Composition and Diversity of Weed Flora in Paddy Fields of Bhaktapur, Nepal

A Dissertation Submitted for Partial Fulfillment of the Master's Degree in Botany
Central Department of Botany, Tribhuvan University

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RECOMMENDATION

This is to recommend that the thesis entitled **"Composition and Diversity of Weed Flora in Paddy Fields of Bhaktapur, Nepal"** has been carried out by Mr. Lesar Unat Basukala for the partial fulfilment of Master's Degree of Science in Botany (Plant Systematic and Biodiversity Conservation Unit).

This is his original work and has been carried out under my supervision. To the best of my knowledge, this thesis work has not been submitted for any other degree in any institutions.

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LETTER OF APPROVAL

The dissertation presented by Mr. Lesar Unat Basukala entitled **"Composition and Diversity of Weed Flora in Paddy Fields of Bhaktapur, Nepal"** submitted at the Central Department of Botany, Tribhuvan University has been accepted for partial fulfillment of the requirements for the completion of Master's Degree in Botany (Plant systematics and Biodiversity Conservation Unit).

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ACRONYMS AND ABREVIATIONS

ANOVA	Analysis of Variance
asl	Above Sea Level
CC	Jaccard Coefficient of Community
cm	Centimeter
CRPC	Field with crop rotation of rice, potato and cauliflower
CRW	Field with crop rotation of rice and wheat
CRB	Field with crop rotation of rice and brick kiln
D	Simpson Index of diversity
DCA	Detrended Correspondence Analysis
E	Evenness
GPS	Global Positioning System
H	Shannon-Weiner index of diversity
IVI	Important Value Index
IPNI	International Plant Names Index
Lat.	Latitude
Long.	Longitude
KATH	National Herbarium and Plant Laboratories, Godawari
RDA	Redundancy Analysis
sq. m.	Square Meter
SD	Standard Deviation
SOM	Soil Organic Matter
SPSS	Statistical Program for Social Science
TUCH	Tribhuvan University Central Herbarium
WFO	The World Flora Online

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ABSTRACT

Weeds are perception-based plant species, which are considered nuisance, undesirable or useful based on, where it flourishes. Generally, weeds are known for their damage, increasing labor and causing economic loses. The weeds can also possess a lot of use value from biodiversity aspect, ecological aspect, utilitarian benefits as well as using them as herbicides and insecticides. So, enumeration and understanding environmental variables affecting weed composition and diversity is important. The study was carried in Changunarayan Municipality of Bhaktapur District. An approach for enumeration of weeds and its response to environmental variables was studied. A total of 60 quadrats of (1 × 1) m^2 were studied in three different sites which were categorized based on their crop rotation practice as Site A (CRPC), Site B (CRW) and Site C (CRB). The environmental variables used were soil organic matter, soil pH and water level in the field. Weed population and their density were recorded, which were subjected to multivariate analysis.

Altogether 32 species of weeds were enumerated that were making up community assemblage in paddy ecosystem, which belong to 27 genera and 14 families. Among the enumerated weeds 20 species found inside paddy fields and 12 species in the levee. Asteraceae, Poaceae and Cyperaceae were most dominant families in the paddy field. Mainly the field were dominated by broad leaved species (dicots) than the narrow leaved species (monocots). The study of IVI showed that *Acmella paniculata*, *Lindernia antipoda*, *Blyxa aubertii*, *Cyperus iria*, *Cyperus difformis* and *Alternanthera philoxeroides* were major dominant species in the paddy fields. The density of weeds in Site A (CRPC), Site B (CRW) and Site C (CRB) was 40, 44 and 85 individuals per square meter respectively.

The application of diversified crop rotation in the field change the soil properties, level of fertilizer input and soil organic matter. The diversified crop rotation field experience higher diversity than monoculture or fallow land. The DCA and RDA analysis showed beta diversity was found low and linear relationship in the study. It might be due to habitat homogeneity, management practice or similar climatic conditions. RDA showed preference of specific environmental variables by species, whose manipulation can cause change in composition & diversity of those species. The water level and soil pH had positive correlation to species density. The soil pH, water level, SOM and crop rotation were important environmental variables. They were not acting alone, but the multitude of other variables might be related to weed species composition and their diversity.

1. INTRODUCTION

1.1. Background

In agricultural landscapes, there were multiple plant species coexisted in paddy fields under various agricultural practices (Kosaka *et al.* 2006). There is increasing concern about the conservation of biodiversity (Gall and Orians 1992). In Asia, paddy farming is predominant monoculture cultivation and some studies have examined plant biodiversity (Bambaradeniya *et al.* 2004; Edirisinghe and Bambaradeniya 2006). Rice fields are unique ecosystems and rich in biodiversity, it not only sustains people whose staple diet is rice, but also act as the diverse assemblage of plants and animals which are dynamic and rapidly changing ecosystems (Edirisinghe and Bambaradeniya 2006). Paddy fields are not homogenous landscape which produce merely rice. It also harbors many plant species, insects, reptiles, animals, including exploited species, beneficial species and rare species. It also acts as temporary refuge home to those species who visit this ecosystem for variety of purposes (Kosaka *et al.* 2006; Edirisinghe and Bambaradeniya 2006).

Rice, the principal food crop, which is the most extensively grown cereal in the tropical and subtropical regions, mainly grown in China, India, Pakistan, Japan, Southern Asia and the adjacent islands of the Pacific (Sen 1992). There are about twenty-three species of rice, out of which only two species have been known for their commercial value, like *Oryza sativa* (Asian rice) and *Oryza glaberrima* (African rice). However, *Oryza glaberrima* cultivation is very limited to South Africa. *Oryza sativa,* the most important commercial species of rice have three sub species: *indica, japonica* and *javanica* based on their commercial production zones. The sub–species, *indica* refers to the tropical and sub-tropical varieties grown throughout Indian subcontinents of south, southern China and south-east Asia. The *japonica* variety is grown in the temperate region of Japan, Korea and China, while *javanica* variety is grown in Indonesia (MoAD 2015). In Nepal, rice is grown in an area of 1.54 million hectare of land (CBS 2006). It is grown from 60 to 3, 050 m altitude (MoAD 2015). Rice ranks first in terms of area, production and livelihood of the people. It is most important staple food consumed by Nepalese people, which accounts about 40% of total food calorie intake and contributes about 7% to the gross domestic product (GDP) and almost 20% to agricultural gross domestic product (AGDP) (MoAD 2015).

1.2. Weed biodiversity in crop land

Weeds are the nuisance plants (Harper 1960) which are judged by man not of use and undesirable at the place where it flourishes and interferes with the human activities and welfare of human (Salisbury 1961; Patil *et al.* 2010). Rice paddies are artificial, seasonal wetlands that provide ecosystem services and sustain vegetation as well as wildlife habitats. Modern agriculture system are basically chemicals driven and have homogenized the biodiversity in paddy fields, resulting in the outbreak of disease and threats the biodiversity (Luo *et al.* 2014). Despite of the crop loss, maintaining weeds in the farm land can support many useful insects, pollinators and microbes which can provide diverse ecological services, reduce effect of harmful weeds and support the nutrient dynamic (Storkey 2006; Nowak 2016). The floristic composition of an area, species number, and plant resources are affected by the anthropogenic disturbances, ecological and natural factors (Zeb *et al.* 2017). The prevalence of weeds in rice fields is dynamic and governed by the cultivation system, crop rotation, soil moisture, tillage system, light, soil temperature, fertilizers application, rice cultivar in use, seedling rate and weed management practices (Azmi and Baki 2007). The weeds growth occurs within forty-one days after sowing or planting and they may propagate by seeds and propagules or both (Bhatt *et al.* 2009).

Biodiversity is low in synthetic rice farms than the organic rice farm lands (Deb 2009). Biological assessment such as floristic composition, species diversity and the analysis of structural components are necessary to develop management strategies, exploring ecology and understanding the functions of the ecosystem (Zeb *et al.* 2017). Paddy fields were characterized by rich flora, with more than 1800 plant species, both aquatic and terrestrial associated with rice in south East Asia which were more than in any other crop, 269 weed species were reported in Nepal (Moody 1989). Ecological sustainability and plant biodiversity can be maintained by restoring and protecting the ecological environment surrounding the paddy fields, improving cropping patterns, using less agricultural chemicals and chemical fertilizers, constructing sound paddy systems with plants and animals (Luo *et al.* 2014).

In today's world, weeds are permanent constraint to crop productivity, labor and economic loss in agriculture (Holst *et al.* 2007). However, Luo *et al.* (2014) suggests introduction of species such as ducks, fish and Azolla was effective strategy to enhance species richness and biodiversity. Weed species composition varies with the type of land use, cultivation method, rice cultivar or paddy types, habitat type, agricultural practice and distance from the irrigation cannel (Kosaka *et al.* 2006; Bhatt *et al.* 2009; Kamoshita *et al.* 2014; Paudel *et al.* 2017; Zeb *et al.* 2017). The floristic composition of weeds are basically herbs, in upland dry or shallower water depth habitat which are dominated by the growth of Cyperaceae and Poaceae, while lowland with higher water depth are dominated by broad leaved species (Bhatt *et al.* 2009; Kamoshita *et al.* 2014). Kosaka *et al.* (2006) found 184 plant species, exotic as well as rare in paddy fields, and suggested the higher species diversity is due to presence of unique species in different paddy types, remnant species of original vegetation and impact of different agricultural practices. Anthropogenic rice fields harbor extremely rare species as well as accounts for relatively rich lush and water vegetation (Nowak 2016). The change in weed community composition is reflected in dominant species, weed population density, level of crop damage, succession of weed community, soil pH and nutrient of soil and crop weed competition (Manandhar *et al.* 2007; Luo 2014; Pavithra and Poonguzhalan 2018).

1.3. Weed management

Famers employ several control tactics aimed at killing as many weeds as possible in every season, as zero weed seedbank is never attainable, paddy fields serve as temporary home for several unique, rare as well as common species (Edirisinghe and Bambaradeniya 2006; Holst *et al.* 2007). Weed populations are dynamic in time, seasons and between space. In the paddy fields, *Fimbristylis littoralis, Lindernia oppostifolia, Ageratum conyzoides, Cyperus iria, Echinochloa crus-galli, Echinochloa colona, Cyperus difformis, Ludwigia hyssopifoli* are the dominant weeds (Zeb *et al.* 2017). Hand weeding is laborious, costly and time-consuming however, twice hand weeding is more effective than use of herbicides (Rekha *et al.* 2002; Hussain *et al.* 2008)

1.4. Crop weed services

Weeds are a major constraint on crop production, yet they may be regarded as an important component of the agro-ecosystem (Marshall *et al.* 2003). A total of 158 weed species of paddy field were documented from West Bengal, out of which 124 species were identified as useful (Datta and Banerjee 1978). Paddy fields are seasonal wetlands which had received much attention (Gopal and Sah 1995). It provides different ecosystem services, such as provisioning services; rice grain, straw and other plants, i.e. weed, regulating services;

temperature regulation, flood control, cultural services; festivals and rituals that are associated with farming, support nutrient cycles and maintain genetic diversity (Kamoshita *et al.* 2014). The paddy fields also provide ethnomedicinal important plants like *Bidens pilosa* extract used in leprosy, diarrhea; *Eclipta prostrata* used for natural hair dying; soup made from leaves of *Alternanthera sessilis* used by anemic patients in the rural area, etc. (Lal *et al.* 2012). In this context, the plant diversity of an area is not merely measure of the number of species, but also it reflects the dependence of the indigenous people and communities on that plant resource (Jain 2000).

1.5. Rationale

Paddy ecosystem tends to have limited diversity because human want to have certain plants only to live in the ecosystem, while unwanted plants are removed (Amarullah *et al.* 2017). Agricultural expansion and intensification are major drivers of biodiversity loss and biotic homogenization worldwide (Kehoe *et al.* 2017). So, biodiversity friendly management is important for sustainable agriculture, but farmers rarely put it into practice despite mounting evidence of the social, environmental and economic benefits (Maas *et al.* 2021).

Weeds are mostly known for their damage to productivity, but the ecosystem services they gave and biodiversity are less considered. Agro-fields can also harbor large number of biodiversity flora as well as fauna, and provide ecosystem services such as pollination, biological pest control, soil structure maintenance, nutrient cycle and hydrological cycle unconfined to human's necessities such as food, fuel, pharmaceuticals (Power 2010). The value of these ecosystem services is enormous, but often underappreciated. Crop rotation, tillage system, application of agrochemicals and other agricultural practices affect the soil seed bank and weed flora of agro-fields (Marshall *et al.* 2003). Preceding studies were mainly concentrated to protected areas and outside of agro-fields. It is important to explore and protect the weeds as well as manage them sustainably to account least productivity loss. Periodic survey, diversity analysis and documentation help catalogue the changing weed biodiversity and it also helps in finding as well as applying management and control strategies. Weeds are less studied, as they are considered nuisance plants which hinder proper identification due to lack of relevant literatures making it challenging to researchers and agriculturist. So, this study aims to enumerate the weeds prevailing in the paddy fields and study the effect of environmental variables as well as habitat characteristics on the weed's composition and diversity.

1.6. Objectives

The study is aimed to access the weeds species associated with paddy fields and access their composition as well as diversity in relation to environmental variables in Bhaktapur, Nepal.

The specific objectives are

- To enumerate angiosperm weeds in paddy field.
- To access the weed species composition pattern in relation to environmental variables.
- To access the effect of habitat characteristics on weed diversity.

1.7. Limitation:

- The sampling was done after first hand weeding, as it was missed in certain fields.

2. LITERATURE REVIEW

2.1. Weed flora

Weeds are unwanted and unwelcomed plants in a place, where it flourishes and interfere with resource utilization, increase human labor, affect agricultural input and cause multifarious crop-weed competition affecting crop yields (Harper 1960; Salisbury 1961; Rao 1983; Patil *et al.* 2010; Schonbeck 2013). The perception of weeds depends on where it flourishes. A plant may be weed to one person in that particular place, in the particular cultivation and might not be weed to another person or it might be valuable to someone. Its prevalence in rice fields is dynamic and affected by soil type, latitude, longitude, temperature, cultivation system, soil temperature, fertilizers application, rice cultivar in use, seedling rate and weed management practices (Smith and Moody 1979; Azmi and Baki 2007). Crop fields are the human intervened habitat with extraordinary species rich environments (Wittig 2002).

Several studies and researches had been done about the weeds worldwide, on different aspects such as floristic composition, diversity, taxonomic point, control measures, their ethnobotanical aspects and biodiversity. Most of the literatures are floristic and deals on control measures and their effect on crop. Very few works have been done to see the response of environmental variables in the weeds. So general review of research works carried on weeds in Nepal and worldwide is reviewed here.

Gupta *et al.* (1977) studied weed problems in Rampur, Chitwan and reported that most of the weeds infesting the crop fields belonging to Poaceae and Cyperaceae.

In the wheat crop of Kathmandu valley, Chaudhary (1979) reported altogether 108 weed species which belonged to 36 families. Compositae was the largest family followed by Poaceae, Leguminosae and Cruciferae. The most abundant species in the field were *Chenopodium album, Polygonum* sp., *Vicia* sp., *Cannabis saliva* and *Alopecurus nepalensis* in one or different fields. Later, Chaudhary and Shrestha (1981) studied the weed flora of Kirtipur area (Kathmandu valley). They reported altogether 185 species belonging to 49 families. They found most of the weeds belonged to Compositae (32 spp.) followed by Poaceae (21 sp.), Leguminosae (15 spp.) and Cyperaceae (9 spp.)

Harrington *et al.* (1992) conducted a survey on weed flora in wheat fields of Kabhrepalanchowk, district and doccumented *Polygonum hydropiper, P. viscosum, Phlaris minor, Chenopodium album* etc as the important weeds.

Similarly, Rajbhandari and Joshi (1998) reported 364 species of weeds in various crop fields of Nepal. Among 364 species, 263 were broad leaved species and 101 species of narrow leaved species. The book had short botanical treatment, common names, english name and brief phenology. The weed species reported by them in wheat fields includes *Cynoglossum zeylanicum, Stellaria media, Chenopodium album, Circium verutum, Sonchus asper, Capsell bursa-pastoris, Medicago lupulina, Avena fatua* etc.

Dangol (2002) carried out survey of weed flora in various crop fields of Chitwan like spring rice, finger millet, pea, oat and mustard. Altogether 113 angiospermic weeds were reported, belonging to 81 genera and 36 families. He found 74 dicots and 39 monocots. The major weeds of crop field were *Chenopodium album, Ageratum conyzoides, Phlaris minor* etc.

In the wheat fields of Pokhara, Thapa (2003) studied weed flora and reported 57 weeds which were composed of 45 Dicots, 11 monocots and 1 peteridophyte.

Bhatt *et al.* (2004) studied weed flora of paddy field in Mahendranagar and reported 54 weed species in the paddy fields. The study reported the presence of *Echinochloa crus-galli, Echinochloa colona, Cynodon dactylon, Eleocharis* spp., *Fimbristylis* spp., *Cyperus rotundus*, and *Ischaemum rugosum*, in the paddy fields of Nepal.

Kosaka *et al.* (2006) Studied Plant diversity in Paddy fields in relation to agricultural Practice in central Laos and inventoried 184 weeds species dominated by Cyperaceae (30 spp.), Poaceae (29 spp.) and Scrophulariaceae (22 spp.) while dominant species are *Fimbristylis miliacea, Ludwigia hyssopifolia,* and *Melochia corchorifolia*. Rare species like *Drosera indica* L., *Stylidium kunthii* Wall., *Stylidium tenellum* Sw. ex Kunth. And 43 exotic species are reported. He suggested the higher species diversity is due to presence of unique species in different paddy types, remnant species of original vegetation and impact of different agricultural practices.

Azmi & Baki (2007) carried weed surveys in 2001-2005 in Muda rice granary and recorded 58 weed species belonging to 26 families, of which 27 are broad-leaved, 14 grasses, 12 sedges and 5 aquatic plants. He found *Echinochola crus-galli*, *Leptochloa chinensis* and *Ludwigia hyssopifolia* as dominant weeds.

Manandhar *et al.* (2007) Studied weeds of paddy field in Kirtipur, Kathmandu and enumerated 52 weed species of which 27 are dicots and 25 monocots, belonging to 32 genera and 15 families, *Echinochloa colona*, *E. crus-gali*, *Cyperus iria* and *Ageratum conyzoides* were dominant weeds. An attempt had been made to find the allelopathic effects and crop-weed competition. Weed species richness and diversity causes change in soil pH, reduction in nitrogen and phosphorus, which cause loss in straw and grain yield of paddy (Manandhar *et al.* 2007).

Bhatt *et al.* (2009) carried a field experiment in paddy fields in lowland and upland areas of Mahendranagar, and recorded 61 weed species belonging to 42 genera and 23 families. Mainly the weed floristic composition is dominated by cyperaceae and poaceae in uplands than the lowlands. *Fimbristylis miliaceae, Lindernia oppostifolia, Eleocharis Atropurpurea, Ageratum conyzoides, Cyperus iria, Echinochloa crus-galli, Echinochloa colona, Cyperus difformis* and *Schoenoplectus juncoides* are reported as dominating weeds.

Sapkota *et al.* (2010) studied weed composition in wheat field of Khokana, Kathmandu valley and recorded 44 weed species belonging to 18 families, mainly *Chenopodium album, Polygonum plebeium* and *Spergula arvensis* were reported as abundant. He suggested periodic survey helps catalogue existing weeds and their extinct of harm.

Dangwal *et al.* (2012) extensively studied weeds of paddy field from 2009-2011 in Rajouri district of India and enumerated 65 weed species belonging to 23 angiospermic and 1 pteridophyte which are predominated by monocots, Cyperaceae and Poaceae

Nowak *et al.* (2016) studied weed communities of central Nepal and classified segetal plant communities occurring in paddy field into 9 communities and reported 80 species. They found relatively rich lush of vegetation in rice fields even extremely rare species recorded in world red list. The altitude had also significant effect in species distribution and their composition.

Zeb *et al.* (2017) carried a floristic study of weeds in Pakistan and explored 89 species belonging to 76 genera and 34 families of which Asteraceae was dominant. He classified species based on habitat dry, wet, and wet-dry. Floristic diversity is mainly dominated by herbaceous species and affected very fast by ecological factors. In the paddy fields *Fimbristylis miliaceae, Lindernia oppostifolia, Ageratum conyzoides, Cyperus iria, Echinochloa crus-galli, Echinochloa colona, Cyperus difformis, Ludwigia hyssopifoli* are the dominant weeds. They found plant and their distribution had strong correlation with environment.

2.2. Weed composition and diversity

The weed composition varies from one crop to another crop, from one region to another region, from one farm to another farm and even one section of a farm to another farm (Rao 1983). The concept of weed biology and its mechanism is essential for the environment friendly and sound weed management practices. So, weed species must be studied to understand their growth and development, phenology and interaction with other species under different agricultural practice (Bhowmik 1997). The floristic composition and its diversity serve as indicator of the field conditions. Most of the weeds are characterized to have enormous seed production, large seed dormancy and can multiply under environmental extremities. The composition and diversity of weeds are governed by environmental factors, anthropogenic as well as biological factors. The farmers are the person whose agricultural actions, species selection, crop rotation, fertilization application, weed management and soil conservation practices affect the weed communities and microenvironments. (Thapa 2005). Weeds have a lot of use value that is undervalued being nuisance. Some of weeds are used as medicinal purpose, food and fodder. It also helps in maintaining soil fertility, nutrient cycles, provide home for refuges and maintain genetic diversity (Kamoshita *et al.* 2014). Various works had been done to study weeds composition and their diversity which are presented below.

Pysek and Leps (1991) studied the composition of weed communities in barley fields of Czechoslovakia to see the influence of different nitrogen fertilization. They evaluated the results by using CCA diagram. They found that there was direct impact of the type and differential dose of nitrogen fertilization and indirect effects of the crop-weed competition.

Barberi *et al.* (1997) studied the influence of cropping system with three different inputs (Low, intermediate, high) and crop rotation of summer crop and winter wheat on the density and composition of winter weed flora of wheat at university of Pisa Italy. They used multivariate analysis CCA. They found that the weed density generally decreases with the increase in the disturbance due to cropping intensity. The weed species composition changes over the different cropping seasons while some remain constant in both crop rotation. However, Anderson and Milbrig (1998) could not find significant change in weed flora in different crop rotation. They found the greatest difference was due to the site and other second important factor was the crop species. The application of nitrogen also had weak influence in weed flora. Bhowmik (2000) said weed species must be studied about their biology to understand the growth, development and competition. This way we can understand the weed species or their population about biotypes/ecotypes, selection pressure and response of agricultural practice. The soil seed bank composition and diversity influence the population dynamics of the weeds. It's essential to study soil seed bank dynamics to understand the weed composition and their management. Generally, the grain yield of paddy declines with the increase in weed density and influenced by the size of the weed species as it causes the higher rate of competition for the same resource.

Kleijn and Verbeek (2000) studied the factors affecting arable fields of the central and eastern Netherlands. They used multivariate analysis CCA to see the effect of nutrients and crop rotation on weeds composition and diversity. From the CCA analysis diagram they found that there was great influence of nutrients nitrogen, phosphorus and crop rotation on species diversity of field boundary.

Shrestha *et al.* (2002) studied the weed composition in sandy soil in Delhi in bean and wheat to see the effect of the tillage and crop rotation. The tillage system, cover crops and the type of crop had differential effects in the weed density, community composition and their association. They found weed densities were affected by tillage or crop cover in bean but were not affected in wheat.

According to Walter *et al.* (2002) the weed species composition was field specific and changes with the spatial variation of the soil properties. The spatial variation of soil properties causes patchiness of the weeds. The spatial change due to heterogeneous landscape causes the large weed species diversity with different niches (Gabriel *et al.* 2005). The weed populations were influenced by the crop rotation, tillage system adopted and the timing of herbicide application (Streit *et al.* 2003). According to Legere *et al* (2005) the tillage showed little effect on weed diversity but it played a major role in determination of weed composition.

The weed species diversity and their community composition change with the cropping practices and intensity of herbicides as well as fertilizer inputs. Alternative cropping practice changes the species composition and increases the diversity of weed communities.

The low input fields with lower nitrogen supply and without herbicides had higher weed species diversity than conventional cropping, which had high mineral fertilizers as well as herbicides application. The application of herbicides affects to those species which are susceptible to herbicides and causes skewed dominance patterns of the weed community (Hyvonen *et al.* 2002).

Fried *et al.* (2008) had studied 700 arable fields of France to see the effect of environment and management factors in weed species composition and diversity. Multivariate analysis (CCA) was used to see the environmental factors versus management practices affecting on weed species composition and richness. Sowing season, spring, summer and winter-sown crops were used as three main weed communities. They found soil pH, precipitation, longitude and tillage depth affect species composition. The species richness and community composition had contrasting relationship to altitude and the species richness was high in 300-400 altitude but had low species.

Pinke *et al.* (2010) studied environmental factors affecting on weed species composition in the cereal fields of western Hungary. They recorded 309 species and analyzed the species composition by using multivariate analysis (RDA). They observed that most of the variation in species composition was caused by the soil pH, mean annual precipitation, mean annual temperature, soil texture and altitude.

Kamoshita *et al.* (2014) conducted survey on weed species in paddy fields at different distances from the main irrigation canal and identified 76 weed species from 224 quadrate studied in Cambodia. Weed species diversity varied with spatial change in the water depth, shallower upstream paddy field accounts higher weed species diversity of Poaceae & Cyperaceae and lower in downstream mainly of aquatic herbs.

De Mol *et al.* (2015) surveyed weed species of maze fields from 2001 to 2009 in germany. They studied the species composition influenced by site and crop sequence. Multivariate analysis of principal component analysis and redundancy analysis was used to see the effect of site and crop sequence in weed species composition. The weed species composition was significantly affected by the environmental factors particularly latitude and precipitation (9.1% explained variance) then management factors particularly crop sequence (4.7% explained variance). They suggest crop sequence can be used to suppress the individual species but should not have too high hopes for great weed management.

3. MATERIALS AND METHODS

3.1. Study area

3.1.1. Bhaktapur

The study area is in Jhaukhel-2, Changunarayan Municipality of Bhaktapur District, Bagmati Province no. 3, Nepal. It is about 16 km far from the capital city, Kathmandu. The precise geographical location is between 27º 36' to 27º 44' northern latitude and 85º 21' to 85º 32' eastern longitude. Bhaktapur is the smallest district of Nepal with an area of 119 square kilometer (DCC 2015) (Figure 1). The average altitude of Bhaktapur is 1331 m from sea level and east-west length is 16 km, whereas north-south length is 12.2 km (DCC 2015).

3.1.2. Geomorphology

Bhaktapur is a small district which can be divided into two regions: hill areas and valley floor. Its North boundary is Kathmandu and Kavrepalanchok district, Lalitpur district is in South, Kavrepalanchok district is in East, and Kathmandu and Lalitpur districts are in West. The prime rivers of Bhaktapur district are Manohara, Hanumante, Tabyakhusi, Mahadev khola and Ghatte khola (DCC 2015).

3.1.3. Climate

Bhaktapur is in the eastern part of Kathmandu Valley and have a humid subtropical climate. The average temperature ranges between 20º C to 25º C. The maximum recorded temperature is 32ºC, while the minimum is -2ºC. Average annual rainfall is 56 mL. The relative humidity in average is 95 percent (DCC 2015).

3.1.4. Vegetation

Land topography is divided into two parts viz. hill and valley. Soil in valley is more fertile so the area is used in cultivation, while perimeter of Bhaktapur is surrounded by different types of forest. Forest of Bhaktapur has Uttis (*Alnus nepalensis*), Rhododendron (*Rhododendron arboreum*), Chutro (*Berberis nepalensis*), Pine (*Pinus roxburghii*), Oak (*Quercus robur*), etc. (DCC 2015).

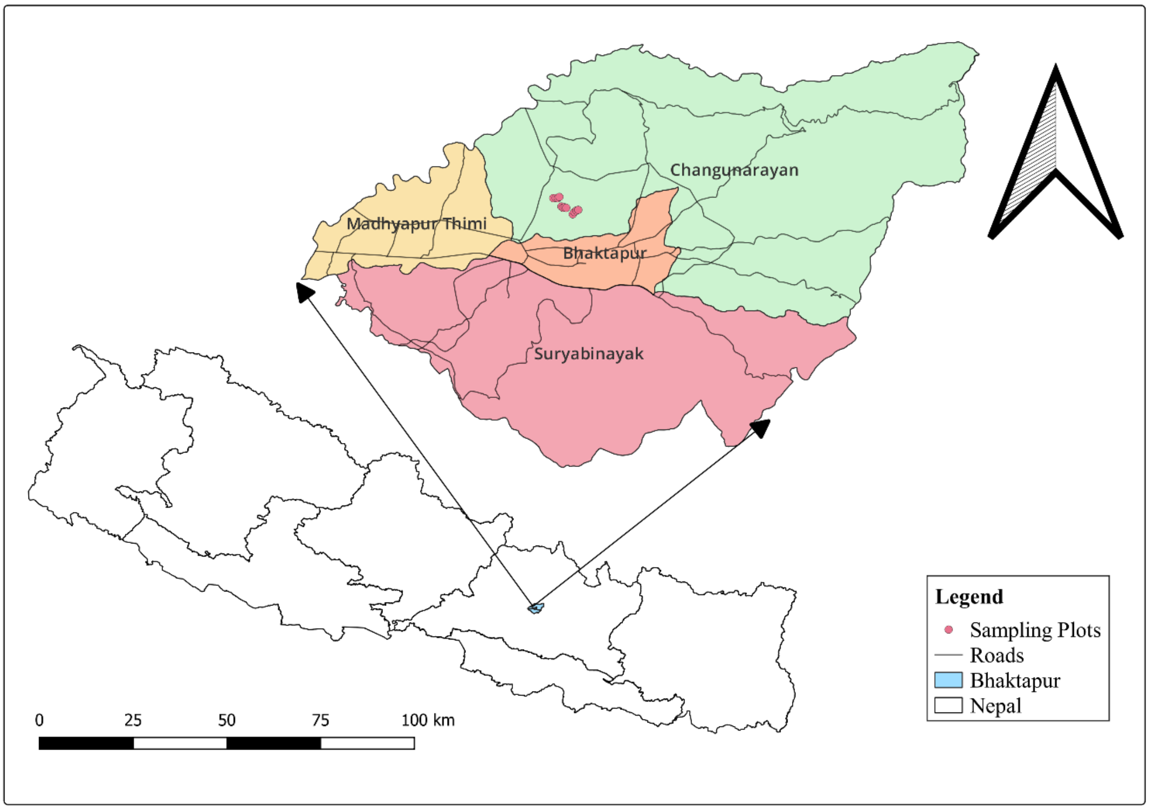

Figure 1: Map of study area showing sampling plots in Bhaktapur

3.2. Study design

3.2.1. Reconnaissance survey

Reconnaissance survey was done in April-May 2019 at farmers field in Changunarayan Municipality of Bhaktapur District for possible field identification for the study. Detailed information about crop rotation and weed management practices was collected after discussion with local farmers and direct observation.

3.2.2. Field sampling procedures

Field sampling was done by frequent visits to the field, (twice a month) and quantitative data was taken when maximum number of weeds were at flowering stage in the month of August. For quantifying the weeds, the plots selected in the agricultural field were more or less similar in size, its location and classified based on the field history of crop rotation. Twelve agricultural fields were selected and classified as Site A for field with crop rotation of rice, potato and cauliflower (CRPC), Site B for field with crop rotation of rice and wheat (CRW), and Site C for field with crop rotation of rice and brick kiln (CRB). The spatial scale between different crop rotation fields was at least 300 m, but no more than 400 m. In each cropping system 4 fields were selected which were about 50 m apart from each other. In each field 10 m × 10 m plot was established from center of field for field uniformity, reduce leeve effect and weeds collection. In each plot five quadrats were placed for quantitative data collection of which four quadrats were placed at four corners and one at center to represent the whole field.

3.2.3. Materials required for the study

Herbarium press, camera, polythene bags, tags, corrugated sheet, measuring scale, digger, metal pegs for plot, soil tester, pH meter, scale, rope, GPS, Herbarium sheet, newspapers, field notebook, pen, pencil, etc. were used.

3.2.4. Collection technique

Photographs of habitat and plants species were taken prior to collection by using Nikon Coolpix S8100 With Nikkor 10x Wide Optical Zoom Ed Vr 12.1 Megapixels camera. The plant specimen was pulled out from the root by using a digger. The specimen was cleaned to remove debris and other soil particles, then it was tagged with proper code number and field information was noted down in a notebook. The collection and herbarium preparation were done by following standard taxonomic process (Bridson and Forman 1992). The information about the date of collection, field collection number, scientific name, family, Latitude/Longitude Altitude/ GPS, habit and habitat of the plant, local name, uses, remarks; special distinguishing characters were noted.

3.2.5. Herbarium preparation and preservation

The collected plant specimens, if large in size were cut into required sizes without losing important characteristic features. Collected specimens were pressed in newspaper. Larger specimens were pressed in N or V forms and corrugated sheet was kept in every specimen for quick drying. After that, they were pressed in herbarium press and used artificial heater for quick drying. The newspaper of the specimens was regularly checked for dampness in daily basis and changed daily until the plants dried. The dried specimens were mounted on herbarium sheets having standard size of 45 cm length and 30 cm wide (Bridson and Forman 1992). Then the herbarium sheets were stitched using a cotton thread by making a knot on reverse side of the sheet and kept in dry place for storage.

3.2.6. Laboratory techniques and identification

Plant specimens were identified first by morphological features. The morphological characters of reproductive and vegetative parts were studied using a hand lens of 40x and 60x. Identification of the species were done with the help of standard literatures such as Flora of China (FOC), Flora of Bhutan (FOB), and Flora of Kathmandu Valley (FOK),A Handbook of Flowering plants of Nepal (Grierson and Long 1983; 1984; 1991; 1999; 2001; Noltie 1994; Noltie 2000; Malla *et al.* 1986). Further confirmation was done, by comparing herbarium of national herbarium and Plant Laboratories, Godavari (KATH) and Tribhuvan University Central herbarium, Kathmandu (TUCH). Species names were confirmed with the help of Tropicos which is authentic database of International Plant Names Index (IPNI), The Plant List (TPL), The world flora Online (WFO), which are online versions.

3.3. Data collection

3.3.1. Soil sampling

Soil sampling was done following Motsara *et al.* (2008). About 1 kg of soil sample from each plot was collected from 15 cm depth from five sub plot. Before taking samples, the unnecessary plants and materials were removed from the soil surface. A V-shaped pit was dug and soil was extracted by scooping from top to bottom of the pit using spatula. The soil sample thus collected were screened for unnecessary debris. These soil samples were collected in the polythene zip-lock bags and labeled well. After that they were air dried to minimize chemical changes due to wetness and stored to determine soil pH and soil organic matter.

3.3.2. Soil pH

Soil pH is a measure of the acidity or alkalinity of a soil. Soil pH is considered as the master variable of the soils which specifically affects plant nutrients availability by controlling the chemical reactions they undergo. The soil pH affects the plant nutrient uptake, growth and development; so, it is essential to measure it. For determining the soil pH, 10 gm of sieved soil sample was dissolved in 20 ml of distilled water and stirred well for 5 minutes then it was allowed to stand for half an hour and measured by dipping the electrode of pH Meter PH-98107 of the tester family company. The pH meter was calibrated using buffer solutions of pH = 7 and pH = 4.

3.3.3. Soil organic matter

Soil organic carbon is one of the constituents of soil organic matter. Soil organic matter roughly contains 58 % of organic carbon. Soil organic carbon and organic matter was determined by using rapid titration method (Walkley and Black 1934). 0.5 gm of air-dried soil sample sieved through 2 mm was taken in a dry 250 ml conical flask. Then, 5 ml of 1N Potassium dichromate ($K_2Cr_2O_7$) and 10 ml of conc. H_2SO_4 was added to it and swirled two or three times, and the flask was allowed to stand for 30 minutes. After that, 100 ml of distilled water, 5 ml of 85 % phosphoric acid and 0.5 ml of diphenylamine indicator solution were added respectively. Then the titrand was titrated with 0.5N Ferrous sulphate solution till the color changes from blue violet to complete greenish color and burette reading was noted. A blank without soil was also titrated against 0.5N Ferrous sulphate solution and burette reading was noted.

$$\text{Organic carbon (\%)} = \frac{3(\text{S} - \text{T})}{\text{S} \times \text{wt. of soil}}$$

Where,

S = milliliters of $FeSO_4$ solution required for blank

T = milliliters of $FeSO_4$ solution required for soil sample

The organic carbon obtained by above method was multiplied by a factor of 1.3 based on the assumptions that there was 77 % recovery

$$\text{Amount of Organic Carbon (Y)} = \text{percent value of organic carbon obtained} \times 1.3$$

To determine organic matter content of soil, the organic carbon estimated is multiplied by Van Bemmelen factor of 1.724, because organic matter contains 58% organic carbon.

$$\text{Soil organic matter (SOM)} = \text{Y} \times 1.724$$

3.3.4. Water level

Water level of the studied plots were measured by using a measurement scale in centimeter (cm). Water level measurement were carried out from the surface of the soil up to the lower meniscus of the water by dipping inside the water in field and noted the readings.

3.4. Data analysis

3.4.1. Weed diversity analysis

Weed diversity was recorded at the time of second week of the August from the selected plots of 1 m × 1 m from the farmer's field when maximum numbers of weeds were at reproductive stage. Density, frequency, coverage, importance value index (IVI), Shannon-Weiner index (H), Simpson's Index of diversity (D) and species evenness (E) were calculated following Misra (1968); Zobel *et al.* (1987).

Frequency and Relative frequency

Frequency is the percentage occurrence of a particular species in the quadrat studied to the total number of quadrats studied. It was calculated using following formula.

$$\text{Frequency}(\%) = \frac{\text{Number of quadrats in which the species occured}}{\text{Total number of quadrats studied}} \text{x}100$$

Relative frequency is the percentage occurrence of a particular species in relation to the total frequency of all the species present in the community. It was calculated by using following formula.

$$\text{Relative Frequency}(\%) = \frac{\text{Total frequency of particular species}}{\text{Total frequency of all species}} \text{x}100$$

Density and Relative density

Density is the number of individual species per unit area. It shows the quantitative diversity of species in the community which changes with management action and other various environmental factors. It shows the numerical strength of species in the community. It was calculated using following formula.

$$\text{Density}(\text{No./m}^2) = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrats studied x Area of each quadrat}}$$

Relative density is the percentage occurrence of particular species in relation to total density of all the species present in community.

$$\text{Relative Density}(\%) = \frac{\text{Total density of particular species}}{\text{Total density of all species}} \text{x}100$$

Coverage and relative coverage

Coverage is the amount of surface area occupied by a plant. It is measured as the actual vertical projection downward to the ground plant crowns enclosed in sampling plots. For a small plot, visual assumption of coverage can be done following (Zobel et al. 1987).

$$\text{Coverage}(\%) = \frac{\text{Total midpoint value of coverage of species}}{\text{Number of the plots studied}} \text{x100}$$

Relative coverage is the percentage coverage for a particular species in relation to total coverage of all the species present within the community.

$$\text{Relative coverage}(\%) = \frac{\text{Coverage of a particular species}}{\text{Total coverage of all the species}} \text{x100}$$

3.4.2. Importance value index (IVI)

Important value index is the sum of relative frequency, relative density and relative coverage (Muller-Dombois and Ellenberg 1974). It shows the relative contribution and interaction of the species existing in the community.

$$\text{IVI} = \text{Relative frequency} + \text{Relative Density} + \text{Relative coverage}$$

3.4.3. Shannon-Wiener index of diversity

Species diversity was calculated by using Shannon-Wiener Diversity index (H) and Community Dominance by Simpson index (D) (Zobel et al. 1987).

$$\text{Shannon} - \text{Wiener Index of diversity}(\text{H}) = -\sum_{i=1}^{s} p_i \ln p_i$$

Where,

H = Shannon index of diversity

s = it is the number of categories (e. g. species)

p_i = proportion of one particular species found (n) to total individual found (N) $\left(p_i = \frac{n}{N}\right)$

ln = natural log

Note: High value of (H) (ranges from 0 to 1) represents more diversified communities.

Evenness is a measure of relative abundance of different species making up the richness of an area.

$$\text{Evenness (E)} = \frac{H}{\ln(s)}$$

Where,

H = Shannon index of diversity

S = number of unique species

ln = natural log

3.4.4. Simpson's index of diversity

Simpson index is a dominance index which gives more weight to common or dominant species. It is calculated using following expression:

$$\text{Simpson index (D)} = 1 - \sum_{i=1}^{s} p_i^2$$

Where,

D = Simpson index of Diversity

p_i = proportion of one particular species found (n) to total individual found (N) $\left(p_i = \frac{n}{N}\right)$

Note: High value of (D) (ranges from 0 to 1) represents more diversified communities.

3.4.5. Jaccard coefficient of community

The Jaccard coefficient is a coefficient of community that indicates the degree of similarity of two communities based on the number of species that they have in common. It calculates the unique (unshared) species as a proportion of the total species recorded in the two communities. It is calculated using following formula.

$$\text{Jaccard Coefficient (CC)} = \frac{c}{S_1 + S_2 - c}$$

Where,

CC is the Jaccard Coefficient of Community

S_1 is the number of species in community 1

S_2 is the number of species in community 2

c is the number of species in common between community 1 and community 2

3.5. Statistical analysis

Statistical analysis was carried out using the Statistical Product and Service Solutions (SPSS) version 25, software of International Business Machines Corporation (IBM). It was applied for Analysis of Variance (Anova) to see the change in environmental variables between sites with different crop rotation. Pearson correlation was applied to see the relation of species richness and density with environmental variables. Canoco for windows version 4.56 (ter. Braak and Smilauer 2002) was applied for DCA to find the length of gradient and see whether the data follows unimodal or linear relationship. The length of gradient (axis length) was less than 2.5 SD units so, RDA analysis was used to find species response to the environmental variables. Ms. Excel 2019 was used for data management, tabulation, graphs and figures.

4. RESULTS

4.1. Enumeration of weed in paddy fields of Bhaktapur

In the paddy fields of Bhaktapur, altogether 32 plant species were identified as weeds. Among the enumerated weeds 20 species were found inside paddy field and 12 species were found in the levee of paddy fields (Table 1).

Table 1: Weeds enumerated from paddy fields of Bhaktapur.

S.N.	Species	Type	Family
1	*Alternanthera philoxeroides* (Mart.) Griseb.	Dicot	Amaranthaceae
2	*Amaranthus blitum* L.	Dicot	Amaranthaceae
3	*Alternanthera sessilis* (L.) R. Br. ex DC.	Dicot	Amaranthaceae
4	*Bidens pilosa* L.	Dicot	Asteraceae
5	*Ageratum conyzoides* L.	Dicot	Asteraceae
6	*Eclipta prostrata* (L.) L.	Dicot	Asteraceae
7	*Parthenium hysterophorus* L.	Dicot	Asteraceae
8	*Galinsoga quadriradiata* Ruiz & Pav.	Dicot	Asteraceae
9	*Acmella paniculata* (Wall. ex DC.) R.K. Jansen	Dicot	Asteraceae
10	*Rorippa palustris* (L.) Besser	Dicot	Brassicaceae
11	*Drymaria cordata* (L.) Willd. ex Schult.	Dicot	Caryophyllaceae
12	*Cyperus rotundus* L.	Monocot	Cyperaceae
13	*Fimbristylis littoralis* Gaudich.	Monocot	Cyperaceae
14	*Cyperus iria* L.	Monocot	Cyperaceae
15	*Cyperus difformis* L.	Monocot	Cyperaceae
16	*Kyllinga brevifolia* Rottb.	Monocot	Cyperaceae
17	*Blyxa aubertii* Rich.	Monocot	Hydrocharitaceae
18	*Clinopodium umbrosum* (M. Bieb.) K. Koch	Dicot	Lamiaceae
19	*Lindernia antipoda* (L.) Alston	Dicot	Linderniaceae
20	*Ammannia auriculata* Willd.	Dicot	Lythraceae
21	*Oenothera rosea* L'Hér. ex Aiton	Dicot	Onagraceae
22	*Ludwigia prostrata* Roxb.	Dicot	Onagraceae
23	*Plantago major* L.	Dicot	Plantaginaceae
24	*Eleusine indica* (L.) Gaertn.	Monocot	Poaceae
25	*Eragrostis unioloides* (Retz.) Nees	Monocot	Poaceae
26	*Digitaria ciliaris* (Retz.) Koeler	Monocot	Poaceae
27	*Echinochloa colona* (L.) Link	Monocot	Poaceae
28	*Echinochloa crus-galli* (L.) P. Beauv.	Monocot	Poaceae
29	*Setaria pumila* (Poir.) Roem. & Schult.	Monocot	Poaceae
30	*Persicaria hydropiper* (L.) Delarbre	Dicot	Polygonaceae
31	*Persicaria barbata* (L.) H. Hara	Dicot	Polygonaceae
32	*Monochoria vaginalis* (Burm. f.) C. Presl ex Kunth	Monocot	Pontederiaceae

4.2. Species composition

The present study revealed that the study area was rich in different types of weed species. The weeds species collected from paddy fields showed wide diversity of weeds with 32 species, 27 genera and 14 families (Figure 2).

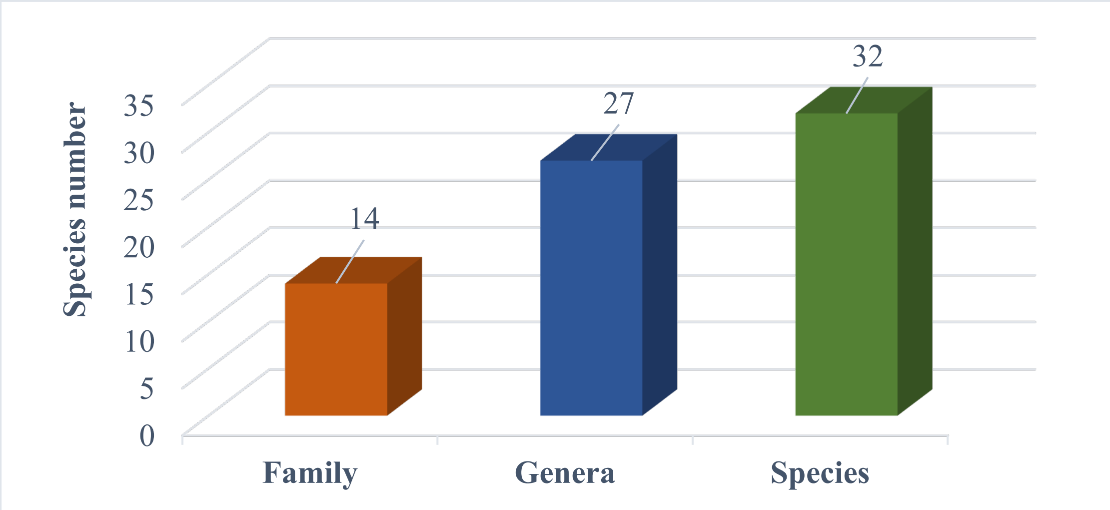

Figure 2: Number of taxa

There was wide variety of species and genera found in the study. The study revealed wide species and genera in different families. Asteraceae (6, 6), Poaceae (6, 5), and cyperaceae (5, 3) were most species and genera rich families. Polygonaceae (2, 1), Onagraceae (2, 2), and Amaranthaceae (3, 2) were moderately rich in species and genera. Other, rest of family had only one species and genera (Figure 3).

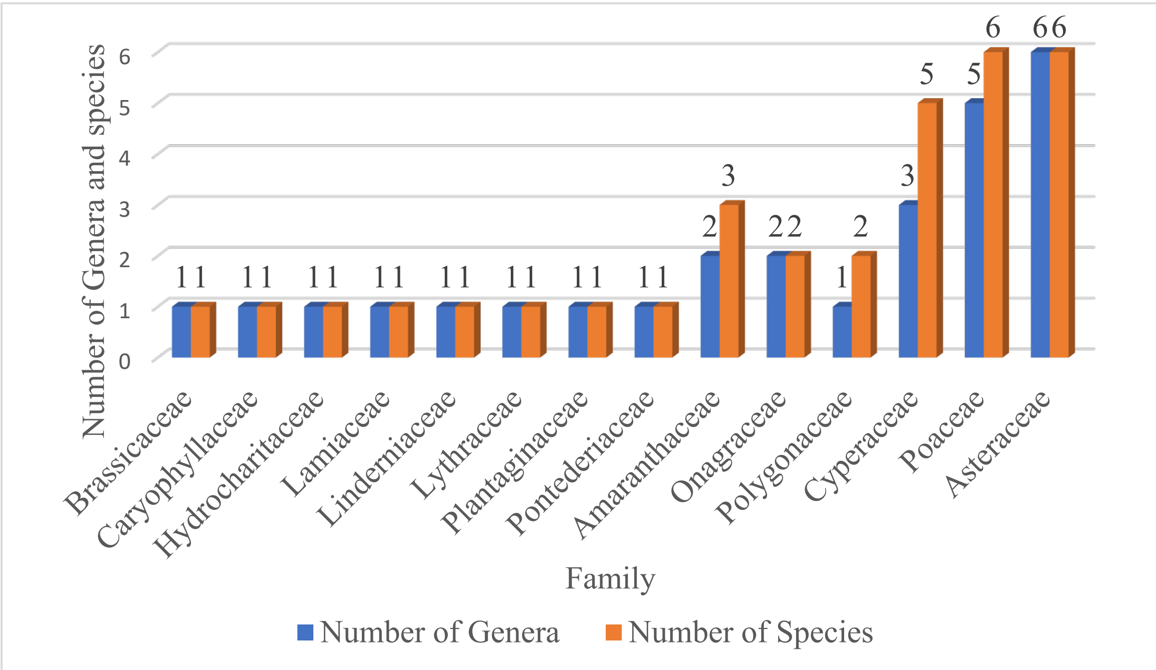

Figure 3: Number of species in each family

Among the 27 genera, *Cyperus* was the largest genera with 3 species followed by *Persicaria*, *Echinochloa* and *Alternanthera* with 2 species in each. Other genera like *Setaria, Rorippa, Plantago, Parthenium, Oenothera, Monochoria, Ludwigia, Lindernia, Kyllinga,* etc had one species (Figure 4).

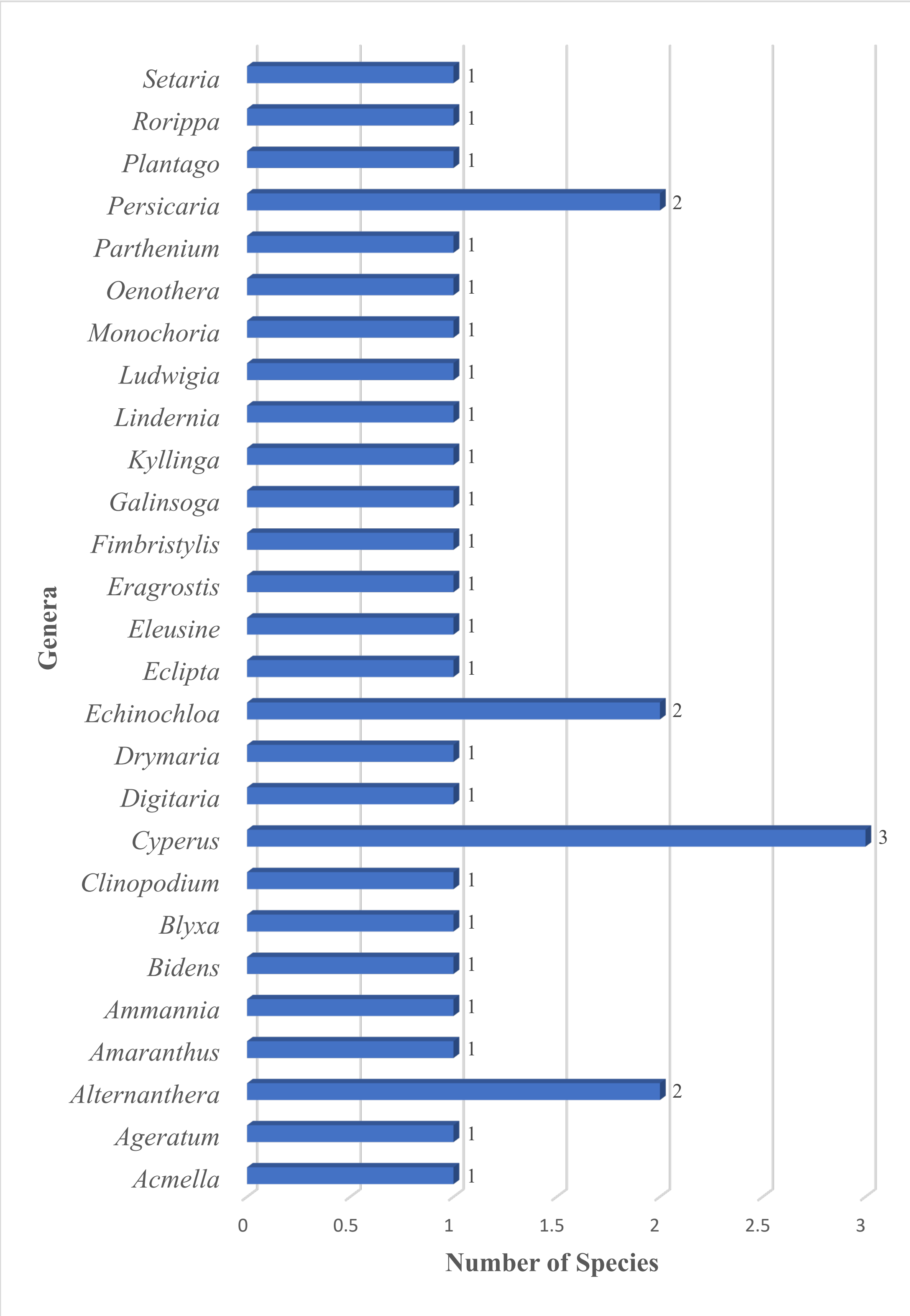

Figure 4: Number of species in each genus

The total species enumerated in the paddy fields were 32 species. Out of which 59 % were found as dicots and 41 % were monocots. Dicot species occurrence was more that monocots (Figure 5).

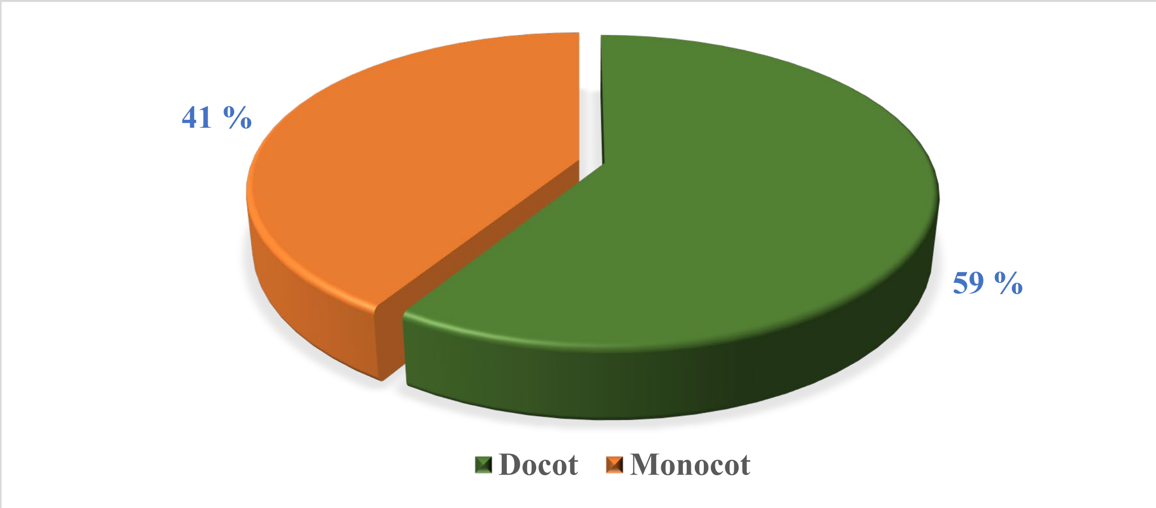

Figure 5: Species composition of dicot and monocot

Among the total species collected, 59 % were comprised of broad-leaved weeds, 19 % grasses, 16% sedges, and 6% were aquatic (Figure 6). The field was mainly composed of broad-leaved weeds like *Alternanthera philoxeroides*, *Acmella paniculata*, *Lindernia antipoda*, *Eclipta prostrata* followed by grasses like *Echinochloa crus-galli*, *Echinochloa colona*, *Eleusine indica*, sedges like *Fimbristylis littoralis*, *Cyperus rotundus*, *Cyperus iria*, *Cyperus difformis* and aquatic to semi aquatic *Blyxa aubertii* and *Monochoria vaginalis*.

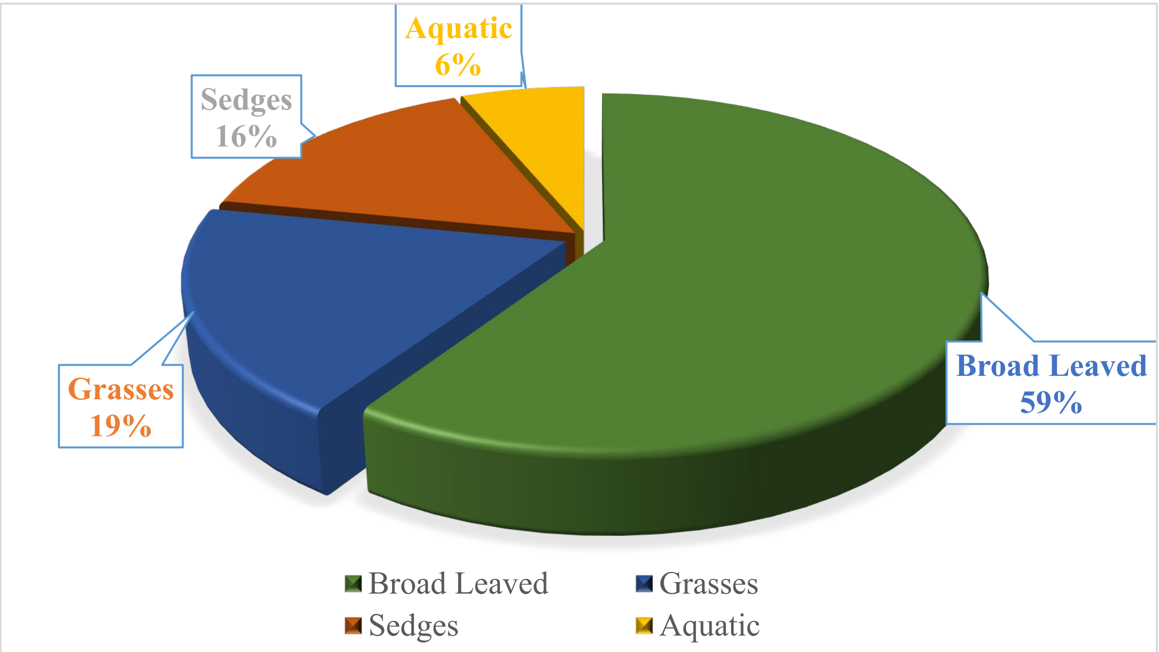

Figure 6: Species composition by different groups

4.3. IVI analysis of weed diversity in different sites.

Quantitative analysis of weed diversity in 3 sites of paddy field with different cropping system was carried in the month of August. On the basis of important value index (IVI), mainly paddy fields were dominated by seven major species of weeds that were *Acmella paniculata, Lindernia antipoda, Blyxa aubertii, Cyperus iria, cyperus difformis, Alternanthera philoxeroides and Echinochloa crus-galli.* Other species like *Ammannia auriculata, Monochoria vaginalis, Ludwigia prostrata, Persicaria hydropiper, Rorippa palustris* etc were minor weeds (Table 2). Site A (CRPC), Site B (CRW) and Site C (CRB) had individual weed species densities of 40, 44 and 85 per square meter, respectively (Appendix III, IV, V). These were the important weeds in the study area.

Table 2: Important value index (IVI) of weeds species in different sites.

S.N.	Weed Species	Important Value Index (IVI)			Average
		Site A (CRPC)	Site B (CRW)	Site C (CRB)	
1	*Acmella paniculata*	23.84	58.27	96.18	59.43
2	*Lindernia antipoda*	62.15	43.04	39.77	48.32
3	*Blyxa aubertii*	66.11	36.37	35.60	46.02
4	*Cyperus iria*	29.37	40.62	24.54	31.51
5	*Cyperus difformis*	26.68	39.83	10.80	25.77
6	*Alternanthera philoxeroides*	24.62	15.83	23.17	21.20
7	*Echinochloa crus-galli*	10.40	10.08	11.87	10.78
8	*Eclipta prostrata*	8.42	11.44	9.78	9.88
9	*Eleusine indica*	9.42	7.23	8.33	8.32
10	*Echinochloa colona*	9.91	10.54	3.47	7.97
11	*Fimbristylis littoralis*	2.30	-	19.81	7.37
12	*Ammannia auriculata*	8.30	8.96	3.42	6.89
13	*Monochoria vaginalis*	4.86	5.68	7.06	5.87
14	*Ludwigia prostrata*	10.87	6.55	-	5.81
15	*Persicaria hydropiper*	-	4.48	-	1.49
16	*Alternanthera sessilis*	-	-	3.59	1.20
17	*Rorippa palustris*	-	-	2.62	0.87
18	*Cyperus rotundus*	1.43	-	-	0.48
19	*Digitaria ciliaris*	1.31	-	-	0.44
20	*Galinsoga quadriradiata*	-	1.09	-	0.36
	TOTAL	300	300	300	300

4.4. Weed species diversity in different community sites

Shannon diversity index shows that weeds community in site B was more diverse than site A and site C. Site A was less diverse than site B, but more diverse than site C. Site C was less diverse than both Site A and Site C (Table 3).

Table 3: Weed species diversity, Shannon diversity (H), Simpson index of Diversity (D) and Evenness (E) in different sites

Diversity indices **Site**	**Richness**	**Shannon Diversity (H)**	**Evenness (E)**	**Simpson index of Diversity (D)**
Site A (CRPC)	16	4.10	1.48	0.82
Site B (CRW)	15	4.19	1.55	0.85
Site C (CRB)	15	3.44	1.27	0.72

4.5. Weed species similarity in different community sites

The Jaccard coefficient of community (CC) analysis shows that weeds community in site A (CRPC) and site C (CRB) had high species similarity with value (CC=0.82) then other sites. The weed communities of site A (CRPC) and site B (CRW) (CC=0.72) had medium species similarity. While site B and C (CC=0.67) had least shared species (Table 4).

Table 4: Jaccard coefficient of community similarity between sites

Site	Jaccard Coefficient of Community (CC)
A and B	0.72
A and C	0.82
B and C	0.67

4.6. Relation of crop rotation and management practice in environmental variables.

The soil pH of paddy fields was acidic in all sites which ranged from 5.35 to 5.8. The water level in the field ranged from 0 to 5 and SOM ranges from 2.69 to 5.16 (Appendix III). The one-way anova analysis between different sites with different crop rotation showed that soil pH between sites was not found statistically significant ($F_{2,57} = 2.910$, $p = 0.063$). Soil organic matter (SOM) between different sites was found to be statistically significant ($F_{2, 57} = 11.647$, $p < 0.01$). Water level between sites was not found statistically significant ($F_{2, 57} = 1.350$, $p = 0.267$) (Table 5). While plotting mean of SOM and sites, negative graph was obtained. There was decline in SOM with crop rotation practice.

Table 5: One-way anova between different sites.

		Sum of Squares	df	Mean Square	F	Sig.
Soil pH	Between Groups	0.085	2	0.043	2.91	0.063
Soil organic matter	Between Groups	15.46	**2**	**7.73**	**11.647**	**<0.01**
Water Level	Between Groups	6.533	2	3.267	1.35	0.267

From the graph there was a decline in the soil organic matter with different crop rotation and farming practice adopted by farmers in different sites. Site A had high mean of SOM (Mean = 4.87±1.07), Site B had medium mean of SOM (Mean = 3.82±0.12) and Site C had least SOM (Mean = 3.77±0.91) (Figure 7).

Figure 7: Mean of soil organic matter with site

4.7. Correlation analysis

The statistical pearson correlation coefficient analysis of species richness with water level, soil pH, and organic matter showed that there was no any statistically significant correlation 95 % significance level ($p < 0.05$). Correlation of species density and water level was found to be negative and statistically significant (Table: 4, $r = -0.299$, $p = 0.02$). Whereas species density and soil pH had negative correlation and statistically significant ($r = -0.742$, $p < 0.05$). Similarly Soil organic matter and water level showed positive correlation and statistically significant ($r = 0.485$, $p < 0.05$) (Table 6).

Table 6: Pearson correlation (r) between species density, species richness, water level, soil pH and organic matter (N=60).

		Water level	**Soil pH**	**Soil organic matter**	**Density**	**Species richness**
Water level	Pearson Correlation	1				
	Sig. (2-tailed)					
Soil pH	Pearson Correlation	0.211	1			
	Sig. (2-tailed)	0.106				
Soil organic matter	Pearson Correlation	**0.485****	0.113	1		
	Sig. (2-tailed)	**<0.01**	0.391			
Density	Pearson Correlation	**-0.299***	**-0.742****	-0.104	1	
	Sig. (2-tailed)	**0.02**	**<0.01**	0.428		
Species richness	Pearson Correlation	-0.055	0.047	-0.039	0.246	1
	Sig. (2-tailed)	0.675	0.723	0.767	0.058	

****. Correlation is significant at the 0.01 level (2-tailed).**

***. Correlation is significant at the 0.05 level (2-tailed).**

4.8. Distribution of species along environmental variables

To understand the relationship between the species and environment, Detrended correspondence analysis (DCA), an indirect gradient analysis, was carried out. It was used to study the distribution pattern of sample units and species in space (Leps and Smilauer 2003). The value of DCA first axis (Length of gradient) was estimated to be 2.367 so confirmed linear relationship. Redundancy analysis (RDA) was employed to explain the species environment relationship. RDA is a direct gradient analysis (ter Brank 1986).

The RDA ordination explained the relationship between samples, species and environmental variables. Manual selection and Monte Carlo permutation tests revealed that water level (F=10.76, p = 0.0003) and Soil pH (F=59.53, p = 0.0001) was significant variable for governing the species composition (Table 7). Summary of the Monte Carlo permutations tests showing the relative importance of environmental variables on the species composition is given in Table 7.

Table 7: The relative importance of environmental variables on species composition based on RDA analysis. The statistically significant (P<0.05) variables were obtained using Monte Carlo test with 9999 permutations.

Environmental variables	**Abbreviation**	**F**	***p***
Water level	Water_lv	10.76	0.0003
Soil pH	Soil_pH	59.53	0.0001
Soil organic matter	SOM	2.69	0.0824

The DCA ordination calculated a lower gradient length (2.367 SD units) for the DCA first axis, indicating the linear relationship among species along the main gradient. The RDA ordination clearly explained that the axis I explains about 96.8 variances in the species-environment relation data and 56.2 % in the species data. The second axis explained 57.8 variances in species data. The eigen–value for RDA second axis was comparatively lower (0.016) than the first axis (Table 8).

Table 8: Summary of RDA ordination (sum of all canonical eigenvalues = 0.580)

Parameters	**Axes**			
	1	**2**	**3**	**4**
Eigen values	0.562	0.016	0.002	0.284
Species-environment correlations	0.825	0.483	0.314	0
Cumulative percentage variance				
of species data	56.2	57.8	58	86.5
of species-environment relation	96.8	99.6	100	0

The sample by environment ordination diagram (Figure 8) showed that the most sampling plots lies in the field with high SOM and water level which can be seen in upper left side of diagram. The first canonical axis was correlated with water level and SOM. The water level and SOM were positively correlated with each other. Most of sampling plots above axis I experienced higher water level and SOM. The sampling plots below axis I experienced lower water level and SOM. The most samples of Site A and B tend to distributed along higher water level and SOM while, samples of Site C tend to be distributed in places with lower water level and SOM. Majority of the sample plots were acidic in nature (Figure 8).

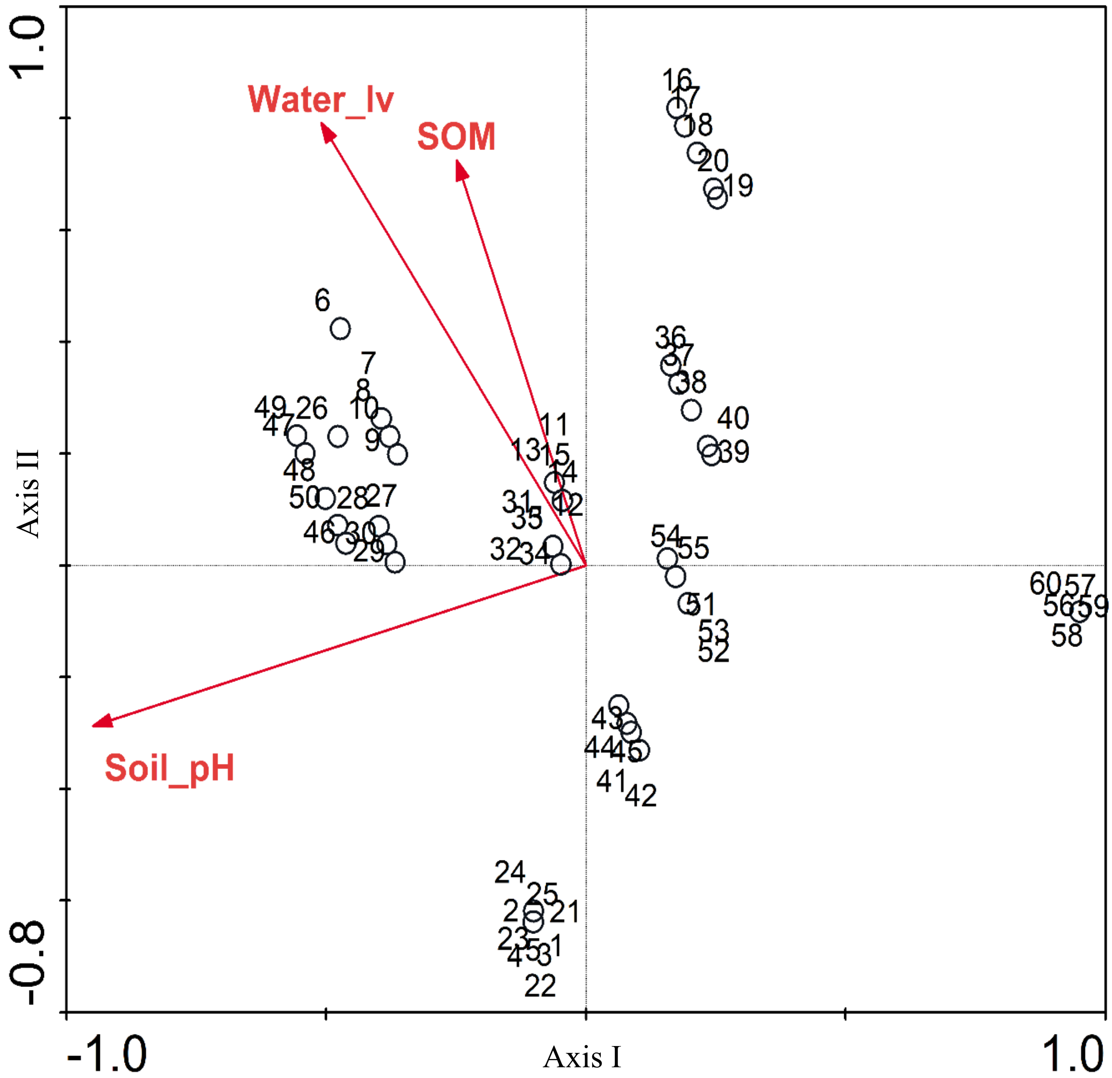

Figure 8: RDA biplots for sample plots and environmental variables; numerical values denoted by the plot number, (Water_lv = water level, Soil_pH = Soil pH and SOM = Soil organic matter)

Species, such as *Cyperus difformis* (Cype_dif), *Alternanthera sessilis* (Alte_ses), *Galinsoga quadriradiata* (Gali_qua) and *Cyperus iria* (Cype_iri) seemed to be evenly distributed and positively correlated to water level and SOM which can be seen in upper left quadrat (Figure 9). In lower right quadrat, species, like *Acmella paniculata* (Acme_pan), *Rorippa palustris* (Rori_pal), *Fimbristylis littoralis* (Fimb_lit), *Eleusine indica* (Eleu_ind), *Eclipta prostrata* (Ecli_pro), and *Echinochloa* crus-galli (Echi_cru) preffered plots with low to no water level and low in soil organic matter as they were negatively correlated to SOM and water level. We can see in the lower left quadrat high abundance of species *Blyxa aubertii* (Blyx_aub), *Echinochloa colona* (Echi_col), *Monochoria vaginalis* (Mono_vag), *Ammannia auriculata* (Amma_aur), *Ludwigia prostrata* (Lugw_pro) and *Persicaria hydropiper* (Pers_hyd) were positively correlated to soil pH while in the opposite in upper right quadrat, the species *Lindernia antipoda* (Lind_ant), *Digitaria ciliaris* (Digi_cil), *Cyperus rotundus* (Cype_rot) and *Alternanthera philoxeroides* (Alte_phi) were negatively correlated to soil pH while weakely correlated to water level and soil organic matter (Figure 9)

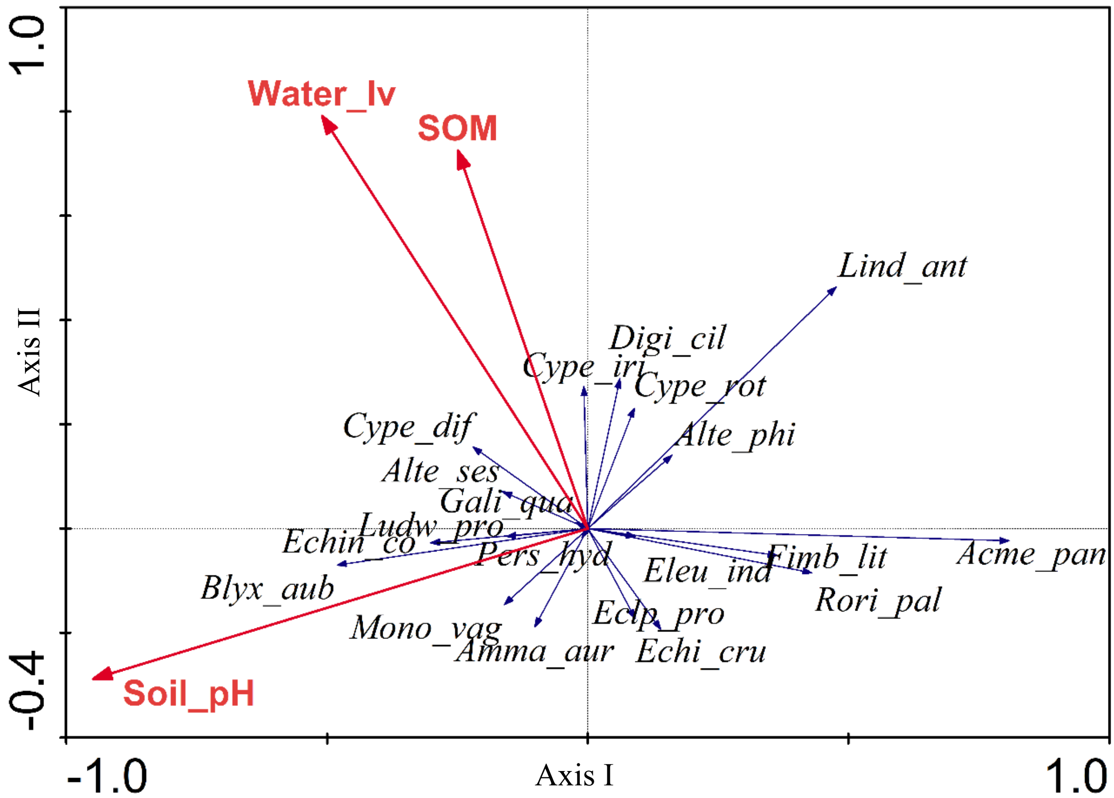

Figure 9: RDA biplots for species and environmental variables

5. DISCUSSION

5.1. Floristic composition

The weed species are human perception-based plants, considered nuisance as well as useful based on occurrence at where it flourishes. In current study, altogether 32 weed species were enumerated in paddy fields of Bhaktapur which belongs to 14 families and 27 genera (Figure 2). Out of the total species collected, 20 species were found inside paddy field and 12 species in the levee of the fields. The other studies carried in paddy fields of Nepal had also reported about 40-60 species of weeds (Bhatt *et al.* 2004; Manandhar *et al.* 2007; Bhatt *et al.* 2009). There was difference in the number of species reported by various authors. The change in species number might be due to change in agricultural practices, soil seed bank, land use type, climate, spatial change in soil properties and temporal change in heterogenous landscape (Walter *et al.* 2002; Gabriel *et al.* 2005). The paddy fields of Bhaktapur were mainly dominated families of Asteraceae (6 spp.), Poaceae (6 spp.) and Cyperaceae (5 spp.) (Figure 3), however Bhatt *et al.* (2009) found Cyperaceae and Poaceae dominated the paddy fields. The community of weeds in paddy field in study area was diverse as there were variety of species that belongs to different genera. The *Cyperus*, *Echinochloa*, *Persicaria*, and *Alternanthera* had more diverse species. Other genera had only one species in them. Most of the weed species were dicots (59%) and monocots (41%), similar results were found by (Manandhar *et al.* 2007).

Anderson (1996) found broad-leaved species were more competitive than grasses, while studying the composition of the species similar results were obtained, most of the field were dominated by broad leaved species (59%), grasses (19 %), sedges (16%) and aquatic (6%) (Figure 6). While the result contrasts with the other several studies as they infer fields were mainly dominated by monocots (Dangol *et al.* 1988, Moody 1994). There were mixed results between different sites, ecological features, agricultural practice, climate, spatial and temporal effects which suggests no strict categorization about the composition of weed flora. The weed composition and dominance of species, genera, and family depends upon the field conditions. The upland fields had lower water depth so they were mainly dominated by Poaceae and Cyperaceae, however in the lowlands with higher water depth the broad-leaved species dominates the field (Bhatt *et al.* 2009; Kamoshita *et al.* 2014). Kosaka *et al.* (2006). The weed flora of any agro-ecosystem changes as result of long-term change or temporary fluctuations occurring in species composition. The weed flora and its composition depend upon the selection pressure, genetic variability of weed populations, characteristics of weeds, environmental factors, application of herbicide and intensive mechanization (Murphy *et al.* 2006).

5.2. Diversity of weeds

In the plot and farm scales, biodiversity was unlikely to be maintained other than for direct use or utilitarian benefits. The analysis of biodiversity, its use and management were highly perspective based. High biodiversity systems might be protected by intrinsic religious and social customs. Agricultural development directly affects local field level diversity and homogenize as well as facilitate in movement of superior germplasm (Swift *et al.* 2004). In the modern agricultural practices with intensive farming, which were mainly chemicals driven to ensure high productivity, had resulted in homogenization and deteriorated balance in paddy fields ecosystem. This have resulted in outbreaks of diseases, variety of insects and weeds become more persistent in paddy fields (Luo *et al.* 2014).

Quantitative analysis of the weed diversity in different sites which had different crop rotation practice had different species diversity. Based on IVI, five most dominant and major species in Site A were *Blyxa aubertii*, *Lindernia antipoda*, *Cyperus iria*, *Cyperus difformis* and *Alternanthera philoxeroides*. Whereas, based on IVI five most dominant and major species in Site B were *Acmella paniculata*, *L. antipoda*, *C. iria*, *C. difformis* and *B. aubertii*. In Site C based on IVI most dominant and major species were *A. paniculata*, *L. antipoda*, *B. aubertii*, *C. iria* and *A. philoxeroides* (Table 2). Overall looking at IVI average mainly paddy fields of Bhaktapur were dominated by major weeds of *A. paniculata* (59.43), *L. antipoda* (48.32), *B. aubertii* (46.02), *C. iria* (31.51), *C. difformis* (25.77) and *A. philoxeroides* (21.20). Other species like *Ammannia auriculata*, *Monochorea vaginalis*, *Ludwigia prostrata*, *Rorippa palustris* etc were minor weed species (Table 2). The species *C. difformis* and *C. iria* were also reported as dominant weeds in paddy fields of Kirtipur and Mahendranagar (Manandhar *et al.* 2007; Bhatt *et al.* 2009). There was considerable change in the IVI of species in different sites which was associated with the crop rotation and land use pattern. *A. paniculata* was mostly dominated in Site C (CRB) and Site B (CRW) but less dominant in Site A (CRPC). But, *L. antipoda* and *B. aubertii* were mainly dominant in Site A, whereas they were less dominant in site B and C of the field. *A. philoxeroides* was more dominant in Site A and Site C compared to Site B. The density of weed species in Site A was 40, in site B was 44 and in site C was 85 individuals per square meter. The weeds species composition might be similar in different time and space but the dominant species vary (Bhatt *et al.* 2009). The weed diversity in agricultural field might also be affected by use of fertilizer cases and use of different pesticides and herbicides which was not studied in this case. Ruhai *et al.* (2008) found different weed community compositions and dominant species varies due to effect of long-term fertilization, pesticide and herbicides use.

Paddy field act as a seasonal and artificial ecosystem, the stability of this ecosystem and diversity of plant/weed community was mainly affected by environmental characteristics, soil properties, landscape and anthropogenic interaction. Human limit the diversity of paddy fields by controlling and letting those species only that they think were important and useful, other were destroyed, this results in low biodiversity. Measuring the diversity of given species was an important character of plant community and it plays a crucial role in the ecosystem conservation of threatened species (Demie 2019). Vegetation of a given area was said to have high diversity, if it had many species and their abundance was even, conversely, the diversity was low when the species were few and their abundance was unevenly distributed (Sewale and Mammo 2022).

The results of Shannon-wiener diversity index revealed that weed community in Site B (CRW) (H = 4.19) had highest species diversity and richness as well as evenness in species followed by weed community in Site A (CRPC) (H = 4.10 and Site C (CRB) (H=3.44). While results of Simpson diversity index for dominance revealed similar results to Shannon index of diversity, community type in site B (D = 0.85) showed highest species diversity followed by site A (D = 0.82) and C (D = 0.72) (Table 3). The species diversity of particular place is dependent on even distribution of unique species, remnant species of original vegetation and impact of different agricultural practices (Kosaka *et al.* 2006). The possible reason for site B (CRW) being high in diversity could be an intermediate favorable condition of SOM, soil pH and water level that made optimal conditions of environmental factors for their growth. The weed community in Site C (CRB) have least richness, evenness and diversity compared to other sites. The location of this community site has mono crop, fallow period and anthropogenic disturbance that could have depleted soil seed bank resulting in low diversity.

Agricultural weeds are group of unique plant species, which have ability to thrive and infest in intensively disturbed habitats. They are plastics in characteristics which help them to invade any ecosystem. They differ from between field, regions, climatic zones and cropping systems (Murphy *et al.* 2006). The weeds are successful plants because of their plasticity traits such as long seed dormancy, resistance to pathogens and large number of seed production. Their genetic variations and characteristics help them to survive and dominate any environment (Jasieniuk and Maxwell 2001).The weed flora and their diversity are markedly influenced by the change in soil texture, type of irrigation,, slope aspect and altitude, than soil pH and carbonate content of soil (Saavedra *et al.* 1990). Moreover, the change of management practices and soil disturbances creates micro-sites for weed species to germinate and grow. These changes directly affect weed physiology, their growth, crop-weed competition, weed management options, reproduction and species distribution (Thill *et al.* 1997).

5.3. Similarity between three community sites

Based on Jaccard coefficient of community among the three community sites A, B and C, communities in site A and C had high number of species composition similarity (CC = 0.82), followed by communities in site A and B (CC = 0.72). In community sites B and C, relatively low similarity (CC = 0.67) was observed. This could be associated to soil pH, SOM, water level, crop rotation and other environmental factors such as soil type and properties, anthropogenic activities which were not considered in this study. SOM increases with diversified crop rotation, tillage and crop management. According to Koocheki *et al.* (2009) seed bank density and species composition changes with the crop rotation.

SOM was higher in field where crop rotation and minimal soil disturbances was practiced. SOM levels relates to soil fertility and availability of carbon, nitrogen and phosphorus which were necessary for plant growth and development (Palm *et al.* 2014). The paddy fields soil was acidic in nature. One-way anova showed that soil organic matter (SOM) between different sites was found to be statistically significant ($F_{2, 57}$ = 11.647, p = <0.01). The difference in mean of SOM was due to cropping pattern and crop rotation. Site A had high SOM (Mean = 4.87±1.07), Site B had medium SOM (Mean = 3.82±0.12) and Site C have least SOM (Mean = 3.77±0.91) (Figure 7). However, soil pH and water level were not found statistically significant to show the difference in between sites. The site C (CRB) was disturbed by anthropogenic activities and fallow period of half season due to brick kiln, which had caused change in soil properties. Farmers experience higher amount of fertilization input was needed in monocultured fields than multi-cropped or multiple crop rotation fields, however fertilization input were not considered in this study. The SOM is important indicator of soil quality. Its quality and quantity depend on edaphic and environmental factors (Martyniuk *et al.* 2019). In past it was believed synthetic fertilizers and pesticides could replace crop rotation without yield loss. In current scenario, it is believed that diversified crop rotation could improve the soil physical properties and SOM, which could increase the yield 5 to 20% (Bullock 1992).

5.4. Correlation with species and environment

The species distribution was correlated with different environmental factors in different significance level. The correlation analysis of species richness with water level, soil pH, and organic matter showed that there was no any statistically significant correlation at 95 % significance level ($p < 0.05$). Correlation of species density and water level was found to be negative and statistically significant (Table: 8, $r = -0.299$, $p = 0.02$). This means the rise in water level decreases the weed density and vice versa but not significant to show relation with species richness. The change in standing water table and alternating dry and wetting of field changes the growth of dominant species, weed density reduction and increase weed height. It also helps in controlling weeds and reduces the risk of weed outbreaks (Luo *et al.* 2016). Whereas species density and soil pH had negative high correlation and statistically significant ($r = -0.742$, $p = <0.01$). Soil pH have negative effect on the species density, with the increase in soil pH species density decreases whereas becoming acidic to normal soil pH, increases the weed density. The confounding effect of both soil pH and water level affects the weeds density. While comparing Soil pH and water level they were not statistically significant. But Soil organic matter and water level showed positive correlation and statistically significant ($r = 0.485$, $p = <0.01$) (Table 6). The water distribution in the soil is important factor for SOM decomposition. The spatial distribution of water affects enzyme diffusion and microbial activity, which changes the nutrient availability for the plants (Goebel 2007).

5.5. Species distribution with environmental variables

Weed species diversity vary with spatial change in the water depth and are influenced by various environmental factors (Komoshita *et al.* 2014). Soil pH, water level and SOM were main predictor variables for ordering the species in different quadrats. The change in floristic composition of an area, species number, and plant resources are affected by the anthropogenic disturbances, ecological and natural factors. Other factors like cultivation system, soil moisture, crop rotation, cropping pattern, tillage system, light, soil temperature, fertilizers application, rice cultivar in use, seedling rate and weed management practices were equally important (Marshall *et al.* 2003; Azmi and Baki 2007; Zeb *et al.* 2017). These variables affect mutually, which makes it difficult to find role of each variable in species determination (Kohn and Walsh 1994).

The DCA is an ordination analysis which represents the species turnover or beta diversity in term of standard deviation (SD) units. The gradient length greater than 2.5 SD units indicate that species found in one gradient are different from the species found in another gradient and shows unimodal relationship. In our study the DCA analysis, the length of gradient was 2.367 standard deviation (SD) units which was less than 2.5 SD. This suggests the species composition is homogeneous and shows linear relationship. The RDA analysis of samples, species and environmental variables was found canonical with eigen value (axes 1 = 0.562), and (axes 2 = 0.018). The species environment correlation value (r) for first axis was 0.825 and 0.483 for second axis. This suggests that the whole data is not influenced by single dominant variable. The arrow head and its length indicates the strength and direction of the correlation with dependent and independent variable.

The sample by environment ordination diagram showed that most of sampling plots lies in the field with high SOM and water level. The water level and SOM were highly correlated to each other while they were weakly correlated to soil pH (Figure 8). *Cyperus difformis*, *Alternanthera sessilis*, *Galinsoga quadriradiata* and *Cyperus iria* seemed to be evenly distributed and positive correlated to water level (water_lv) and SOM which can be seen in upper left quadrat. These species were ordered mainly due to effect of water level and SOM making community assemblages, this shows that these species prefer to occupy spaces with high water level and SOM rich field. Mainly field, which have low crop rotation, monocrop cultivation system and fallow lands possesses low SOM. Crop rotation of more than one species substantially increases the soil microbial biomass or SOM and nitrogen content irrespective of crop type or management (Mcdaniel *et al.* 2014). Species which were found in lower right quadrat were *Acmella paniculata*, *Rorippa palustris*, *Fimbristylis littoralis*, *Eleusine indica*, *Eclipta prostrata*, and *Echinochloa* crus-galli, which preffered plots with low water level and low in SOM. In the lower left quadrat species *Blyxa aubertii*, *Echinochloa colona*, *Monochoria vaginalis*, *Ammannia auriculata*, *Ludwigia prostrata* and *Persicaria hydropiper* were positively correlated to soil pH while in opposite of it in upper right quadrat, the species *Lindernia antipoda*, *Digitaria ciliaris*, *Cyperus rotundus* and *Alternanthera philoxeroides* were negatively correlated to soil pH while they were weakly correlated to water level and SOM (Figure 9). The weed composition and their diversity are not attributed by single environmental variable, instead it is the result of complex and multitude of factors which affect weed communities. The organic farm lands are characterized to have organic matter and retention of seeds as well as microbes. The synthetic farm lands uses derived chemical nutrients, artificial fertilization which lacks organic matter naturally occurring in nature. This results in high biodiversity in organic farm lands as compared to synthetic rice farms (Deb 2009).

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

In the present study, floristic composition of weeds and its diversity in Paddy fields of Bhaktapur was studied. Altogether 32 species of weeds were enumerated that were making up community assemblage in paddy ecosystem. The 32 species belong to 27 genera and 14 families. Among the families, Asteraceae, Poaceae and Cyperaceae were most dominant in the paddy field. Mainly the field were dominated by broad leaved species (dicots) than the narrow leaved species (monocots). The paddy fields are human intervened habitat and their agricultural activity have direct relation to the dominance of particular species in that place. The Study of IVI showed that *Acmella paniculata*, *Lindernia antipoda*, *Blyxa aubertii*, *Cyperus iria*, *Cyperus difformis* and *Alternanthera philoxeroides* were most dominant species in the paddy fields. The density of weeds in Site A (CRPC), Site B (CRW) and Site C (CRB) was 40, 44 and 85 individuals per square meter respectively. However, their dominance changed from one site to another whose relation might be incorporated due to confounding effect of multiple management practices, crop rotation, availability of standing water, soil properties and climatic factors.

The diversity of weeds in different sites was variable which was subject to change due to the soil pH, water level, SOM and crop rotation. The crop rotation is one of important factor which changes over all soil properties and soil seed bank, which influences the evenness of weeds and diversity. The increasing number of diversified crops in the field might have changed the soil properties, level of fertilizer input and soil organic matter. The diversified crop rotation field experience higher diversity than monoculture or fallow land. Shannon index of diversity and Simpson index of diversity showed the diversity of weeds were more in field with diversified crop rotation field than mono culture.

In the paddy fields the standing water level is important for decomposition of SOM and change in soil pH. The water level and SOM had positive correlation. There was negative correlation between water level and species density. Others studies had also shown that the water level changes the species composition and diversity. The DCA and RDA showed beta diversity was found low and linear relationship in the study. This might be due to habitat homogeneity, similar climatic conditions. The RDA showed preference of specific environmental variables by species, whose manipulation can cause change in composition & diversity of those species.

6.2. Recommendation

Weeds are dynamic in nature; their periodic enumeration and floristic composition analysis are necessary to catalogue biodiversity. So, following points are recommended.

1. It is recommended to study large scale temporal and spatial change in biodiversity in paddy fields, its causes of change in biodiversity.
2. It is recommended to study relation of environmental variables on morphology, composition and diversity of weeds in paddy fields incorporating variables like, light, soil temperature, aspect of field, herbicides and pesticides etc.

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APPENDICES

Appendix I: Species present in paddy fields in quadrat and in levee.

S.N.	Species	Abbrevation	Family	Month of Collection
1	*Alternanthera philoxeroides* (Mart.) Griseb.	Alte_phi	Amaranthaceae	July
2	*Amaranthus blitum* L.	Amar_bli	Amaranthaceae	August
3	*Alternanthera sessilis* (L.) R. Br. ex DC.	Alte_ses	Amaranthaceae	August
4	*Bidens pilosa* L.	Bide_pil	Asteraceae	August
5	*Ageratum conyzoides* L.	Ager_con	Asteraceae	August
6	*Eclipta prostrata* (L.) L.	Ecli_pro	Asteraceae	August
7	*Parthenium hysterophorus* L.	Part_hys	Asteraceae	August
8	*Galinsoga quadriradiata* Ruiz & Pav.	Gali_qua	Asteraceae	August
9	*Acmella paniculata* (Wall. ex DC.) R.K. Jansen	Acme_pan	Asteraceae	August
10	*Rorippa palustris* (L.) Besser	Rori_pal	Brassicaceae	August
11	*Drymaria cordata* (L.) Willd. ex Schult.	Drym_cor	Caryophyllaceae	August
12	*Cyperus rotundus* L.	Cype_rot	Cyperaceae	August
13	*Fimbristylis littoralis* Gaudich.	Fimb_lit	Cyperaceae	August
14	*Cyperus iria* L.	Cype_iri	Cyperaceae	August
15	*Cyperus difformis* L.	Cype_dif	Cyperaceae	August
16	*Kyllinga brevifolia* Rottb.	Kyll_bre	Cyperaceae	August
17	*Blyxa aubertii* Rich.	Blyx_aub	Hydrocharitaceae	August
18	*Clinopodium umbrosum* (M. Bieb.) K. Koch	Clin_umb	Lamiaceae	August
19	*Lindernia antipoda* (L.) Alston	Lind_ant	Linderniaceae	August
20	*Ammannia auriculata* Willd.	Amma_aur	Lythraceae	August
21	*Oenothera rosea* L'Hér. ex Aiton	Oeno_ros	Onagraceae	August
22	*Ludwigia prostrata* Roxb.	Ludw_pro	Onagraceae	August
23	*Plantago major* L.	Plan_maj	Plantaginaceae	August
24	*Eleusine indica* (L.) Gaertn.	Eleu_ind	Poaceae	August
25	*Eragrostis unioloides* (Retz.) Nees	Erag_uni	Poaceae	September
26	*Digitaria ciliaris* (Retz.) Koeler	Digi_cil	Poaceae	August
27	*Echinochloa colona* (L.) Link	Echi_col	Poaceae	August
28	*Echinochloa crus-galli* (L.) P. Beauv.	Echi_cru	Poaceae	August

29	*Setaria pumila* (Poir.) Roem. & Schult.	Seta_pum	Poaceae	August
30	*Persicaria hydropiper* (L.) Delarbre	Pers_hyd	Polygonaceae	August
31	*Persicaria barbata* (L.) H. Hara	Pers_bar	Polygonaceae	August
32	*Monochoria vaginalis* (Burm. f.) C. Presl ex Kunth	Mono_vag	Pontederiaceae	August

Appendix II: Environmental data of different sites.

	SOM range (%)	**Mean**	**Soil pH range**	**Mean**	**Water level Range (cm)**	**Mean**
Site A	3.66-6.45	4.87	5.53-5.75	5.67	0-5	2.67
Site B	3.66-3.98	3.82	5.53-5.75	5.67	0-5	2.67
Site C	2.69-5.16	3.77	5.35-5.80	5.59	0-4.2	1.97

Appendix III: Weed diversity of paddy field IVI, Shannon and Simpson diversity in Site A

							Site A						
S.N.	**Weed species**	**Total**	**Density (no./m²)**	**RD**	**RF**	**RC**	**IVI**	**Pi**	**Pi²**	**lnPi**	**Pi(lnPi)**	**Richness**	**Evenness**
1	*Acmella paniculata*	62	3.1	7.69	8.20	7.95	23.84	0.07692	0.00592	-5.12990	-0.39461		
2	*Eclipta prostrata*	8	0.4	0.99	5.74	1.69	8.42	0.00993	0.00010	-9.22528	-0.09157		
3	*Lindernia antipoda*	222	11.1	27.54	15.57	19.04	62.15	0.27543	0.07586	-2.57881	-0.71029		
4	*Ammannia auriculata*	9	0.45	1.12	5.74	1.45	8.30	0.01117	0.00012	-8.98972	-0.10038		
5	*Blyxa aubertii*	224	11.2	27.79	12.30	26.02	66.11	0.27792	0.07724	-2.56088	-0.71171		
6	*Monochoria vaginalis*	5	0.25	0.62	3.28	0.96	4.86	0.00620	0.00004	-10.16529	-0.06306		
7	*Ludwigia prostrata*	6	0.3	0.74	4.10	6.02	10.87	0.00744	0.00006	-9.80065	-0.07296		
8	*Alternanthera philoxeroides*	57	2.85	7.07	9.84	7.71	24.62	0.07072	0.00500	-5.29806	-0.37468		
9	*Echinochloa crus-galli*	24	1.2	2.98	5.74	1.69	10.40	0.02978	0.00089	-7.02806	-0.20927		
10	*Eleusine indica*	18	0.9	2.23	5.74	1.45	9.42	0.02233	0.00050	-7.60342	-0.16980		
11	*Echinochloa colona*	22	1.1	2.73	5.74	1.45	9.91	0.02730	0.00075	-7.20208	-0.19658		
12	*Cyperus iria*	65	3.25	8.06	9.02	12.29	29.37	0.08065	0.00650	-5.03539	-0.40608		
13	*Cyperus difformis*	69	3.45	8.56	6.56	11.57	26.68	0.08561	0.00733	-4.91595	-0.42084		
14	*Fimbristylis littoralis*	10	0.5	1.24	0.82	0.24	2.30	0.01241	0.00015	-8.77900	-0.10892		
15	*Digitaria ciliaris*	2	0.1	0.25	0.82	0.24	1.31	0.00248	0.00001	-11.99787	-0.02977		
16	*Cyperus Rotundus*	3	0.15	0.37	0.82	0.24	1.43	0.00372	0.00001	-11.18694	-0.04164		
	Total	806	40.3	100	100	100	300	1	0.18047	-117.50	-4.10	16	1.48

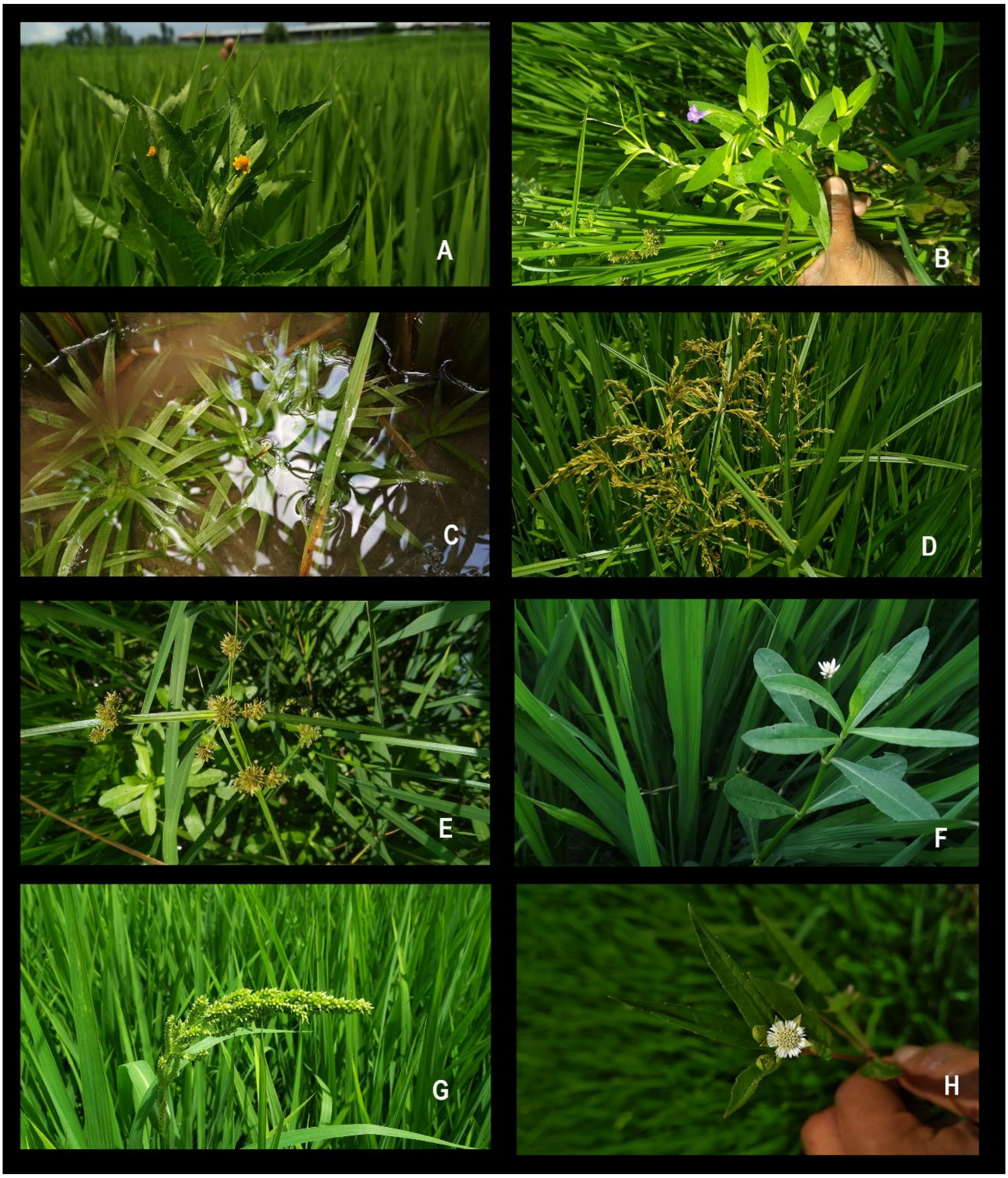
Appendix IV: Weed diversity of paddy field IVI, Shannon and Simpson diversity in Site B

						Site B							
S.N.	Weed species	Total	Density (no./m^2)	RD	RF	RC	IVI	Pi	Pi^2	lnPi	Pi(lnPi)	Richness	Evenness
1	*Acmella paniculata*	210	10.5	23.68	13.43	21.16	58.27	0.23675	0.05605	-2.88147	-0.68220		
2	*Eclipta prostrata*	13	0.65	1.47	6.72	3.26	11.44	0.01466	0.00021	-8.44579	-0.12378		
3	*Lindernia antipoda*	169	8.45	19.05	11.19	12.79	43.04	0.19053	0.03630	-3.31589	-0.63178		
4	*Ammannia auriculata*	10	0.5	1.13	5.97	1.86	8.96	0.01127	0.00013	-8.97052	-0.10113		
5	*Blyxa aubertii*	121	6.05	13.64	9.70	13.02	36.37	0.13641	0.01861	-3.98411	-0.54349		
6	*Monochoria vaginalis*	7	0.35	0.79	3.73	1.16	5.68	0.00789	0.00006	-9.68387	-0.07642		
7	*Ludwigia prostrata*	6	0.3	0.68	4.48	1.40	6.55	0.00676	0.00005	-9.99217	-0.06759		
8	*Alternanthera philoxeroides*	40	2	4.51	5.97	5.35	15.83	0.04510	0.00203	-6.19793	-0.27950		
9	*Echinochloa crus-galli*	27	1.35	3.04	4.48	2.56	10.08	0.03044	0.00093	-6.98402	-0.21259		
10	*Eleusine indica*	12	0.6	1.35	4.48	1.40	7.23	0.01353	0.00018	-8.60588	-0.11643		
11	*Echinochloa colona*	24	1.2	2.71	5.97	1.86	10.54	0.02706	0.00073	-7.21958	-0.19534		
12	*Cyperus iria*	115	5.75	12.97	10.45	17.21	40.62	0.12965	0.01681	-4.08583	-0.52973		
13	*Cyperus difformis*	127	6.35	14.32	9.70	15.81	39.83	0.14318	0.02050	-3.88732	-0.55658		
14	*Persicaria hydropiper*	5	0.25	0.56	2.99	0.93	4.48	0.00564	0.00003	-10.35681	-0.05838		
15	*Galinsoga quadriradiata*	1	0.05	0.11	0.75	0.23	1.09	0.00113	0.00000	-13.57569	-0.01531		
	Total	887	44.35	100	100	100	300	1	0.15	-108.19	-4.19	15	1.55

Appendix V: Weed diversity of paddy field IVI, Shannon and Simpson diversity in Site C

							Site C						
S.N.	Weed species	Total	Density (no./m^2)	RD	RF	RC	IVI	Pi	Pi^2	lnPi	Pi(lnPi)	Richness	Evenness
1	*Acmella paniculata*	839	41.95	48.89	12.82	34.47	96.18	0.48893	0.23905	-1.43108	-0.69970		
2	*Eclipta prostrata*	15	0.75	0.87	7.05	1.85	9.78	0.00874	0.00008	-9.47940	-0.08286		
3	*Lindernia antipoda*	251	12.55	14.63	11.54	13.60	39.77	0.14627	0.02140	-3.84460	-0.56235		
4	*Ammannia auriculata*	4	0.2	0.23	2.56	0.62	3.42	0.00233	0.00001	-12.12291	-0.02826		
5	*Blyxa aubertii*	192	9.6	11.19	8.33	16.07	35.60	0.11189	0.01252	-4.38051	-0.49013		
6	*Monochoria vaginalis*	12	0.6	0.70	5.13	1.24	7.06	0.00699	0.00005	-9.92569	-0.06941		
7	*Alternanthera philoxeroides*	73	3.65	4.25	10.26	8.66	23.17	0.04254	0.00181	-6.31458	-0.26863		
8	*Echinochloa crus-galli*	33	1.65	1.92	5.77	4.17	11.87	0.01923	0.00037	-7.90249	-0.15197		
9	*Eleusine indica*	39	1.95	2.27	5.13	0.93	8.33	0.02273	0.00052	-7.56838	-0.17201		
10	*Echinochloa colona*	5	0.25	0.29	2.56	0.62	3.47	0.00291	0.00001	-11.67663	-0.03402		
11	*Cyperus iria*	56	2.8	3.26	11.54	9.74	24.54	0.03263	0.00106	-6.84480	-0.22337		
12	*Cyperus difformis*	36	1.8	2.10	5.77	2.94	10.80	0.02098	0.00044	-7.72846	-0.16214		
13	*Fimbristylis littoralis*	150	7.5	8.74	7.05	4.02	19.81	0.08741	0.00764	-4.87423	-0.42607		
14	*Rorippa palustris*	4	0.2	0.23	1.92	0.46	2.62	0.00233	0.00001	-12.12291	-0.02826		
15	*Alternanthera sessilis*	7	0.35	0.41	2.56	0.62	3.59	0.00408	0.00002	-11.00368	-0.04489		
	Total	1716	85.8	100	100	100	300	1	0.28	-117.22	-3.44	15	1.27

Appendix VI: Photo plates



A. *Acmella paniculate*, B. *Lindernia antipoda* C.*Blyxa aubertii*, D. *Cyperus iria*, E. *Cyperus difformis*, F. *Alternanthera philoxeroides*, G. *Echinochloa crus-galli*, I. *Eclipta prostrata*

A. Paddy field infested by weeds, B. Farmers weeding C. Weeds emerging in field,
D. Weeds dominted by *Acmella*, E. Materials used for study, F. Herbarium pressing