1	47.4	37.7	100
G. ciliata	30.3	32.3	6.0	38.3	31.4	100	24.	37.9	6.0	43.9	32.0	100	18.1	46.8	7.5	54.3	27.3	100
P. alatum	16.6	15.2	4.8	20.0	63.4	100	13.	26.4	6.8	33.2	52.9	100	9.4	29.1	7.5	36.6	53.8	100
A. artemisiifolia	15.1	9.3	5.4	14.8	70.2	100	11.2	11.1	7.1	18.2	70.6	100	8.5	17.1	9.6	26.7	64.8	100
R. piolosa	9.6	19.7	29.2	48.9	41.5	100	6.1	13.7	36.8	50.5	43.4	100	4.8	16.6	40.0	56.6	38.6	100
B. pilosa	15.9	26.6	4.0	30.6	53.5	100	8.3	35.3	4.6	39.9	51.8	100	8.6	40.6	8.5	49.1	42.3	100

The values represent the pooled means over 12 months.

*S = G + L + D.

Table 9.5 - Change in the proportion (%) of germinable fraction of the weed seed population after 1-year burial at different soil depths.

Species	Soil depth (cm)		
	2	7	15
S. arvensis	- 2.9	-10.0	-15.1
G. ciliata	-21.7	-27.9	-33.5
P. alatum	+ 6.6	+ 3.8	- 0.5
A. artemisiifolia	+ 7.1	+ 3.2	+ 0.5
R. piolosa	- 2.5	- 5.9	- 7.2
B. pilosa	-44.2	-51.7	-51.4

- Denotes loss and + denotes gain.

fact, most of the weed seeds recovered from 2 cm soil depth were non-dormant (Table 9.4).

DISCUSSION

At the time of seed burial, a high degree of seed dormancy was shown by _P_. _alatum_, _A_. _artemisiifolia_ and _R_. _piolosa_. This indicates that perhaps, these species require some more time for after ripening. A high degree of initial seed dormancy reported in knotweed by Ransom (1935), Courtney (1968) and Conn & Farris (1987) and in _A_. _artemisiifolia_ by Willemsen & Rice (1972), has been attributed to the association of innate dormancy in these seeds at the time of burial. Hard seed coat present in _R_. _piolosa_ could be a barrier to seed germination in this weed. Seeds of _A_. _artemisiifolia_ and _P_. _alatum_ recovered after 2-3 months burial showed greater germinability indicating that burial in soil provided conditions which enhanced after ripening.

Significantly ($P<0.05$) larger number of viable seeds at greater soil depths than in the top soil layer indicates that seed longevity increases with the depth of burial. This has also been reported by several other workers (Dawson & Bruns, 1975; Egley & Chandler, 1978; Rampton & Ching, 1966; Roberts & Feast, 1972; Toole & Brown, 1946; Zorner _et_ _al_. 1984a, 1984b; Conn & Farris, 1987; Conn, 1990). Seeds present in the top layer of soil are always exposed to diurnal temperature fluctuation, high O_2:CO_2 ratio (Russell, 1961) and to stimulatory concentrations of nitrate ions in the soil solution (Roberts & Lockett, 1978). These factors promote germination, thereby bringing about reduction in viable seed population in the superficial layers of soil. On the other hand, factors associated with soil environment in deeper layers such as improper aeration (Bibbey, 1948), low soil temperature (Mukherjee et al. 1980), high CO_2 : O_2 ratio (Russell, 1961; Kidd, 1914a, 1914b; Thornton, 1945), induction of light requirement (Wesson & Wareing, 1967, 1969a, 1969b; Black, 1969) and production of volatile inhibitor (Holm, 1972) prevent seed germination to a great extent and enforce dormancy in the viable seeds. Seed population of the weeds showed differential response to depth and duration of burial. For example, S. arvensis seeds did not show any change in the germinable fraction of their seed population on burial, whereas the percentage of germinable seeds in P. alatum and A. artemisiifolia increased after a few months of burial. This is in sharp contrast to G. ciliata in which germinability jof seeds decreased and they entered into dormancy on burial (Fig. 9.1 and 9.2, Table 9.4). Changes in the dormancy status of the viable seeds of P. alatum and A. artemisiifolia due to burial as observed in the present study have also been reported by Courtney (1968), Willemsen & Rice (1972) and

Baskin & Baskin (1980). Seeds of these weeds when matured, attain innate dormancy (Primary dormancy) which may be broken by chilling (stratification) in laboratory (Payne & Kleinschmidt, 1961) or by the low temperature prevailing during winter (Courtney, 1968; Bazzaz, 1970; Willemsen, 1975; Baskin & Baskin, 1977). In B. pilosa, there was a highly significant (P<0.01) increase in the population of seeds with depth of burial indicating that a larger proportion of them are enforced into dormancy as the depth of burial increases. Presence of a larger proportion of dormant seeds of B. pilosa at greater depths compared to the germinable fraction indicates that germination at deeper soil layers was presumably inhibited due to non-availability of light indicating that the seeds of B. pilosa are photoblastic as also reported by Gorski (1975). Non-dormant seed population of R. piolosa did not show any variation until 9th month after burial. After 9 months burial there was a significant increase in the germinable fraction of its seed population, but the period during which the seeds were tested for germination represented rainy season; which indicates that it is a rainy season annual.

In S. arvensis, G. ciliata and B. pilosa a higher fraction of the seed population remained under enforced-dormancy throughout the burial period, while in R. piolosa, a greater proportion of the seed population always remained under induced-dormancy. The increase in enforced-dormancy associated with the decrease in germinable seed population at different soil depths depicts a possible transfer of a part of the non-dormant seed population to the enforced-dormant fraction of seed population. The burial of seeds also caused the transfer of a part of the seed population under enforced-dormancy to the induced-dormant fraction during spring and winter seasons and then a reversal from induced-dormancy to enforced-dormancy during rainy season. These shifts in dormancy-transfer were also clearly reflected in the seed population of *P. alatum* and *A. artemisiifolia*. The transfer of innate-dormant seeds to non-dormant or germinable fraction was yet another dormancy-transfer phenomenon in these two weeds.

Burial also had a marked influence on the status of the viable seed population as was evident from the seed viability test at the end of 12 months burial time (Table 9.4). The seeds of *G. ciliata* and *B. pilosa* which showed a high viability at the time of burial suffered greater loss of viability to a greater extent over a period of 1-year burial compared to the other species. A substantial reduction in seed viability observed in *B. pilosa* and *G. ciliata* over 1-year burial period depicts that their entire seed population can be depicted from the soil seed bank over the years. It implies that the severity of infestation of these two most abundant weeds of this region can be greatly minimised if the fresh seed input to the crop fields could be prevented.

CHAPTER X

Depletion in soil seed bank of different crop fields.

INTRODUCTION

The soil seed bank gets depleted due to *in situ* germination (Zorner *et al.*, 1984a), death, decay & decomposition of seeds and their removal through cultural operations and run-off water. The pattern of seed survival in soil is greatly influenced by these variables. The extent of loss of weed seed population through each one of these variables has not been, so far, quantified, though this aspect of study has great significance in devising an integrated weed management programme. Besides being important from weed control point of view; such a quantification is essential for a complete understanding of the dynamics of weed seed bank in soil. Thus the present chapter includes some data relating to weed seed losses from the crop fields.

STUDY SITES

The study was conducted in potato and cabbage fields under 'Jhum' and terrace cultivation at Upper Shillong and in maize and paddy fields under terrace cultivation on the ICAR farm at Barapani.

MATERIALS AND METHODS

From each of the crop fields selected for this study 36 soil cores (5.727 cm diameter down to 20 cm depth) were dug out and brought to the laboratory. The soil cores were kept in an oven at 105°C for 48 hrs to kill all the viable seeds present in the soil. These soil samples which were devoid of viable weed seeds, were put back in the crop fields at the pre-marked spots.

Seeds of six weeds viz. *B. pilosa*, *G. ciliata*, *A. haustonianum*, *S. arvensis*, *S. paniculata* and *E. indica* collected from the two study sites during February 1989 were kept at room temperature (8-18°C) for a period of 8 weeks. Six thousand healthy seeds from each weed species were mixed together and the mixed seed population was tested for viability and dormancy. These seeds showed 95-100% viability and had no dormancy. 36 samples of 1000 seeds each were taken from the mixed seed population. The seed samples were put in separate nylon bags (5 cm x 5 cm size and 50µ mesh diameter). These bags were buried at 0-10 and 10-20 cm depth in the pits which were filled with soil devoid of viable weeds seeds. Three replicate bags were sampled from each depth on each of the six sampling dates at bimonthly intervals. On each sampling date the seed samples were carefully dug out of the soil and the proportions of total viable (Vt), germinable (G), enforced-dormant (ED), induced-dormant (ID) and dead (D) seeds present in the total population of the recovered seeds were determined. Germinable fraction (G) of the seed population was calculated using the following expression.

$$G = (Vt) - (ED + ID)$$

The germinable fraction also includes the seeds that germinated in the soil but seedlings failed to emerge. The population of such seeds will be henceforth referred to as GSNE (germinated but seedlings not emerged) and the fraction of the seed population represented by the seedlings that emerge out will be referred to as GSE. The seedling population growing over the filled pits was considered equivalent to the seed population under GSE category. Since the seed packets were kept at different places for the two depths, it was possible to accurately determine the GSE fraction. The GSNE fraction was derived by subtracting GSE from the total germinable fraction (G). The losses due to predation, death, decay & decomposition are covered under GSNE. Soil disturbance and other agricultural operations were not allowed on the spots where the seed packets were buried. As far as possible the seed input to these spots was avoided by frequent removal of weeds that grew there and in the adjacent surrounding areas.

In order to determine the loss of weed seeds through run-off water along with sediments, an area of 2 x 2 m along the slope in each crop field was demarcated. The area was well protected by putting tin pieces on the three sides to avoid the entry of run-off water and sediments from the adjacent areas, while the fourth side i.e. bottom side of the 2 x 2 m slopy area was left open for the flow of run-off water down the slope. The run-off water and sediments were collected in a big tin (Ca 40 litre capacity) to determine the weed seed loss through run-off water. The samples were removed at 15 days interval during mild rainy periods and at frequent interval if the rainfall was heavy. The water and sediments containing weed seeds were filtered through a tier of three mesh sieves having pore diameters of 1.5, 0.7 and 0.5 mm, keeping 1.5 mm sieve at the top and 0.5 mm at the bottom. The seeds retained in different mesh sieves due to the difference in their size, were picked up with the help of a forcep and magnifying lens (x 10 times). The seeds were grouped into viable and non-viable categories after testing their viability.

The weed seed population that remained alive after varying periods subsequent to burial indicated the pattern of seed survival in relation to the duration of burial at two soil depths.

RESULTS

Seeds of 28 weed species were observed in the run-off water and sediments eroded from the crop fields (Table 10.1). The loss of seeds ranged from 87 m^{-2} in paddy field at ICAR farm to 156 m^{-2} in potato field under 'Jhum' cultivation at Upper Shillong. Out of the seeds thus lost, Ca 59% were viable (Table 10.1). The loss of weed seeds due to emergence of seedlings in different crop fields ranged from 338 in the linseed field under terrace cultivation to 1951 m^{-2} in the potato field under 'Jhum' cultivation (Table 10.2).

Pattern of seed loss from the buried weed seed population was dependent on the depth and duration of burial. After 2 months of burial, the viable seed population sharply declined to 20%, however, at subsequent sampling dates there was a steady loss in viable seed population. Viable seeds showed significantly ($P < 0.05$) greater persistence with increase in soil depth from 0-10 to 10-20 cm (Table 10.3). 20% of the seed population lost viability when buried at 0-10 cm soil depth, whereas only 15% of the seeds buried at 10-20 cm depth lost viability (Table 10.4).

The decrease in the population of viable seeds during burial could be due to various factors such as seed germination, death and decay decomposition of seeds. Depth of burial

Table 10.1 - Loss of weed seeds (number m^{-2}) from the various crop fields under 'Jhum' and terrace cultivation through run-off water and sediment removal.

Weed species	'Jhum'				Terrace (CPRS Farm)				Terrace (ICAR Farm)			
	Potato		Cabbage		Potato		Cabbage		Maize		Paddy	
	V	NV	V	NV	V	NV	V	NV	V	NV	V	NV
S. arvensis	32	17	14	9	21	14	19	11	-	-	-	-
Galinsoga spp.	21	14	13	13	14	9	20	14	18	16	14	12
P. alatum	8	3	6	4	4	3	4	3	-	-	-	-
A. artemisiifolia	2	4	2	2	1	5	2	1	-	-	-	-
D. adscendens	3	5	1	2	2	1	1	1	-	7	6	2
D. cordata	1	-	-	-	-	1	-	2	1	-	-	-
P. latispicatus	2	1	1	3	4	2	2	1	-	-	-	-
Isachne sp.	1	-	2	1	3	1	2	1	-	-	-	-
Bidens pilosa	-	-	-	-	-	-	-	-	3	2	8	4
Ageratum spp.	-	-	-	-	-	-	-	-	12	6	10	2
R. pilosa	-	-	-	-	-	-	-	-	3	2	2	2
Setaria spp.	7	5	2	4	1	3	2	2	1	4	2	1
S. paniculata	-	-	-	-	-	-	-	-	2	1	3	3
B. hispida	-	-	-	-	-	-	-	-	1	2	2	-
A. benghalensis	-	-	-	-	-	-	-	-	1	1	-	-
E. sonchifolia	-	-	-	-	-	-	-	-	3	1	-	2
I. cylindrica	-	-	-	-	-	-	-	-	1	-	-	1
Oxalis sp.	8	3	4	2	2	1	2	2	1	2	2	1
Unidentified species (7)	13	6	8	4	3	3	4	2	11	3	7	2
Total	98	58	53	44	55	43	58	40	58	47	55	32

V - Viable, NV - Non-viable seed.

Table 10.2 - Loss of weed seeds (number m^{-2} ± S.e.m.) due to seedling emergence (GSE) in different crop fields under 'Jhum' and terrace cultivation.

Type of Cultivation	Crop field	Number m^{-2}
'Jhum'	Potato	1951±126
	Radish	1036±66
	Cabbage	1235±116
	Cabbage + Radish (mixed)	1339±111
	Mean	1390±171
Terrace (CPRS Farm)	Potato	1067±76
	Radish	567±67
	Cabbage	667±104
	Cabbage + Radish (mixed)	809±48
	Mean	778±94
'Terrace-normal' (ICAR Farm)	Linseed	338±20
	Maize	906±20
	Mustard	491±52
	Paddy	603±43
	Mean	585±104
'Terrace-dibbling' (ICAR Farm)	Linseed	420±16
	Maize	382±14
	Mustard	406±24
	Paddy	404±21
	Mean	403±7

Table 10.3 - The effect of soil depth on seed depletion from buried germinable seed population as a percentage of the total buried seed population.

Burial period* (Months)	% of buried seed population			
	GSE		GSNE	
	Depth		Depth	
	0-10 cm	10-20 cm	0-10 cm	10-20 cm
0	0	0	0	0
2	91.1	30.0	8.9	70.0
4	91.7	26.7	8.3	73.3
6	80.0	20.0	20.0	80.0
8	85.0	25.0	15.0	75.0
10	80.0	30.0	20.0	70.0
12	85.0	15.0	15.0	85.0

* Period in months after seed burial on 14th April 1989, GSE - the population of seeds which germinated in the soil and emerged out over the the filled pits, GSNE - the population of seeds which germinated but the seedlings failed to emerge.

Table 10.4 - The effect of depth and duration of seed burial on viability of the burial seeds.

Burial period* (months)	% Viability Depth 0-10 cm	 10-20 cm
0	100	100
2	80	85
4	74	82
6	72	80
8	71	78
10	70	76
12	69	74

* Period in months after burial on 14th April 1989. Values are means of three replicates of 1000 seeds.

had a significant (P< 0.01) effect on the depletion of the viable seed population. Seed exhaustion during germination followed by failure of seedlings to emerge out of the soil caused greater mortality in the case of seeds buried at 10-20 cm depth than at 0-10 cm. As revealed by the seed population under GSE category, the chances of seedlings emerging out of the soil increased with decrease in depth of burial.

DISCUSSION

The viable seed population showed a decline just after two months of burial. The reduction in viable seed population during burial may be attributed largely to germination of seeds in the soil. Though a good proportion of the seed population buried at 10-20 cm soil depth germinated, the seedlings failed to emerge out of the soil. Such seeds obviously cannot contribute to the weed infestation. The increase in proportion of such seeds in the seed bank would obviously have a negative effect on weed population. Schafter & Chilcote (1969) pointed out that emerging organs of the germinating seeds deteriorate rapidly unless the seed is near enough to the surface to develop into a functional plant. Cavers (1983) stated that if the seeds having a reduced amount of endosperm tissue are buried in too deep they might not be able to merge from a depth in the soil, which is otherwise regarded as critical or optimal depth for seedling establishment.

The viable seeds lying at 0-10 cm depth decayed faster than those at 10-20 cm soil depth indicating that seeds buried in deep soil can survive longer than those present in the surface layer of the soil. Roberts & Feast (1972) and Cavers (1983) reported that "seeds from deeper layer always tend to remain dormant for longer period and suggested that they must be brought nearer the surface by cultivation or by some other means if they are to give seedlings." The pattern of seed decay is akin to the exponential decay curve observed by Roberts (1970) and Harper (1977).

Weed seed loss from the crop fields by various other means may also have considerable influence on the seed pool. Egginton & Robbins (1920) reported that seeds of 81 species of weeds are lost through irrigation water in Colorado, USA. Dastgheib (1989) have reported a loss of 53-120 seeds m^{-2} 24 hr^{-1} through irrigation water. In the present study, an average of 76 and 57 viable seeds m^{-2} were lost from 'jhum' and terrace fields, respectively through run-off water, which are equivalent to 760,000 and 570,000 ha^{-1}. Majority of the species produced light seeds which had high degree of buyoncy. This helps them in dispersal by wind and water since such seeds can easily be carried to long distances.

Seed loss also occurs through farm tools and stalked hay particles as reported by Fryer & Makepeace (1977) and King (1974). However, this aspect could not be taken up in the present study as there was some difficulty in collecting reliable and accurate data. As revealed by the data, the loss of weed seeds from the soil seed bank is very high and this would mean that in course of time, the seed bank may get exhausted if no fresh inputs are there. This would be helpful in containing the weed density in the crop fields. However, the input and output data as summarised in Table 10.5 depicts that the population of weed seeds added to the crop fields is much larger than the weed seed losses. This aggravates the weed problem.

The major input of weed seeds is through seed rain, while seed germination is the major process causing depletion of soil seed bank. There have been losses of viable weed seeds to the extent of 8,711-15,217 m^{-2}, while the seed inputs to the crop fields were far much larger (666,291-1,671,404 m^{-2}). Evidently, there is a substantial gain to the soil seed bank, which is of course, reflected in serious weed problem encountered in the agroecosystems of Meghalaya.

Table 10.5 - Inputs to/outputs from the viable soil seed bank of different crop fields at Upper Shillong and Barapani.

Factors	Upper Shillong		Barapani	
	'Jhum'	Terrace	'Terrace-normal'	'Terrace-dibbling'
Inputs: (A)				
Seed rain (a)	1,671,362	1,023,486	665,923	1,355,858
Contaminated crop seed (b)	<1	<1	<1	<1
FYM application (c)	42	289	368	<1
Total (a+b+c)	1,671,404	1,023,775	666,291	1,355,858
Outputs: (B)				
Seedling emergence (GSE) (a_1)	16,680	9,336	7,020	4,832
Seedling emergence (GSNE) (b_1)	5,608	5,824	4,684	3,822
Run-off water (c_1)	76	57	57	57
Total (a_1+b_1+c_1)	22,364	15,217	11,761	8,711
Balance (A-B)	**1,649,026**	**1,008,550**	**654,494**	**1,347,111**
Existing soil seed bank (C)	1,572,000	972,000	612,000	27,900
Unaccounted soil seed population (A-B)-(C)	77,026	36,550	42,494	1,319,211

The values (number m^{-2}) are pooled means for different crop fields on an annual basis.

CHAPTER XI

General Discussion

The data presented in the foregoing chapters reveal that the weed flora is in a state of flux and is determined by various factors which are themselves interlinked. The type of crop rotation practised and the kind of crops grown played important role in determining the species composition of weed flora as well as the soil seed bank. The successive growth of different crops in the same field on rotational basis provided a variety in the competitive environment of the weed population and brought a change in the number of fertile plants and their reproductive capacity, which in their turn, influenced the species composition and size of the soil seed bank. It is worth noting that only a few species are the major contributors to the soil seed bank and all of them are annuals. As for example, the annuals like *Spergula arvensis*, *Galinsoga ciliata*, *Polygonum alatum* and *Ambrosia artemisiifolia* together accounted for 86% of all the seeds recovered from the soil seed bank of different crop fields at Upper Shillong. *S. arvensis*, the most abundant weed in the crop fields at Upper Shillong, contributed 64% (Chapter IV). In the crop fields at ICAR farm, Barapani, the major contributors to the soil seed bank were *Ageratum* spp., Richardsonia piolosa and Bidens pilosa. Together they accounted for 66% of the total weed seed population in soil. Several other workers (e.g. Kropac, 1966; Roberts & Stokes, 1966; Fekete, 1975; Sarkany, 1975; Kazantseva & Tuganaev, 1972; Dvorak & Krejic, 1974; Lockett & Roberts, 1976; Fryer & Makepeace, 1977; Leguizamon et al., 1979; Leguizamon & Cruz, 1980 and Roberts, 1981) have also reported that the annual weeds are the main contributors to the weed seed bank in arable soil.

The species composition of the weed flora of a particular crop field was also dependent to some extent on the crop type and duration of crop cycle. The occurrence of a larger number of weed species in the maize field compared to the other crop fields under the same type of cultivation at Barapani may be attributed to the longer crop-cycle of maize than the other crops (Chapter V). This finding is in conformity with that of Saavedra et al. (1990). The seasonality of the crops seems to have some influence on the emergence of weeds, their flowering and seeding time (Chapters IV and V). The number of perennials was greater in the less disturbed crop fields than in more disturbed fields, which suggests that in the less disturbed situation the perennial weeds become more abundant. On the other hand, intensive agricultural operations as practiced in the crop fields under terrace cultivation, seem to have favoured the annuals like *B. pilosa*, *R. piolosa*, *A. conyzoides*, *A. haustonianum* and *G. ciliata* which completed their life cycle before the crops were harvested (Chapter V). This was, perhaps, one of the reasons for the preponderance of seeds of annual weeds in the soil seed bank (Chapters IV and V).

The species composition of the weed flora was linked with the species composition of the soil seed bank particularly in the crop fields at the lower elevation (i.e. the ICAR Farm at Barapani). Majority of the weed species present in the soil seed bank were also represented in the weed flora. In fact, the presence of such weed species in the soil seed bank is attributable to the seed rain from the existing weed population (Chapters IV and V). The altitude-induced variations in temperature, moisture and rainfall appear to be quite important in determining the species composition of the weed flora as well as soil seed bank. The seed production by total weeds in the crop fields at upper elevation was significantly greater than those at lower elevation, which may be ascribed to greater abundance of such weeds at upper elevations which produce seeds in larger numbers. Production of larger number of seeds in *G. ciliata* in the crop fields at upper elevation (Chapter VI) compared to lower elevation indicated that, perhaps, the higher rainfall and relatively less soil disturbance in the former contributed to better survival and more luxuriant growth of this weed. The survival of greater number of weed plants till seeding would mean more input through seed rain and larger soil seed bank at Upper Shillong than at Barapani (Chapters IV and V).

Seed production by the whole weed population declined in the second year of the study compared to that in the first year. Individual weeds showed conspicuous seasonal fluctuation in seeding/seed output which was largely dependent on the number of fertile plants surviving till maturity. This is in contrast with the findings of Harper & Gajic (1961) who reported that the seed output per unit area by Agrostema githago remained constant over a wide range of sowing density. However, there are reports (Hickman, 1975; Rai & Tripathi, 1982; Yadav & Tripathi, 1981) suggesting that the seed production is mainly determined by the prevailing environmental conditions.

Although most of the component species of the weed flora were also present in the soil seed bank, in few instances, this was not true. It was interesting to note that though the seeds of D. adscendens, Isachne sp. were present in the radish field and mixed crop field, their seedlings were absent from these fields, whereas they were present in the neighbouring fields. Conversely, in the case of E. indica, seedlings were present in the field but seeds were not present in the soil. These differences may be attributed to several factors, which need to be pinpointed.

The time of the year at which the land preparation is made for crop sowing had a marked influence on the emergence of different weeds, their establishment and on the weed seed dynamics. During land preparation, a large number of seeds from the surface soil layers is thrown to the deeper layers of soil, while a smaller number of seeds present initially in the deeper soil layers is brought to the surface soil. This causes disturbance in the depth-related distributional trend of the buried weed seed population (Chapters IV, V and VII). When seed input was prevented or minimized by regular weeding, the soil seed bank was sharply reduced by 26-32% over 1-yr period and by 34-46% at the end of the second year (Chatper VII). This is in agreement with the findings of Roberts (1962, 1981), Roberts & Dawkins (1967), Lozovatskay (1968), Roberts & Feast (1972), Roberts & Feast (1973b), Kolesnikov & Sidarov (1974), Fekete (1975), Dechkov & Atanassov (1976), Lueschen & Andersen (1978), Warnes & Andersen (1978) and Barralis et al. (1988), who have shown that in the absence of significant production of fresh seeds, the number of viable weed seeds in arable soil, which is subject to frequent cultivation, decreases exponentially.

The size of the soil seed bank partly reflects the history of the land and, to some extent, the soil management practices. The presence of a larger soil seed bank in different crop fields under 'Jhum' than under terrace cultivation is largely attributable to the long fallow period in the former before the crop fields were again brought under cultivation in 1988. This might have allowed luxuriant growth of the weeds and caused large input of weed seeds into the soil. On the contrary, continuous cultivation for the last eight years with regular use of herbicides and crop rotation in the fields under terrace cultivation might have been responsible for the lower weed seed input in the soil and reduction in soil seed bank (Chapter IV). Perhaps, this was also one of the reasons of smaller soil seed bank in different crop fields at lower elevation (Chapter V) where terrace cultivation was practised. The size of the soil seed bank at any time depends upon the balance between the total seed input into the soil and total seed output from the soil. Seed rain and application of farmyard manure are among the major sources of weed seed input into the arable soil as reported in Chapter VI, while seed germination is the major source of weed seed loss from the soil seed bank (Chapter X). As suggested by the data, the contaminated crop seeds were not so important from the weed-infestation point of view. The surface run-off down the hill slopes caused considerable depletion in the soil seed bank (Chapter X). These findings are largely in agreement with those of Salisbury (1942), Egginton & Robbins (1920), Dastgheib (1989), Toky & Ramakrishnan (1981), Dore & Raymond (1942), Boeker (1959) and Sugawara & Lizumi (1964).

The buried weed seed population as observed in the present investigation has been compared with the available data for temperate and tropical and sub-tropical agricultural soils of the world (Table 5.6 and 5.7). The large weed seed bank in soil and the capacity of buried weed seeds to remain viable for longer period (Table 9.4) bring about weed infestation for several years even in absence of fresh input jof weed seeds into the cropland, making the weed control programme less effective. Several flushes of weed seedlings were observed to emerge in the crop fields at the ICAR Farm as observed in the present study (Chapters IV and V) and as also reported by Pradhan (1990) and Misra _et al_. (1992), which indicates that seeds come out of dormancy in batches from the large soil seed bank at different times during the crop cycle.

The weed species differed in their contribution to the soil seed bank and their relative contribution was not determined only by the quantity of seeds produced by them. For example, _G. ciliata_ and _Ageratum_ spp. produced large quantities of seeds, but they did not contribute to the soil seed bank to the same extent. On the other hand, the seed production by B. pilosa and A. artemisiifolia was small but their contribution to the soil seed bank was proportionately larger (Chapters IV, V and VI). Thus many a time, there is no intimate link between the number of seeds produced and the number of seeds reaching the soil seed bank. This is in agreement with McNaughton & Wolf (1979) who stated that the plants producing passively dispersed seeds spread by wind and gravity (e.g., G. ciliata, Ageratum spp., E. sonchifolia) produce more number of seeds and have a larger wastage compared to the plants producing actively dispersed seeds spread by becoming attached to mobile organisms (e.g., B. pilosa).

The dormant fraction of weed seed population was much larger in the case of seeds buried in the deeper layers of soil compared to those in the surface soil. This could be attributed to several factors such as, lack of light, low soil temperature and poor aeration in the soil-seed environment at deeper soil layers which enforced a larger fraction of seed population to enter into dormancy. The higher CO_2 evolution rate at deeper soil layers compared to the surface soil induced dormancy in larger number of seeds (Chapter VII) at deeper soil layers. These findings are in agreement with the earlier reports (Wesson & Wareing, 1967; 1969a; 1969b; Black, 1969; Gorski, 1975; Mukherjee et al., 1980; Schafter & Chilcote, 1970 and Hay, 1962). Seeds present in the surface soil layer, generally, have an access to greater number of 'safe microsites' than those buried in deeper layers. In the former case, they are subjected to the dirunal temperature fluctuation and get better aeration, which tend to favour their germination and establishment. This could be the possible reason for the germination of a greater proportion of the weed seeds lying at 0-10 cm soil depth (Chapter X) than those at 10-20 cm depth. Compared to the jhum fields, germination and seedling emergence were observed to be better in the terrace fields subjected to more frequent weeding and other agricultural disturbances which act as trigger for germination.

Seeds of some of the weeds (e.g. G. ciliata, B. pilosa) entered the soil seed bank mostly in readily germinable condition, while in the case of other species (e.g. P. alatum, A. artemisiifolia, R. piolosa) they entered the soil mostly in dormant condition (Chapter IX). However, their germinability and dormancy status were altered when they remained buried in the soil for longer period. Seeds of the former two species were enforced into dormancy, while those of the latter three weeds which had entered the soil in dormant state (innate dormancy) became non-dormant during winter and were capable of germinating in Spring and then they re-entered the dormant state. On the other hand, seeds of G. ciliata, B. pilosa and S. arvensis which showed three germination peaks during a year, failed to germinate during winter season as they developed low temperature-induced dormancy. The changes in the status of dormancy due to burial indicated that the buried seeds undergo an annual dormancy - non-dormancy cycle. The findings of several earlier investigators (summarised by Baskin & Baskin, 1985), also indicate that weed seeds in soil go through annual dormancy - non-dormancy cycles, exhibiting a continuum of changes in physiological responses.

The cultivation practice had a marked effect on the longevity and dormancy of weed seeds. In the crop fields under 'jhum' cultivation greater proportion of soil seed bank was in dormant state. This may be attributed to less soil disturbance/soil inversion and absence of many agricultural operations in jhum cultivation. On the other hand, greater depth of ploughing in the crop fields under terrace cultivation helped in bringing the buried seeds to the soil surface where light requirement was met and other factors were also favourable for germination. Thus a large fraction of weed seed population could come out of the dormancy enforced on them, as indicated by the smaller population of viable-dormant seeds in the soil seed bank under terrace cultivation compared to the jhum fields (Chapters VII and IX). This is further confirmed by the rapid depletion of the soil seed bank of the crop fields under terrace cultivation when the seed input to the fields was prevented (Chapters IV and VIII). The emergence of larger population of seedlings during cropping periods than during the fallow period as observed in the present study (Chapters IV and V) also substantiates that soil disturbance is helpful in overcoming the enforced dormancy.

In conclusion, it may be said that the soil seed bank is in a state of flux. The seeds enter into the bank and leave it, and while remaining in it they undergo physiological changes which can affect their response to the present and future environment. When the weed seeds enter into the soil seed bank in readily germinable condition, the weeds can rapidly colonize and establish by competing with the crop plants. The readily germinable weed seeds do not pose much of a problem in weed control, but those remaining in the soil for longer period in viable-dormant condition, adversely affect the economic return from the croplands by giving rise to weed plants which compete with the crops at a time

it is quite undesirable. The 'jhum' fields which are generally subjected to least soil disturbance retained much larger viable weed seed population in the soil compared to the terrace fields. Thus, whenever such fields are brought under terrace cultivation or any other type of cultivation involving soil disturbance, a large number of weed plants result from the germination of the viable-dormant fraction of the weed seed bank in soil. Potentially large weed seed reserve and unchecked weed growth in the crop fields under 'jhum' cultivation may give rise to high weed density which may cause a serious competition to the crops grown in the jhum fields. The weed seeds present in deeper soil layers could be brought on the surface by ploughing to enable them to come out of enforced dormancy. These seeds can then germinate and the weed seedlings thus emerged may be knocked down using suitable herbicides.

The study provides a meaningful comparison of the species composition of weed seed bank in soil, vertical distibution of weed seeds, their dormancy status and dynamics, in relation to soil microenvironment, and input and output of weed seeds in different crop fields under jhum and terrace cultivation. However, a quantiative analysis of the effect of ploughing on the distribution of weed seeds which forms an important aspect of weed seed dynamics in arable soil could not be made. There are indications that such an analysis may not only provide clues for a better understanding of weed seed dynamics but may also provide information which could be profitably used for evolving suitable weed management programmes. Therefore, this aspect needs to be studied in future.

Summary

The present investigation on the dynamics of buried weed seed population was carried out during October 1988 to September 1990, in potato, radish, cabbage and cabbage-radish (mixed) crop fields under two contrasting types of cultivation viz., 'Jhum' (shifting agriculture) and terrace cultivation at Upper Shillong (altitude 1825 m asl) and during March 1989 to February 1991, in linseed, maize, mustard and paddy fields under terrace cultivation at ICAR farm, Barapani (altitude 952 m asl). Upper Shillong is 12 km south and Barapani is 22 km north of Shillong, the capital of Meghalaya. In Upper Shillong, the 'jhum' and terrace fields are 4 km apart. The terrace cultivation at Barapani is of two types viz., 'terrace-normal' (sowing done on the terraces after tilling the soil) and 'terrace-dibbling' (crop sowing done through dibbling). The 'terrace-normal' and 'terrace-dibbling' fields selected for the study at Barapani are adjacent to each other.

The soil of the study sites is lateritic, silty loam to clay loam, pale brown to deep brown in colour and acidic (pH 5.1 - 5.7) in reaction.

The study was made to cover the weed seed input to the crop fields through seed rain, farmyard manure and contaminated crop seeds; species composition of the soil seed bank and weed flora; distribution of seeds in soil; density, seasonal and depth-related variation in buried weed seed population; dormancy status of the buried weed seeds and changes in the proportion of germinable, enforced-dormant, induced-dormant and non-viable seed population in relation to the ongoing changes in the soil-seed microenvironment such as temperature, moisture, pH and CO_2 evolution; weed seed loss from the crop fields through germination of seeds while still buried in soil, their decay and decomposition and removal with run-off water. The major findings of the study are as follows:

1) The weed flora of the crop fields under 'jhum' and terrace cultivation at Upper Shillong was composed of a total of fourteen species while that of the crop fields under 'terrace-normal' and 'terrace-dibbling' cultivation at ICAR farm, Barapani had a total of thirty-two species. The seeds of most of these weeds were also present in the soil seed bank.

2) The species represented in the soil seed bank were mostly the annual weeds and the major proportion of the soil seed bank was contributed by them. Four dominant weeds viz., *Spergula arvensis*, *Galinsoga*

ciliata, *Polygonum alatum* and *Ambrosia artemisiifolia* together accounted for 86% of all the seeds recovered from the soil seed bank of different crop fields at Upper Shillong. In the crop fields at ICAR farm, Barapani, the major contribution to the soil seed bank was by *Ageratum* spp., *Richardsonia piolosa* and *Bidens pilosa* which accounted for 66% of the total weed seed population in soil.

3) The weed seed population showed conspicuous seasonal fluctuation in all the crop fields. The soil seed bank during winter months was larger than that during rainy season.

4) The soil seed bank under 'jhum' cultivation was larger than that under terrace cultivation at Upper Shillong. The weed seed population in soil under 'terrace-normal' cultivation was higher than that under 'terrace-dibbling' cultivation at ICAR farm, Barapani.

5) Among the different crop fields at Upper Shillong, cabbage had the maximum buried weed seed population and radish, the minimum. At ICAR farm, Barapani, the maize field had the highest soil seed bank, while linseed, the smallest.

6) The ratio of weed seedlings to total viable weed seeds at 0-20 cm soil depth was significantly ($P<0.05$)

higher in the terrace fields compared to the 'jhum' fields at Upper Shillong. At Barapani, it was higher in the fields where crop sowing was done after tilling the land than in those fields where crop sowing was done by dibbling. During the cropping period, maximum seedling recruitment was recorded in the radish field and minimum in the cabbage field irrespective of the type of cultivation at Upper Shillong. At Barapani, maximum seedling recruitment was noticed in the linseed field and minimum in the maize field under both 'terrace-normal' and 'terrace-dibbling' types of terrace cultivation. The weed seedling recruitment during the cropping period was significantly ($P<0.05$) higher than that observed during the fallow periods.

7) Individual weeds showed conspicuous seasonal fluctuation in their seed production which was mainly dependent on the number of fertile plants surviving to maturity. The seed production by all the weeds was significantly higher in the 'jhum' field compared to terrace fields. The seed output by all the weeds during 1988-89 was higher than during 1989-90 both at Upper Shillong and Barapani.

8) Seeds of thirty-seven species were present in the samples of farmyard manure. About 64% of the seeds

recovered from FYM samples were found to be viable. Seeds of thirteen weed species were recorded from the crop seed samples. The number of viable seeds of different weed species that entered into the crop field through FYM was very large compared to those which entered through contaminated crop seeds. About 26% of the weed seeds present in soil was attributed to FYM application, while the contaminated crop seeds contributed only 0.01%.

9) The germinable seed population of S. arvensis, G. ciliata, P. alatum and A. artemisiifolia was greater in the terrace fields than in the 'jhum' fields and it declined with increasing soil depth in both 'jhum' and terrace fields at Upper Shillong. The proportion of seeds under enforced-dormancy, however, increased with depth down to 15 cm, and beyond this depth it declined. The population of the induced-dormant seeds gradually increased with increasing soil depth, however, difference due to depth was significant ($P<0.01$) only in the case of P. alatum and A. artemisiifolia. The proportion of non-viable seeds was always greater in deeper layers of soil than in the surface layers in both 'jhum' and terrace fields.

10) Soil temperature and moisture were positively correla-

ted with the germinable fraction of the soil seed bank. Soil temperature showed a positive correlation with the seed population under enforced-dormancy in the case of all weeds except *S. arvensis*. CO_2 evolution was strongly related with the induced-dormant fraction of the soil seed bank. Soil pH had no effect on germinable seed population of weed species in the 'jhum' field and had very little effect in the terrace field.

11) Seeds of *S. arvensis*, *P. alatum*, *G. ciliata* and *A. artemisiifolia* showed better germination during rainy season and then entered into the state of enforced-dormancy during late part of this season. As winter approached, many of them became induced-dormant. In all the species except *S. arvensis*, seeds held in enforced-dormancy during rainy season encountered conditions which caused induced-dormancy to develop.

12) A distinct variation in the total buried seed population along depth and time was observed in *S. arvensis*, *G. ciliata*, *P. alatum* and *A. artemisiifolia*, but this was not true during February-March and September-october. Size of the weed seed population varied markedly with the type of cultivation. The seed populations of *S. arvensis* and *P. alatum* were significan-

tly ($P < 0.05$) greater in the crop fields under 'Jhum' cultivation than under terrace cultivation, while the opposite was true for G. ciliata and A. artemisiifolia.

13) Proportion of viable seeds showed a significant ($P < 0.05$) increase through soil depth. It also varied with the type of crops and was significantly ($P < 0.05$) higher in the crop fields under 'Jhum' cultivation than those under terrace cultivation. Among different crop fields maximum number of viable seeds was recorded in the mixed culture (cabbage + radish) and minimum in the potato field at Upper Shillong regardless of the type of cultivation.

14) The viable seed population of the four dominant weed species at Upper Shillong viz., S. arvenis, G. ciliata, P. alatum and A. artemisiifolia decreased due to weeding. S. arvensis suffered a greater loss in the viable seed population than other species in the frequently weeded plots. Under low frequency of weeding, the individual species showed differential response. A. artemisiifolia and P. alatum responded to low frequency of weeding by reducing their viable seed population to a considerable extent in all the crop fields in both years, while the other two species

viz., S. arvensis and G. ciliata did not show any decrease in their viable seed population.

15) The frequently weeded plots showed greater reduction in viable seed population than the less frequently weeded fields. The reduction was greater during the second year ('Jhum' - 34%, terrace - 46%) than during the first year ('Jhum' - 26%, terrace - 32%).

16) Species differed significantly ($P < 0.05$) with respect to their seed viability at the time of burial. G. ciliata and B. pilosa had lesser proportion of viable-dormant seeds compared to other four weeds viz., S. arvensis, P. alatum, A. artemisiifolia and R. piolosa. A higher degree of seed dormancy was noticed in P. alatum and R. piolosa at the time of burial compared to the other weeds.

17) Burial depth had a significant ($P < 0.05$) effect on seed viability of the weeds. Viability of the weed seeds was greater at 15 cm than at 2 cm soil depth. Duration of burial had also a significant effect on seed viability. After 1-yr burial at 2 cm soil depth the viable seed population of B. pilosa showed maximum reduction (66%) while R. piolosa showed only to 22% reduction at 2 cm soil depth.

18) Burial had a significant effect on the germinable seed population of S. arvensis, G. ciliata, B. pilosa and R. piolosa, however, it did not affect the germinability of seeds in P. alatum and A. artemisiifolia.

19) Viable seeds in soil showed greater persistence with increase in soil depth i.e., seeds buried in deeper soil layers showed greater viability than those present in surface layer of soil.

20) The depletion in the buried viable seed population was considerably influenced by the depth of burial. Loss of seeds through in situ germination in soil followed by the failure of seedling emergence increased with soil depth. Conversely, the number of weed seeds that germinated and contributed to seedling recruitment decreased with increase in depth of burial.

21) Seeds of twenty-eight weed species were observed in the run-off water and sediments eroded from the crop fields. About 59% of the seeds lost through surface run-off was viable. In general, the loss of buried viable seed population through various means was greater from the crop fields under terrace cultivation than under 'jhum' cultivation.

22) The weed seed population flux was regulated by the

seed rain and seed germination determined by various microenvironmental factors induced by the variation in altitude, crop canopy, type of cultivation and weeding frequency.

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* Original not seen.