Ecological Implications of Soil Seed Bank in Conservation of Grassland of Moist Tropics, India

Upama Mall[1] Kuumari Poonam[2] Gopal S. Singh[3]*

[1,2] Centre of Advanced Study in Botany, Banaras Hindu University, Varanasi-221005 UP, India

[3] Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi-221005, UP, India

Abstract –

Backgrounds: Grassland is one of the most important ecosystems of the world which benefits human directly or indirectly needs to be conserved.

Aims: To examine whether and to what extent soil seed bank has significant role in conservation of grassland of moist tropics.

Methods: Seedling emergence method (seeds m-2) was used for analysis of soil seed bank. Phyto-sociological studies (IVI, biodiversity parameters, similarity index,) were carried out for both soil seed bank and above-ground vegetation. ANOVA, PCA, correlation, regression were used for different statistical analyses.

Results: Large quanta of viable seeds (28450-30750 seeds m-2) were germinated in moist tropical grassland. Significant seasonal ($p < 0.001$) and depth variation were found in germination of seed from soil seed bank. Mainly persistent seed banks play important role in conservation. Most of the species were common in both soil seed bank and above-ground vegetation. High similarity (0.72, 0.55) and positive moderate correlation ($r2 = 0.25$, $p < 0.05$) was found between seed bank and above-ground vegetation.

Conclusion: This result predicted that seed bank can be one of the best options for in situ conservation of grassland of moist tropics, as many others were also reported for various ecosystems of the world.

Key-Words: Soil Seed Bank; Above-Ground Vegetation; Biodiversity Indices; Principal Component Analysis; Grassland Ecosystem; Moist Tropics.

---------------------------------x---------------------------------

INTRODUCTION

Grassland or grazing land (include perennial and annual herbs, grasses, sedges and forbs) are a dominant land use practices globally (Bugalho and Abreu 2009). In spite of the prevalence of acclimate which except in the alpine zones of the Himalayas, favors tropical forest, about 72 million hectares of India are under grasslands (Misra 1978). Although, the grasslands are getting under human and biotic pressure like cattle grazing, fire, agricultural expansion, urban encroachment, habitat destruction and removal of forest but they are key sites for biodiversity conservation (IUCN 1993). Within this dynamic landscape, plant communities are in turn influenced by fire, grazing, cutting and soil moisture gradients and they are strong growers, accumulating a large amount of biomass in such growing season and their seeds are displaced by wind and animals (Lehmkuhl 1994). Grazing is a land use covering approximately 3300 million ha (more than 25%) of the global land surface which makes it the largest and most extensive land use of planet earth (Asner et al. 2004). India has 2.7 AU (animal units) ha^{-1} grazing system (Bugalho and Abreu 2009) where grassland have traditionally been used all around the world for grazing and livestock production fetching products such as milk, meat, fiber, wools and others.

The soil seed bank is reserve of mature viable seeds located on the soil surface or buried in soil, duff or litter (Roberts 1981) and represents an important component in the development and maintenance of plant communities (Simpson 1989). When a seed arrives at soil surface, it may germinate immediately or persist in the soil for a short or long period (Shen et al. 2011). The soil seed bank represents the potential of latent plant populations since it is the source for population replacement (Harper 1977; Han and Zhao 2011). The knowledge of the seed bank and understanding of the population dynamics of buried viable seeds is practical importance in agriculture, forestry and grassland conservation (Li et al. 2011). Various aspects of soil seed bank are known, describe distribution pattern, and dynamics of their density in the soil (Li et al. 2003) harbor seed rain accumulation and germination (Tang and Cao 1999; Zhao and Xu 2000; Zhang 2001) address role in reconstruction and succession (An et al. 1996) play a major role in natural regeneration after disturbances such as fire, logging, and overgrazing in moist environments (Roberts 1981; Swaine and Hall 1983) and determine the composition as an initial step in artificial restoration of degraded vegetation (Vander Valk 1989), act as important attribute to develop the genetic memory with the addition of seeds over several years and under potentially different selective regimes (Han and Zhao 2011) and conservation of biodiversity through soil seed bank. An understanding of formation of persistent seed bank basically gives idea about conservation of rare and threatened plants and diverse ecosystems (Li et al. 2011).

There is an increasing demand for reliable information on seed banks both for scientific and as decision tool in habitat and landscape management (Holzel and Otte 2004). Grasslands often contain large number of persistent seed banks (Perera 2005). An understanding of soil seed bank is the key to many aspects of practical conservation for agriculture, and virtually to effective conservation of rare species and diverse ecosystems (Bertiller and Aloia 1997). Soil seed bank in nature is an important determinant of plant community dynamics and it shows the potential of a community to regenerate after disturbance (Hopkins and Graham 1983; Baker 1989; Mitchel et al. 1998). In order to provide sufficient cuttings, fruits and seeds, large living collections and seed banks are required, if native populations are to remain unthreatened (Kozuharova 2009). Understanding the impact of environmental changes in relation to grazing on soil seed banks is highly important for conservation, grazing management, and restoration purposes (Jones and Esler 2004; Kassahun et al. 2009). Grazing of grassland by livestock pressure may change distribution pattern of seed banks (changes in seed densities and species richness), such related studies were sporadic.

Grassland of moist tropics is degrading day by day due to agricultural practices, buildings, parks, and plantation (artificial forest) encroachment. The study of soil seed bank was mostly confined to temperate and other tropical regions but limited studies were available for moist tropics however, conservation aspects of plant diversity of grassland of moist tropics through soil seed bank are lacking. Limited studies on plant diversity, and community structure of grassland community moist tropics were available (Asthana 1975; Dwivedi, 1978; Tripathi & Shukla 2007). Work on soil seed bank dynamics in grassland absolutely lacking. Therefore, the study of soil seed bank is essential for in situ conservation of grassland of moist tropics. So the main hypothesis of the present study is to know ecological implications of soil seed bank in conservation of grassland of moist tropics. The study aims to evaluate the structural parameters of community (above-ground vegetation) in terms of density, composition, richness, relative density, relative frequency, relative abundance and IVI, and classify transient and persistent seed bank, and lastly to measurement of various biodiversity indices and similarity between above-ground vegetation and soil seed bank.

MATERIALS AND METHODS

Study site and natural conditions

The study site is located (between 26^0 13' and 27^0 29'N latitude and 83^0 05' and 83^{0}56'E longitude) at elevation of 95 m above mean sea level in a tropical moist region of Gorakhpur district of eastern Uttar Pradesh, India. This site is near Kusmahi plantation forest. The climate is annually represented by three distinct seasons - summer (March-June), rainy (July-October) and winter (November-February). Total annual rainfall is about 1992 mm (73% rainfall during monsoonal climate from June to October). Mean maximum temperature is 31^{0}C and mean minimum temperature 18^{0}C. Mean maximum and minimum humidity is 89% and 32%, respectively. The soil is Gangetic alluvium and color is yellowish brown, texture is sandy loam and clay and pH is slightly neutral. Average maximum temperature during wet summer or rainy period (July to October), winter (November to February) and dry hot summer (March to June) is 32^{0}C, 26^{0}C and 35^{0}C, and average minimum temperature is 22.8^{0}C, 9.5^{0}C and 20.7^{0}C, respectively. This site is nearly 45 years old semi-natural grazing land.

Soil sampling design

The first experiment was conducted in semi-natural grazing land in month of June 2007 after seed germination of most species and before the beginning of seed dispersal. For soil seed bank analysis soil was sampled in June 2007 (summer/rainy) and in November 2007 (winter) for seasonal variation of seed germination again this was followed for second annual cycle in next year and analysis was continued till December 2009. At field site, three contiguous permanent plots of 100 m x 100 m were marked. Random sampling for seed bank analysis was done in each plot of grassland. The soil sampling was done by excavating soil monolith of 20 cm x 20 cm area and at three different depth 0-10 cm, 10-20 cm and 20-30 cm. Total eighteen soil samples were taken in each season, therefore total seventy two soil samples had been collected for whole study. Six soil samples from three different depths in each plot in each season were collected. The each soil sample was kept in each marked polythene bags and these were brought to the botanical garden of Department of Botany, BHU, Varanasi for further detailed soil seed bank estimation.

Seed bank analysis (Seedling emergence Method)

Each weighed soil samples of each depth were transferred within 3 to 4 days into in separate marked flat, shallow earthen pots filled to about 1 cm below its brim in botanical garden. Each earthen pot sprayed with water to provide adequate soil moisture according to requirement for seed germination and seasonal variations from time to time and the position of each earthen pot was changed every 15 days interval to avoid differences in light exposure. The composition and vertical distribution of soil seed bank was estimated by seedling emergence method (Poiani and Johnson 1988; Ter Heerdt et al. 1996) as it gives appropriate abundance of viable seeds and its proper distribution which germinate in open field. This seedling emergence method is most appropriate for studying the composition of species and viability of seeds in the soil seed bank, particularly in natural systems with high floristic richness (Gross 1990). Once seedlings emerged were observed and identified by specimen and herbarium; which were collected from the standing vegetation of the grassland from time to time, counted and removed from the pots at 15-days interval. Those seedlings which were not identified were transferred to other earthen pots to allow growing till their flowering stage for proper identification. Soil samples were maintained and checked for emerging seedlings for one year, since a shorter period of study may have resulted estimation of persistent soil seed bank (Baskin and Baskin 1998). During the study period, soil samples in each pot were stirred many times to bring all possible ungerminated seeds to soil surface to increase the number of seedling emergence by proper light exposure. The total emerged seeds were used as the measure of viable seeds in seed bank. In botanical garden, a set of six from different three depths for control, earthen pots were placed during each season to observe seedling emergence due to local seed rain. For this control set, soil samples of botanical garden of each depth were taken and placed into marked polythene and autoclaved in laboratory at 200^{0}C for 4 hours to make sure absence of any viable seeds. The autoclaved soil samples were transferred into each earthen pot. The seedlings which where emerged (*Tridax procumbens*, and *Desmostachya bipinnata*) in control pots were subtracted from the respective seedling numbers in different depth soil samples. Each species which was emerged in soil seed bank of grassland identified at species level. The seed bank types have classified according to criteria given by Thompson et al. (1997). Three main types of seed bank: transient (seeds surviving < 1 year), short-term persistent (seeds surviving 1-5 years) and long-term persistent (seeds surviving > 5 years).

Above-ground vegetation analysis

The species composition in above-ground vegetation was observed at regular monthly interval from June 2007 to December 2009. At experimental site three contiguous permanent plots of 100 m x 100 m was marked. Species were observed with 25 random quadrats sampling of 50 cm x 50 cm in each plot of grassland for above-ground vegetation. Data were analyzed as randomized complete block design established in each plots with 25 quadrats replicates. The botanical name was followed by local flora (Srivastava 1976; Ansari et al. 2006). Plants were categorized into native and exotic species (Khanna 2009). In each subplot, species composition, species richness, species diversity, relative density, relative frequency, relative abundance and Importance value index (IVI) were calculated.

Statistical data analyses

After counting total numbers of seedling emergence, seed density was calculated as seeds m^{-2}. Composition of seed bank of each species in three different depths in each sample and total plant density (plants m^{-2} of each species) in above-ground vegetation were analyzed statistically by one-way ANOVA and Tukey's multiple comparison tests. Multivariate analysis of variance (MANOVA) was performed to show impact of depth and season on seed bank by general linear model (GLM) on SPSS version 16 (2008). The species diversity in soil seed bank and above-ground vegetation was measured using richness index (Magurran 1988), Shannon-Wiener diversity index (1963), Pielou evenness (1966), Margalef abundance index (1958) and Simpson dominance index (1949) on Biodiversity Pro software (McAleece et al. 1997) and Instat +v3.36 Software (2006). We used Sorenson's (1948) similarity coefficient and Jaccard's (1912) similarity coefficient to calculate similarity between soil seed bank and above-ground vegetation.

Magurran richness index = S

Simpson dominance index: $D = 1-\sum_{i=1}^{S} p_i^2$;

Margalef abundance index $D = S\text{-}1/\ln N$

Shannon-Wiener diversity index: $H' = -\sum_{i=1}^{S} p_i \ln p_i$;

Pielou eveness index: $J' = D/(1\text{-}1/S)$;

Equitability (Evenness) (e)

$e = H'/\ln S$ or $J' = H'/H'max$

J': Pielou evenness index

H': The observed value of Shannon index

H'max: ln S

Where pi = the proportion of all individuals which belong to species i (number of all individuals of each species i/N) or relative abundance of the ith species, S = total number of species in the sample or species richness N = total number of individuals of all species.

Sorenson's similarity coefficient: S = (2C/ A+B) 100

C = the sum of common species both of A and B

A = the number of species present in above-ground vegetation

B = the number of species present in soil seed bank

Jaccard's similarity coefficient: J = a/S

a = the number of species common to seed bank and vegetation

S = the total number of species present in both.

The percentage values of the relative frequency, relative density and relative abundance designated as the Importance Value Index (IVI) of the species (Curtis 1959). Importance Value Index (IVI) was used to determine the overall importance of each species in both soil seed bank and above-ground vegetation. IVI of all plants based on relative frequency, relative density and relative abundance was calculated by following formulae-

Relative frequency (RF) = frequency of a species x100 / sum frequency of all species

Relative density (RD) = number of individuals of species x100 / total number of individuals

Relative abundance (RA) = abundance of a species x 100 / abundance of all species

IVI = RD + RA + RF

RESULTS

Above-ground vegetation and soil seed bank diversity and richness

Total 38 species were recorded in both soil seed bank and above-ground vegetation in which total 28 species were in soil seed bank and 31 were in above-ground vegetation; 7 and 10 species were confined to soil seed bank and above-ground vegetation respectively, 21 were common in both (Table 1). Seed bank and standing vegetation had 18, 20 annuals and 10, 11 perennials respectively. Total 16 were monocotyledonous and 22 dicotyledonous in both soil seed bank and above-ground vegetation. 10 species were exotics and 18 natives in seed bank while in above-ground vegetation 12 exotics and 19 natives were recorded. Family Poaceae (10) represented its maximum number of species.

Total 18 species were found in rainy/summer season, 16 in winter and 6 were in entire season during whole study period (Table 2). These 6 species were *Cynodon dactylon*, *Desmodium triflorum*, *Dichanthium annulatum*, *Euphorbia hirta*, *Oplismenus burmanii*, and *Parthenium hysterophorus*.

On the basis of IVI the most prominent species in both soil seed bank and above-ground vegetation were *Cynodon dactylon*, *Euphorbia hirta*, *Oplismenus burmanii*, *Dichanthium annualatum*, and *Digitaria ciliaris*, while *Alternenthera sessilis* had minimum IVI in seed bank. *Jatropha curcus* had maximum IVI and *Sida cordifolia* have minimum IVI in above-ground vegetation. *Cyperus kyllingia* had maximum IVI and *Fimbristylis schoenoides* had minimum IVI in seed bank (Table 3).

Species richness, diversity and density of soil seed bank

Mean of total seed density of each species in all depths showed significant ($p < 0.001$) annual and seasonal variations (Table 4). *Digitaria ciliaris* contributed maximum (12%) and *Alternenthera sessilis* contributed minimum (0.21%) in seed bank. Seed germination with seasonal variation in both annual cycles showed maximum germination during rainy season (42461 m^{-2}) followed by summer (16190 m^{-2}) and winter (16135 m^{-2}). Ten exotic of seed bank contributed 32% of total seed germination but the potential of seed germination (seed m^{-2}) of these exotics (*Euphorbia hirta*, *Evolvulus nummularis*, *Parthenium hysterophorus*) were higher than native in moist tropical grassland.

Monthly variations of total seedling emergence of first annual cycle highlighted maximum number of seeds were in the month of September and minimum in January (Fig. 1). Maximum numbers of seeds were germinated in 0-10 cm in all seasons and minimum in 20-30 cm. In first annual cycle (2007-2008) maximum seedling were emerged than second annual cycle (2008-2009), because heavy rainfall cause seeds non-viable, dead and inactive due to excessive soil moisture.

The numbers of species were found higher in rainy than summer and winter due to favorable condition for maximum seed germination of plants. Significant ($p < 0.001$) seasonal variations were found in seed germination. Seed bank size decreased with increasing of depth in entire season (Fig. 2). As depth increased, the number of seeds decreased from 16050 seeds m^{-2} (0-10 cm) to 9200 seeds m^{-2} (10-20 cm) to 3200 m^{-2} (20-30 cm) during first annual cycle (2007-2008) and also decreased from 17250 m^{-2} (0-10 cm) to 9000 m^{-2} (10-20 cm) to 4500 m^{-2} (20-30 cm) during second annual cycle (2008-2009).

Multivariate analysis of variance (MANOVA) for all plants showed significant impact of depths ($p > 0.05$) and seasons ($p > 0.001$) on germination of seeds $F_{2,1}$ value (4.155, 20.435).

Established vegetation and soil seed bank

Mean plant density (plant density m^{-2}) of each species in above-ground vegetation was significant ($p < 0.001$) (Table 5). *Cynodon dactylon* had maximum (1221 plants m^{-2}) and *Saccharaum spontaneum* minimum (98 plants m^{-2}) density.

The measurement of various biodiversity indices in terms of species richness, diversity, dominance, abundance and evenness were calculated showing for above-ground vegetation and soil seed bank (Table 6). The species confined to soil seed bank only were *Bonnaya brachiata*, *Chrysopogon aciculatus*, *Cyperus kyllingia*, *Echinochloa crus-galli*, *Eragrotis tenella*, *Fimbristylis schoenoides* and *Imperata cylindrica*. The species *C. dactylon*, *E. nummularis* and *O. burmanii* and *E. hirta* were dominant in both soil seed bank and above-ground vegetation.

The result of seed germination denoted that maximum number of species have formed persistent seed bank and also these were dominant in above-ground vegetation, it means seed bank of moist tropical grassland has its implication on conservation.

High similarity was observed between soil seed bank and above-ground vegetation. In grassland, the Sorenson's and Jaccard's similarity coefficient between the established above-ground vegetation and soil seed bank were 0.72 and 0.55 respectively in study period; but during first annual cycle Sorenson's similarity between soil seed bank and above-ground vegetation was 0.78 and in second annual cycle it was 0.65. Jaccard's similarity was 0.57 in first annual cycle and 0.61 in second annual cycle. Similarity between soil seed bank and above-ground vegetation as positively correlated (Pearson r = 0.277). These results showed strong relationship between soil seed bank and above-ground vegetation. Regression analysis showed that there was positive correlation ($r^2 = 0.077$, $p > 0.05$) between soil seed bank and above-ground vegetation (Fig 3). The *p*-value for this relationship is non-significant at 5% significance.

DISCUSSION

Grassland ecosystems, in two of three possible scenarios of biodiversity change for the year 2100, appear to be the most threatened biome; in the third scenario (Sala et al. 2000). Grasslands are among the most vulnerable biomes following tropical forests, arctic ecosystems, and southern temperate forests (Sala et al. 2000). They are quite sensitive ecosystems and are located in most parts of the world where ecosystems are going to be affected most by human activity (Sala et al. 2001). Grasslands are heavily used ecosystems in tropics, so it is necessary to implement new sound management practices as soil seed bank to address biodiversity. Viable seeds in the soil seed bank can be the base of restoration of grassland community, the density of viable seeds declines with time, so restoration should be mostly likely successful on the youngest sites (Bossuyt et al. 2001). In Terai grassland, nearly five species typically contribute than 80-90% of the cover within each grassland assemblage (Peet et al. 1999). The Terai arc landscape (TAL) is best surviving remnant of the once extensive alluvial grassland and forest ecosystems in the eco-region. This particular area harbors a variety of threatened plant and wild animal of India (Semwal 2005), so this particular area required protection and conservation of these rare and vulnerable species using soil seed bank tool.

The seedling emergence method has been used in many studies because of easy of identification of emerging seedlings, and the presumption of the number of viable seeds (Baskin and Baskin 1998). In Californian grasslands dicotyledonous seeds were prominent than monocotyledons in soil seed bank (Rice 1989), as were also find by Roberts (1981) but in present study equal contribution of monocot and dicotyledonous were recorded. The presence of a species in the seed bank but not in the vegetation could be a consequence of seed dispersal from adjacent areas or seed persistence in the soil after the death of adult plant (Esmailzadeh et al. 2011).

Seeds in the soil seed bank were more abundant near the soil surface which decreased with increasing depth. There was marked effect of soil depth on germination of seedling through seedling emergence method in soil seed bank of grassland. Total seed density was much higher in 0-10 cm soil depth than 10-20 cm and then in 20-30 cm soil depth. In grasslands, we found that the upper parts of the soil showed a significantly higher seed density than the lower parts, as has also been described in other grassland (Kalamees and Zobel 1998). Seed density and diversity both significantly decreased below 10 cm. The seed viability strongly depends upon soil moisture as found that maximum number of seeds germinated from uppermost layer but proper moisture content in lower part of soil layer in soil of moist tropics which enhances better seed germination. Generally species which were dominant in standing vegetation, their number of seed are more found near the soil surface. The decrease in soil seed bank density in both rainy, summer and winter season with increasing depth determined by various environmental factors like organic matter, litter, moisture content, pH, seed rain, seed availability, germination, seed predation or seed viability. Soil seed banks vary seasonally in their size and composition time to time. The size of a soil seed bank is controlled primarily both by the numbers of seeds produced at the site and secondarily by the fate of these seeds after dispersal (Li et al. 2011). The size of soil seed bank appeared to be affected by sampling time, altitude, slope, depth, plant communities, plant life form and soil environment parameters such as moisture, aeration, fertility, or activity of soil microorganisms (Li et al. 2011). Heavy grazing, human interferences and soil erosion due to flooding may also decrease species number, seed production and seed bank density. The common contributor of this grassland ecosystem is the predominance of annual species that exclusively produce seeds during growing season.

Seedling emergence is affected by seasonal variation mainly by rainfall and temperature because these two environmental factors maintain moisture content in soil which helps in germination of seeds of various different weeds from season to season, so seeds of weeds mainly germinated in rainy season. Winter annuals in moist tropics germinate during November to February. Summer annuals germinate and flower during the summer rainy season. Seeds banks of winter and summer annuals showed contrasting patterns in most part of the year. Some summer annuals detected in our experimental soil samples were present in June seed bank but were absent from November seed bank, this can be treated as transient. Summer annuals in comparison to winter annuals are long lived in the soil. Seed production is largely controlled by amount of rainfall, light, soil moisture and temperature so soil seed bank size may have increased in second annual cycle. Germination of some species happens soon after dispersal, whereas that of other species is delayed due to dormancy until a favorable season when seedlings are likely to survive, grow and go on to reproduce (Walck et al. 2011).

In tropical grassland seedling emergence occurs when temperatures are favorable and when rain starts. Germination is highly dependent on available soil moisture, temporal changes could alter seedling emergence (Kos and Poschlod 2008). We found maximum germination was in rainy but some results showed that exclusion of rain reduces or does not affect seedling emergence; though the effect was dependent on the pattern of rainfall reduction (Miranda et al. 2009) and on seed production (Penuelas et al. 2004).

The species of soil seed bank of grassland form both transient and persistent seed bank in moist tropics. Seeds of many plants have transient seed bank which persist in soil for only one year and some which grow persist more than one year have persistent seed bank (Thompson et al. 1997). The size and species composition of the community seed bank should reflect seasonal changes in abundance of transient and seasonal-transient seed banks. Persistent species were dominant in both soil seed bank and above-ground vegetation which show that they can better contribute in establishment of vegetation and can be one of the best tools for conservation. External factors such as granivores, fungi, microbes or fire may kill seeds. Input in soil seed bank depends on seed/fruit production, which may increase or decrease due to environmental factors.

Few seeds which are vertically distributed in soil are not viable, but which are viable and distributed vertically show seed persistence in soil (Thompson 1993). Vertical distribution of seeds in soil seed bank may be affected and changed due to grazing of cattle. Natural re-vegetation of grassland of this tropical moist area can occur because of the presence of viable seeds in the soil seed bank which have high richness of grassland species. The composition, size and dynamics of the soil seed bank of grassland are affected by the presence of the seeds buried in the soil, and this soil seed bank of grassland is also affected by environmental factors mainly by rainfall and temperature. The study of soil seed bank composition of grassland gives interpretation of the future vegetation and genetic variability of grassland that gives proper management and conservation of vegetation of grassland. The sensitivity of seedlings to climate change may depend on the timing of their emergence which gets affected by temperature with soil moisture (Baskin and Baskin 1989).

High degree of similarity between the composition of standing vegetation and that of soil seed bank were recorded in moist tropics of grassland. The Sorensen similarity coefficient was high between soil seed bank and an above-ground vegetation, similar finding was also reported in Taklimakan desert (Ning et al. 2007), but low similarity were reported in Patagonia grassland (Ghermandi 1997). Similarity between soil seed bank density and above-ground vegetation is positively correlated as Abella and Springer (2008) reported in pine forest. Regression analysis showed non-significant positive correlation between soil seed bank density and above-ground vegetation density as also described in African savanna grassland (O' Connor and Pickett 1992) in meadows (Kirkham and Kent 1997) and in Jinshajing hot-dry river valley (Hui and Keqin 2006).

IMPLICATIONS FOR CONSERVATION

The study of seed banks is fundamental tool for management and conservation of desirable species in seed bank in conjugation with their successful germination and seedling establishment. The vertical distribution of many seeds of desirable species are viable and present in all depths showed that better seed persistence in moist tropical grassland and enough seed longevity. There is existence of both transient and persistent seed bank characterizing native and exotic species which envisaged best conservation options for moist tropical grassland. Our findings expressed that moist tropical grassland conserve majority of viable seeds in form of persistent bank. Native and exotic species both formed transient and persistent seed bank have no effect on germination of seeds with each other. Management implications focused on grazing during seed production which enhances seed bank formation and storage in the soil. The seeds which are viable would germinate rapidly and played important role in vegetation restoration. The depth to which seeds were distributed in the soil might have several implications for successful regeneration of a plant community. This study is important because after flood or other natural and anthropogenic disturbance can regenerate the grassland community with the presence of seeds in soil seed bank in moist tropics. The use of seed bank as tool for restoration depends strongly on which taxa retain seeds able to recruit in degraded environment, the results present in this finding has shown implications for restoration of disturbed grassland; and useful tool for the conservation and management of moist tropical grassland.

ACKNOWLEDGMENT

The authors are thankful to the Head and Coordinator CAS, Department of Botany, BHU, Varanasi for providing basic laboratory facilities to the Director, Institute of Environment and Sustainable Development, BHU. Upama Mall is thankful to UGC, New Delhi, for providing CAS Junior Research Fellowship. Kumari Poonam is also thankful to UGC, New Delhi for providing Junior Research Fellowship. The authors are thankful to Prof. Ken Thompson for valuable comments and suggestions for the manuscript.

NOTES ON CONTRIBUTORS

Upama Mall is a research scholar in Department of Botany, Banaras Hindu University, Varanasi and works on ecological implications soil seed bank in different ecosystems of moist tropics.

Kumari Poonam is a research scholar in Department of Botany, Banaras Hindu University, Varanasi and works on ethnopharmacology, biodiversity and taungya system of Terai Arc Landscape (TAL).

G. S. Singh is a professor in Institute of Environment and Sustainable Development, Banaras Hindu University Varanasi works on population ecology, forest ecology, eco-sociology, biodiversity and ethno pharmacology, socioeconomic, and taungya system.

REFERENCES

Abella S.R. & Springer J.D. (2008). Estimating soil seed bank characteristics in Ponderosa pine forest using vegetation and forest-floor data. USDA Forest Service Rocky Mountain Research Station, Research note 35: pp. 1-7.

An S.Q., Lin X.Y., Hong B.G. (1996). A preliminary study on the soil seed bank of the dominant vegetation forms on Baohua Mountain. Acta Phytoecologica Sinica 20: pp. 41-50.

Ansari A.A. & Singh S.K., Srivastava R.C. (2006). Flora and vegetation of Madhaulia forest (U. P.). Oriental Enterprises, Dehradun.

Asner G.P. & Martin R.E. (2004). Biogeochemistry of desertification and woody encroachment in grazing systems, Ecosystems and Land Use Change. Defries R, Asner GP, Houghton RA. (eds.). American Geophysical Union, Washington DC.

Asthana M. (1975). Phytosociology, primary production and energetics of natural (control) and modified (clipped) stands of grassland dominated by *Cynodon dactylon* (L) Pers. Ph.D. Thesis, University of Gorakhpur.

Baskin C.C. & Baskin J.M. (1998). Seeds: Ecology, Biogeography and Evolution of Dormancy and Germination. Academic Press, San Diego.

Baskin J.M. & Baskin, C.C. (1989). Physiology of dormancy and germination in relation to seed bank ecology. Ecology of Soil seed banks. Leck MA, Parker VT, Simpson RL. (eds.). Academic Press, San Diego, California, pp. 53-66.

Bossyut B., Honaay O., Van S.K., Hermy M.V., Assche J. (2001). The effect of a complex land use history on the restoration possibilities of heathland in Central Belgium. Belgian Journal of Botany 134: pp. 29-40.

Bugalho M.N. & Abreu J.M. (2009). The multifunctional role of grasslands. Options Mediterranean's Series A 79: pp. 25-30.

Curtis J.T. (1959). The Vegetation of Wisconsin. An Ordination of Plant Communities Madison: Wisconsin Press.

Dwivedi RP. (1978). Studies on productivity, competition and population dynamics of the grassland vegetation of Gorakhpur in relation to herbage removal. Ph.D. Thesis, University of Gorakhpur.

Esmailzadeh O., Hosseini S.M., Tabari M., Baskin C.C., Asadi H. (2011). Persistent soil seed banks and floristic diversity in *Fagus orientalis* forest communities in the Hyrcanian vegetation region of Iran. Flora 206: pp. 365-372.

Ghermandi L. (1997). Seasonal patterns in the seed bank of a grassland in north-western Patagonia. Journal of Arid Environments 35: pp. 215-224.

Gross K. (1990). A comparison of methods for estimating seed numbers in the soil. Journal of Ecology 78: pp. 205-212.

Han B. & Zhao M. (2011). Genetic comparisons between seed bank and *Stipa Krylovii* plant populations. Russian Journal of Genetics 47: pp. 1084-1090.

Harper J.L. (1977). Population biology of plants. Academic Press, London.

Holzel N. & Otte A. (2004). Assessing soil seed bank persistence in flood-meadows: the research for reliable traits. Journal of Vegetation Science 15: pp. 93-100.

Hui L. & Keqin W. (2006). Soil seed bank and above-ground vegetation within hill slope vegetation restoration sites in Jinshajing hot-dry river valley. Acta Ecoligica Sinica 26: pp. 2432-2442.

Instat +v 3.36 2006. Statistical service centre. The University of Reading, United Kingdom.

IUCN (1993). Nature reserves of the Himalaya and the mountains of Central Asia. Prepared by the World Conservation Monitoring Centre. Gland. Switzerland: Oxford University, Press.

Jaccard P. (1912). The distribution of the flora of the alpine zone. New Phytologist 11: pp. 37-50.

Jalili A, Hamzeh'ee B, Asri Y, Shirvany A, Yazdani S, Khoshnevis M, Zarrinkamar F, Ghahramani M, Safavi R, Shaw S, Hodgson JG, Thompson K, Akbarzadeh M, Pakparvar M. 2003. Soil seed banks in the Arasbaran protected area of Iran and their significance for conservation and management. Biological Conservation 109: pp. 425-431.

Jones F.E. & Esler K.J. (2004). Relationship between soil-stored seed banks and degradation in eastern Nama Karoo rangelands (South Africa). Biodiversity and Conservation 13: pp. 2027-2053.

Kalamees R. & Zobel M. (1998). Soil seed bank composition in different successional stages of a species rich wooded meadow in Laelatu, Western Estonia. Acta Oecologia 19: pp. 175-180.

Kassahun A., Snyman H.A., Smit G.N. (2009). Soil seed bank evaluation along a degradation gradient in arid rangelands of the Somali region, eastern Ethiopia. Agriculture, Ecosystems and Environment 129: pp. 428-436.

Khanna K.K. (2009). Invasive alien angiosperms of Uttar Pradesh. Biological Forum 1: pp. 41-46.

Kirkham F.W., Kent K. (1997). Soil seed bank composition in relation to the above ground vegetation in fertilized and unfertilized hay meadows on a Somerset peat moor. Journal of Applied Ecology 34: pp. 889-902.

Kos M. & Poschlod P. (2008). Correlates of inter-specific variation in germination response to water stress in a semi-arid savannah. Basic and Applied Ecology 9: pp. 667-675.

Kozuharova E. (2009). New ex situ collection of rare and threatened medicinal plants in the Pirin Mts (Bulgaria). Ekoloji 18: 72, pp. 32-44.

Lehmkuhl J.F. (1994). A classification of subtropical riverine grassland and forest Chitwan National park, Nepal. Vegetatio 111: pp. 29-43.

Li F.R., Zhao L.Y., Wang S.F., Wang X.Z. 2003. Effects of enclosure management on the structure of soil seed bank and standing vegetation in degraded sandy grassland of eastern Inner Mongolia. Acta Pratsculturae Sinica 12: 90-99.

Li Q., Haiyan F., Qiangguo C. (2011). Persistent soil seed banks along altitudinal gradients in the Quilian Mountains in China and their significance for conservation and management. African Journal of Agricultural Research 6: pp. 2329-2340.

Magurran A. (1988). Ecological Diversity and its Measurement. Croom Helm, London.

Margalef D.R. (1958). Information theory in ecology. General Systems 3: pp. 36-71.

McAleece N., Gage J.D., Lambshead J., Patterson, G.L.J. (1997). Biodiversity Professional. Biodiversity Pro Software Version 2. The Natural History Museum and the Scottish Association of Marine Sciences.

Miranda J.D., Padilla F.M., Pugnaire F.I. (2009). Response of a Mediterranean semiarid community to changing patterns of water supply. Perspectives in Plant Ecology, Evolution and Systematics 11: pp. 255-266.

Misra R. (1978). Productivity and structure of Indian savannas. Proceedings of Institute of Ecology, Jerusalam (Abstract).

Mitchel R.J., Mars R.H., Auld M.A.D. (1998). A comparative study of the seed bank of heath land and successional habitat in Dorset Southern England. Journal of Ecology 86: pp. 588-596.

Ning L., Gu F., Tian C.Y. (2007). Characteristics and dynamics of the soil seed bank at the north edge of Taklimakan desert. Science in China Series D: Earth Sciences 50: pp. 122-127.

O'Connor T.G. & Pickett G.A. (1992). The influence of grazing on seed production and seed bank of some African savanna grassland. Journal of Applied Ecology 29: pp. 247-260.

Peet N.B., Watkinson A.R., Bell D.J., Kattel B.J. (1999). Plant diversity in the threatened sub-tropical grasslands of Nepal. Biological Conservation 88: pp. 193-206.

Perera G.A.D. (2005). Spatial heterogeneity of the soil seed bank in the tropical semi-natural deciduous forest at Wasgomuwa National Park, Sri Lanka. Tropical Ecology 46: pp. 79-89.

Pielou E.C. (1966). The measurement of diversity in different types of biological collections. Journal of Theoretical Biology 13: pp. 131-144.

Poiani K.A., Johnson W.C. (1988). Evaluation of the emergence method in estimating seed bank composition of prairie wetlands. Aquatic Botany 32: pp. 91- 97.

Rice K.J. (1989). Impacts of seed banks on grassland community structure and population dynamics. Ecology of Soil Seed Banks. Leck MA Parker VT Simpson RL (eds) pp. 211-230, San Diego, Academic Press.

Roberts H.A. (1981). Seeds banks in soils. Advances in Applied Biology 6: pp. 1-55.

Sala O.E., Amy T.A., Vivanc L. (2001). Temperate grassland and shrubland ecosystems. Encyclopedia of Biodiversity 5: pp. 627-635.

Sala O.E., Huber R., Lodge D.M., Mooney H.A., Oesterheld M., Poff N.L., Sykes M.T., Walker B.H., Walker M., Wall D.H. (2000). Global biodiversity scenarios for the year 2100. Science 287: pp. 1770-1774.

Semwal R.L. (2005). The Terai Arc Landscape in Indian Securing Protected Area in the Face of Global Change-Forests and Biodiversity Conservation Programme- World Wide Fund for Nature, New Delhi, India.

Shannon C.E. & Wiener W. (1963). The Mathematical Theory of Communication. pp. 360 University of Illinois Press, Urbana.

Shen Y., Zhao C., Liu W. (2011). Seed vigor and plant competitiveness resulting from seeds of *Eupatorium adenophorum* in a persistent soil seed bank. Flora DOI: 10.1016/j.flora.2011.07.002.

Simpson R.L. (1989). Ecology of soil seed banks. Leck MA Parker VT Simpson RL (eds) pp.9-12, Academic Press, San Diego, California.

Simpson E.H. (1949). Measurement of diversity. Nature 163: pp. 688.

Sorensen T. (1948). A method of establishing groups of equal amplitude in plant sociology based on similarity of species content and its application to analyses of the vegetation on Danish commons. Biolgiske Skrifter 5: pp. 1–34.

SPSS (2008). SPSS 16.0 for Windows. SPSS Inc, Chicago, IL.

Srivastava T.N. (1976). Flora Gorakhpurensis. Today and Tomorrow's Printers and Publishers, New Delhi.

Swaine M.D. & Hall J.B. (1983). Early succession on cleared forest land in Ghana. Journal of Ecology 71: pp. 601-625.

Tang Y. & Cao M. (1999). Relationship between soil seed bank and aboveground vegetation in tropical forest of Xishuangbanna. Chinese Journal of Applied Ecology 10: pp. 279-282.

Ter Heerdt G.N.J., Verwey G.L., Bekker R.M., Bakker J.P. (1996). An improved method for seed bank analysis: seedling emergence after removing the soil by sieving. Functional Ecology 10: pp. 144-151.

Thompson K. (1993). Seed persistence in soil. Methods in comparative plant ecology (eds Hendry, G.A.F. & Grime, J.P.) pp. 199-202, Chapman & Hall, London.

Thompson K., Bakker J.P., Bekker R. (1997). The soil seed banks of North West Europe: methodology, density and longevity. Cambridge University Press, Cambridge, UK.

Tripathi S. & Shukla R.P. (2007). Effect of clipping and grazing on various vegetational parameters of grassland communities of Gorakhpur, UP. Tropical Ecology 18: pp. 61-70.

Vander Valk A.G. & Pederson R. (1989). Seed banks and the management and restoration of natural vegetation. Ecology of Soil Seed Banks Leck MA Parker VT Simpson RL (eds) pp. 329-344, Academic Press, San Diego.

Walck J., Hidayati S.N., Dixon K.W., Thompson K., Poschlod P. (2011). Climate change and plant regeneration from seed. Global Change Biology 17: pp. 2145-2161.

Zhang F.G. (2001). Study on the soil seed bank and the characters of seedling bank of bush grassland in Tiantong in Zhejiang. Research Vegetables Yunnan 23: pp. 209-215.

Zhao M.L. & Xu X.Z. (2000). Preliminary study on the soil seed bank of grassland of temperate desert in the west of Wulanchabu league in Inner Mongolia. Grasslands China 2: pp. 46-48.

Table 1: Taxa found in both in soil seed bank and above-ground vegetation of grassland of moist tropics of India. (Note: A=Annual, P=Perennial, H=Herb, S=Sedge, Sh=Shrub, G=Grass, D=Dicotyledonous, M=Monocotyledonous, STP = Short-term persistent, LTP=Long-term persistent).

Taxa found only in above-ground vegetation	Vernacular Name	Life Form	Family	Habit	Morphotypes	Native/Exotic	Seed bank types
Alysicarpous monolifer DC.	Juhi ghas	A	Fabaceae	H	D	Native	-
Argemone mexicana Linn.	Satyanashi, Shailkanta	A	Papaveraceae	H	D	Exotic	-
Boerhaavia diffusa Linn.	Punarnava	P	Amaranthaceae	H	Di	Native	-
Bulbostylis barbata (Rottb.) Clarke	-	A	Cyperaceae	S	M	Native	-
Cannabis sativa Linn.	Bhang	A	Cannabinaceae	Sh	D	Native	-
Cassia tora Linn.	Chakawad	A	Fabaceae	Sh	D	Exotic	-
Cyperus difformis Linn.	Motha, Dila	A	Cyperaceae	S	M	Exotic	-
Jatropha curcus Linn.	Ratanjyot, Bagrendi	P	Euphorbiaceae	Sh	D	Native	-
Sida cordifolia Linn.	Bariyar	A	Malvaceae	H	D	Native	-
Tridax procumbens Linn.	Barahmasi	A	Asteraceae	H	D	Exotic	-
Taxa common to both above-ground vegetation and soil seed banks							
Achyranthes aspera Linn.	Chirchira	P	Amaranthaceae	Sh	D	Native	STP
Ageratum conyzoides Linn.	Gandh	A	Asteraceae	H	D	Exotic	STP
Alternenthera sessilis Br.	Saranchi	P	Amaranthaceae	H	D	Native	Transient
Anagallis arvensis Linn.	Armal	A	Primulaceae	H	D	Exotic	STP
Biophytum sensitivum DC.	Vipreetlajja	P	Oxalidaceae	H	D	Native	STP
Blepharis repens (Vehl) Roth	-	A	Acanthaceae	H	D	Native	STP
Blumea lacera DC.	Kukurundha	P	Asteraceae	H	D	Exotic	STP
Cassia occidentalis Linn.	Chhota chakwad	A	Fabaceae	Sh	D	Exotic	Transient
Centella asiatica (Linn.) Urban	Mandukparni, Brahm-buti	A	Apiaceae	H	D	Native	STP
Commelina benghalensis Wall.	Kanchara	A	Commelinaceae	H	M	Native	STP
Cynodon dactylon Pers.	Doob ghas	P	Poaceae	G	M	Native	LTP
Cyperus rotundus Linn.	Motha	A	Cyperaceae	S	M	Native	STP
Desmodium triflorum (L.) DC	Tikuli	A	Fabaceae	H	D	Native	STP
Dichanthium annulatum Forsk.	Jaunera		Poaceae	G	M	Native	LTP
Digitaria ciliaris Pers.	Chipbans	A	Poaceae	G	M	Native	LTP
Eleusine indica Gaertn.	Malankuri	P	Poaceae	G	M	Native	Transient
Euphorbia hirta Linn.	Dudhi	A	Euphorbiaceae	H	D	Exotic	LTP
Evolvulus nummularius Linn.	Bichhamalia	P	Convolvulaceae	Herb	D	Exotic	LTP
Oplismenus burmanii Beauv.	Chitrabans	A	Poaceae	G	M	Native	LTP
Parthenium hysterophorus Linn.	Gajar ghas	P	Asteraceae	H	D	Exotic	LTP
Saccharaum spontaneum Linn.	Kass	A	Poaceae	G	M	Exotic	Transient
Taxa found only in soil seed banks							
Bonnaya brachiata, Link & Otto	-	A	Scrophulariaceae	H	D	Native	STP
Chrysopogon aciculatus Trin.	Kuro	A	Poaceae	G	M	Native	Transient
Cyperus kyllingia Endl.	Motha	A	Cyperaceae	S	M	Native	STP
Echinochloa crus-galli (Linn.) Beauv.	Sanwan	A	Poaceae	G	M	Exotic	Transient
Eragrostis tenella R. & S.	Jugebans	A	Poaceae	G	M	Native	STP
Fimbristylis schoenoides Vahl	Murena	A	Cyperaceae	S	M	Native	Transient
Imperata cylindrica (Linn.) Raeuschel.	Sirhu, Dachela	P	Poaceae	G	M	Exotic	Transient

Table 2: Seasonal species composition recorded in soil seed bank of different ecosystems in moist tropics of India

Species	Summer season	Rainy Season	Winter Season	Whole year
Achyranthes aspera	-	-	+	
Ageratum conyzoides	-	-	+	
Alternenthera sessilis	-	+	-	
Anagallis arvensis	-	-	+	
Biophytum sensitivum	-	+	-	
Blepharis repens	-	-	+	
Blumea lacera	-	+	-	
Bonnaya brachiata,	-	+	-	
Cassia occidentalis	-	-	+	
Centella asiatica	-	-	+	
Chrysopogon aciculatus	-	-	+	
Commelina benghalensis	-	+	-	
Cynodon dactylon	+	+	+	+
Cyperus kyllingia	+	+	-	
Cyperus rotundus	+	+	+	+
Desmodium triflorum	+	+	+	+
Dichanthium annulatum	+	+	+	+
Digitaria ciliaris	+	+	-	
Echinochloa crus-galli	-	-	+	
Eleusine indica	-	+	-	
Eleusine indica	-	+	-	
Eragrostis tenella	+	+	+	+
Euphorbia hirta	+	+	+	+
Evolvulus nummularius	+	+	+	+
Fimbristylis schoenoides	-	+	-	
Imperata cylindrica (Linn.)	-	+	-	
Oplismenus burmanii	+	+	+	+
Parthenium hysterophorus	+	+	+	+
Saccharaum spontaneum	-	-	+	
Total species in each season	11	19	18	9

Note: + = present, - = absent

Table 3: IVI of each species recorded in both soil seed bank/above-ground vegetation in grassland of moist tropics of India.

Species	RD	RF	RA	IVI
Taxa recorded in AGV				
Alysicarpous monolifer	-/1.07	-/2.11	-/1.36	-/4.54
Argemone mexicana	-/3.37	-/2.82	-/3.22	-/9.41
Boerhaavia diffusa	-/5.24	-/2.00	-/7.08	-/14.32
Bulbostylis barbata	-/4.20	-/2.12	-/5.36	-/11.68
Cannabis sativa	-/1.49	-/1.65	-/2.46	-/5.60
Cassia tora	-/1.83	-/3.29	-/1.50	-/6.62
Cyperus difformis	-/4.32	-/3.88	-/3.01	-/11.22
Jatropha curcus	-/5.02	-/0.59	-/23.07	-/28.69
Sida cordifolia	-/0.749	-/2.58	-/0.78	-/4.12
Tridax procumbens	-/ 1.079	-/3.18	-/0.92	-/5.16
Taxa common to both SSB and AGV				
Achyranthes aspera	1.86/1.29	3.72/2.88	1.35/1.29	6.92/5.46
Ageratum conyzoides	2.62/1.24	4.00/3.96	1.76/1.24	8.38/6.44
Alternenthera sessilis	2.81/0.40	4.35/2.16	1.74/0.40	8.90/2.97
Anagallis arvensis	4.27/1.97	3.67/2.88	3.14/1.94	11.08/6.82
Biophytum sensitivum	3.37/2.56	2.92/3.31	3.12/2.56	9.41/8.44
Blepharis repens	1.08/1.69	2.89/4.17	1.00/1.69	4.98/7.56
Blumea lacera	3.98/3.02	3.95/3.96	2.71/3.02	10.65/10.00
Cassia occidentalis	0.81/1.56	2.23/1.44	0.98/1.57	4.02/4.57
Centella asiatica	1.91/2.32	2.35/2.52	2.19/2.32	6.45/7.16
Commelina benghalensis	3.21/3.04	2.94/3.74	2.94/3.04	9.09/9.84
Cynodon dactylon	7.05/9.26	5.29/5.18	3.59/9.25	15.94/23.69
Cyperus rotundus	4.023/4.33	4.70/4.89	2.30/4.34	11.03/13.58
Desmodium triflorum	3.35/2.93	2.82/3.02	3.21/2.94	9.39/8.90
Dichanthium annulatum	3.797.12	4.00/4.32	2.56/7.12	10.35/18.57
Digitaria ciliaris	3.565.54	2.82/4.46	3.40/5.54	9.79/15.55
Eleusine indica	3.57/1.56	3.41/3.53	2.82/1.57	9.80/6.66
Euphorbia hirta	5.40/9.38	5.29/5.04	2.75/9.38	13.45/23.81
Evolvulus nummularius	6.50/5.26	5.17/2.52	3.39/5.26	15.08/3.45
Oplismenus burmanii	6.13/8.53	5.06/4.61	3.27/8.54	14.46/21.69
Parthenium hysterophorus	0.735.07	1.41/2.76	1.39/5.08	3.53/12.89
Saccharaum spontaneum	1.54/1.95	2.70/2.88	1.54/1.95	5.78/6.79
Taxa recorded only in SSB				
Bonnaya brachiata	4.01/-	5.18/-	4.01/-	13.21/-
Chrysopogon aciculatus	1.81/-	2.52/-	1.81/-	6.15/-
Cyperus kyllingia	4.41/-	4.58/-	4.41/-	13.51/-
Echinochloa crus-galli	2.38/-	2.73/-	2.38/-	7.49/-
Eragrostis tenella	2.29/-	3.89/-	2.29/-	8.47/-
Fimbristylis schoenoides	1.93/-	3.46/-	1.94/-	7.32/-
Imperata cylindrica	3.04/-	3.24/-	3.04/-	9.33/-

Note:- Absent, RD=Relative density, RF=Relative frequency, RA=Relative abundance, IVI=Important

Table 4: Characteristics of seed density of each species with impact of season and depth in soil seed bank in moist tropics of India [values were mean of all three depths (0-10cm, 10-20 cm, 20-30 cm) with standard error (SE) in parentheses] (Summer[1], Rainy[1], Winter[1] are seasons of first annual cycle; Summer[2] Rainy[2], Winter[2] are of second annual cycle).

Species	Summer[1]	Rainy[1]	Winter[1]	Summer[2]	Rainy[2]	Winter[2]	Total	Contribution (%)	*F*	*p*
A. asepra	-	-	137.5 (18.3)	-	-	679.9 (53.6)	817.4	1.30	2.278	NS
A. conyzoides	-	-	298.3 (60.8)	-	-	757.0 (74.0)	1055.3	1.68	5.283	NS
A. sessilis	-	129.2 (18.1)	-	-	-	-	129.2	0.21	1.000	NS
A. arvensis	-	-	383.7(64.9)	-	-	862.0(58.9)	1245.7	1.98	6.795	0.077*
B. sensitivum	-	772.6 (87.8)	-		848.6 (63.1)	-	1621.2	2.58	455.485	0.000*
B. repens	-	-	603.2 (72.3)	-	-	468.1 (109.9)	1071.3	1.70	62.938	0.004*
B. lacera	-	813.4(95.6)	-	-	1099.3 (124.9)	-	1912.7	3.04	44.693	0.006*
B. brachiata	-	1250.8 (131.8)	-	-	1286.4 (162.4)	-	2537.2	4.04	525.400	0.000*
C. occidentalis	-	-	-	-	-	494.6 (122.8)	494.6	0.79	101.099	0.000*
C. asiatica	-	-	661.3 (74.6)	-	-	806.7 (90.9)	1468.0	2.34	35.579	0.002*
C. aciculatus	-	-	-	-	-	574.2 (69.3)	574.2	0.91	1.520	0.008*
C. benghalensis	-	1124.0 (93.4)	-	-	801.2 (84.9)	-	1925.2	3.06	5.491	NS
C. dactylon	1250.5(13.7)	1022.0 (118.2)	698.8 (62.8)	1391(71.2)	1537.0 (158.3)	871.4 (150.4)	6770.7	10.77	11.851	NS
C. kyllingia	602.6 (27.4)	1137.2(139.2)	-	-	916.9 (136.3)	-	2656.7	4.22	7.817	0.038*
C. rotundus	587.2 (27.5)	1014.6 (59.6)	-	-	1134.4 (69.3)	-	2736.2	4.35	4.648	NS
D. triflorum	-	-	-	809.6(74.9)	661.7 (86.4)	620.4 (79.8)	2091.7	3.32	0.230	NS
D. annulatum	1015.3 (110.1)	920.6 (39.4)	588.4 (72.9)	876(100.8)	1300.3 (86.9)	523.8 (75.4)	5224.4	8.31	1.538	NS
D. ciliaris	838.2(86.7))	956.7 (82.4)	443.4 (67.4)	647.4(53.5)	656.4 (186.4)	489.0 (554.2)	7548.4	12.01	0.641	NS
E. crus-galli	-	-	-	-	752.2 (56.8)	-	752.2	1.20	2.366	NS
E. indica	-	-	-	-	495.3 (106.8)	-	495.3	0.79	3.355	NS
E. tenella	370.7(17.9)	759.9 (74.5)	268.3 (37.0)	-	-	-	1398.9	2.23	1.000	NS
E. hirta	1271 (15.5)	968.6 (133.5)	559.8 (77.7)	1222.7 (79.1)	1657.3 (37.0)	951.1 (52.9)	6630.5	10.55	1.000	NS
E. nummularis	775.2(67.6)	835.0 (83.2)	555.2 (58.9)	810.2 (62.2)	477.0 (134.7)	407.7 (48.6)	3860.3	6.14	0.005	NS
F. schoenoides	-	-	-	-	611.6 (63.6)	-	611.6	0.97	1.000	NS
I. cylindrica	-	-	-	-	962.9 (72.6)	-	962.9	1.53	1.000	NS
O. burmanii	1143.3 (115.3)	1098.1 (66.2)	510.2 (37.9)	1318.6 (47.3)	1300.6 (48.6)	829.8 (86.1)	6710.8	10.68	1.000	NS
P. hysterophorus	714.5(76.9)	951.6 (62.1)	367.2 (29.4)	546.7(75.6)	609.4 (137.6)	631.8 (41.4)	3821.2	10.85	1.000	NS
S. spontaneum	-	-	-	-	-	617.9 (136.1)	617.9	0.98	1.000	NS

Note: NS = Not significant at $p > 0.001$, * significant at $p < 0.001$; - = absent.

Table 5: Characteristics of above-ground vegetation of grassland of moist tropics of India [values were means of plant densities (plants m^{-2}) with standard error (SE) in parentheses].

Species	Mean (SE)	*F*	*p*
Alysicarpous monolifer	203.9 (61.0)	9.139	0.015*
Argemone mexicana	504.0 (47.0)	0.991	NS
Boerhaavia diffusa	598.7 (67.3)	0.788	NS
Bulbostylis barbata	544.8 (144.7)	67.721	0.000*
Cannabis sativa	180.0 (91.5)	87.480	0.000*
Cassia tora	278.9 (21.0)	0.015	NS
Cyperus difformis	560.0 (52.1)	8.882	0.016*
Jatropha curcus	507.0 (79.4)	1.784	NS
Sida cordifolia	177.3 (52.1)	2.940	NS
Tridax procumbens	198.0 (57.4)	9.606	0.013*
Achyranthes aspera	263.7 (27.8)	4.841	0.056*
Ageratum conyzoides	373.8 (10.3)	32.868	0.001*
Alternenthera sessilis	381.2 (90.9)	88.709	0.000*
Anagallis arvensis	430.4 (41.4)	0.122	NS
Biophytum sensitivum	495.8 (10.8)	26.969	0.001*
Blepharis repens	141.9 (37.3)	31.508	0.000*
Blumea lacera	449.3 (13.7)	6.438	0.032*
Cassia occidentalis	158.1 (17.14)	1.896	NS
Centella asiatica	263.3(72.4)	23.524	0.001*
Commelina benghalensis	418.3 (115.8)	13.635	0.006*
Cynodon dactylon	1220.6 (86.7)	7.693	0.022*
Cyperus rotundus	389.9 (37.8)	0.728	NS
Desmodium triflorum	187.1 (95.0)	93.725	0.000*
Dichanthium annulatum	570.6 (37.5)	22.865	0.002*
Digitaria ciliaris	453.1 (23.2)	0.155	NS
Eleusine indica	423.1 (11.8)	12.246	0.00*
Euphorbia hirta	647.3 (35.3)	1.881	NS
Evolvulus nummularius	927.3 (94.0)	3.041	NS
Oplismenus burmanii	880.2 (61.3)	1.241	NS
Parthenium hysterophorus	125.6 (34.7)	14.070	0.005*
Saccharaum spontaneum	97.6 (49.6)	87.273	0.000*

Note: NS = Not significant at $p > 0.001$, * significant at $p < 0.001$.

Table 6: Different biodiversity indices of soil seed bank/above-ground vegetation in both annual cycle of grassland of moist tropics of India.

Annual cycle	Richness index	Diversity index	Dominance index	Abundance index	Evenness index
2007-2008	21/32	2.47/3.06	0.086/0.053	1.29/2.6	0.98/0.99
2008-2009	26/30	2.54/3.1	0.091/0.052	1.39/2.7	0.97/0.98

Figure captions:

Figure 1: Monthly variation of seed germination (seeds m^{-2}) in different depths of grassland of moist tropics, India. (1AC = First annual cycle; 2AC = Second annual cycle)

Figure 2: Seasonal variation in seed density (seeds m^{-2}) of grassland of moist tropics, India.

Figure 3: Hypothetical relation between seed density in soil seed bank (SSB) and plant density in above-ground vegetation (AGV).

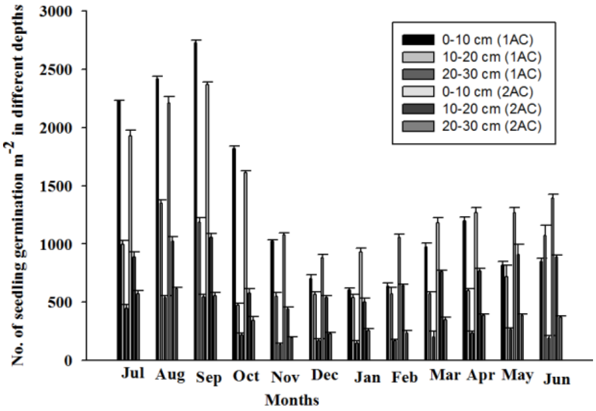

Fig. 1

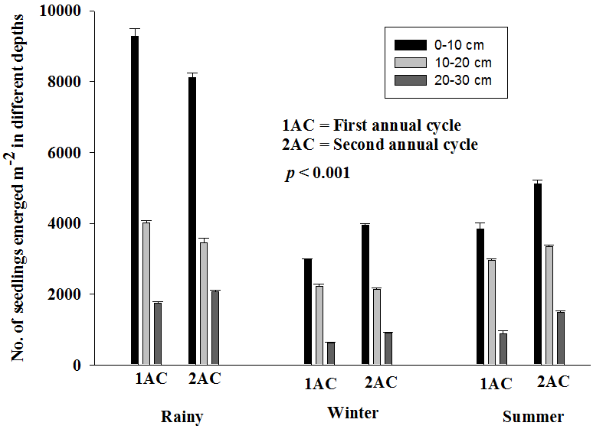

Fig. 2

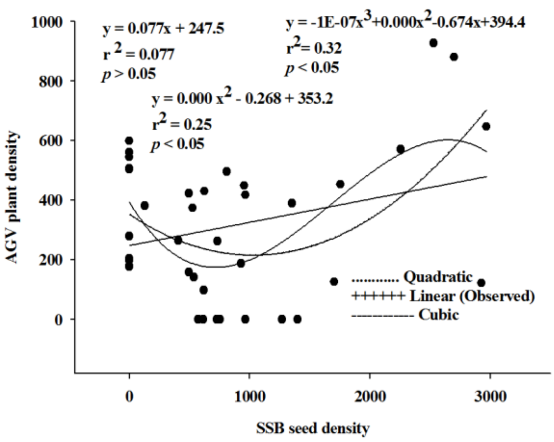

Fig. 3

Corresponding Author

Gopal S. Singh*

Institute of Environment and Sustainable Development, Banaras Hindu University, Varanasi-221005, UP, India

gopalshs@yahoo.co.in