CHAPTER 1

GENERAL INTRODUCTION

1.1 Population biology of plants: General concepts and principles

Plant population biology explains the fluxes and dynamics in the number of individuals of plants as a function of time and space. Studies in plant population biology of Malthusian growth focus on deaths, births, emigration and immigration of individuals, or modules (Harper 1977; Horn 1978). Further, such studies also help in the interpretation of changes in gene frequency and the number of individuals and their phenotypic characteristics in populations, (Harper 1977; Solbrig 1979; Rougharden *et al*. 1989). Population dynamics of many rhizomatous plants are dominated more by the flux as of clonal modules. The ability of a single genotype to form fragmented phenotypes is just one of the variants in the life patterns of modular organism (Harper 1978; Alderman *et. al.* 2011).

Population biology was the research domain of zoologists for more than a century (Baki 1986). The first study of plant population biology was made by, a Carl Nageli (1874) who attempted to model the changes in simple plant populations of two species (Harper 1960 and 1977). The ensuing development in the study of plant population biology involved botanists and plant ecologists other than population biology such as taxonomy, plant ecosystems, community structure, energetic and classification (Harper 1977). In the period of 1917 – 1928, there was a paucity of studies on plant population biology. A leading British ecologist, Tansley, showed that the survival of a mixture of two species of *Galium* was solely determined by their competitive interactions. In addition, made an elegant contribution by studying the effects of density on the development of a single species populations, and attempted to describe the plasticity of plants, variations in reproductive capacity under density stress and the role of mortality in simple experimental populations (Harper 1977). Sukatchew (1928) has done an interesting experiment on the self-thinning phenomena which indicated that the populations of *Matricaria inodora* and *Taraxacum officinale* were density-dependent (White and Harper 1970). Scientists added some assumptions that; there are other problems related to plant characteristics which discouraged plant population biologists from working in the field such as plasticity of plant growth, the spatial heterogeneity, and the dependence of plant growth on size rather as well as age-dominated individuals (Harper 1977), sexual and asexual reproductions exhibited by many plants, neighbourhood interactions between individual plants and their immediate neighbours (Roughgarden 1989).

Studies in plant demography can generate information on survivorship of all individuals living in a particular place and time, involving, longevity, patterns of recruitment and mortality, life expectancy, reproductive rate, older structure, the rates and scales of immigration and emigration, and this permits the estimation of future population trends under similar condition (White 1985). The survival and fertility of the basic components of the demography have a strong influence on population dynamics. These two things help a lot to understand the developing of life and history (Mar *et al*. 2008). For example, there are trade-offs between reproductive rate and growth rates, this is expected to translate in the differences of the demographic patterns of modules. They noted that the greater the longevity of the individual the greater is the chance of increased importance of fertility to the dynamics of the general population, which gradually help to stay the plants alive (Franco and Silvertown 1996; Forbis and Daniel 2004), given to the survival and fertility are the basis of demographics, the presence of a strong relationship between life span and population dynamics (Charnov 1991; Heppell *et al*. 2000; Ricklefs and Wikelski 2002). In 2000, Ghersa *et al.* (2000) investigated three different approaches to study the dynamics of weed populations (demographic, mechanistic and long-term studies) and then provided some ideas on how to expand knowledge to achieve sustainable development strategies for weed management.

In the past, plant demography as a coherent body of theory and practice is an intriguing issue to indulge in research activities (White 1985). Harper's (1967) disciples in the ensuing years signaled the beginning of interest in the study of plant population biology, invariably called for a better understanding of the demography of plant species in natural environments. Plant vegetations, once assumed as complex entities, are good materials with unique advantages for demographic studies by the virtue of being sessile, and was easier to handle, design and replicate experiments with individuals of identical make-up (Solbrig 1979).

Rabotnov (1978) attempted to developed ecologists and population biologists models 0f plant populations. Plant population biologists have developed two models in demographic studies. The first model, the whole plant is regarded as a population of modular units and all parts originated from one zygote. The second model, plant population operates encompassing subunits each of which otherwise known as ramet (Harper 1977). Ramets can be treated as individual plants (Esser and Overdieck 1991). Habitat fragmentation is very importantbecause it seeks to bring the basic concepts of population biology, demography and genetics and cites relevant and new literature on the subject(s) in question. It has two main entities, *viz.*: populations become more isolated and are reduced in size (Liebman and Davis 2000). The potential causes of species geographic distribution limits fall into two broad classes. The first class focuses on limited opportunities to colonize unoccupied areas. The second class focuses on limited adaptation across spatially variable environments. Combining demographic studies, the analyses of demographic responses to environmental variation can contribute to species distribution models (Eckhart *et al.* 2011).

1.1.1 Population regulation

Marshall and Jain (1969) conducted studies in order to understand the factors of the environment and the properties of organisms that affect the stability of population size and dynamics, and these have been the most central and controversial issues. Population size of a given plant species is regulated by two elements of birth and death (Harper 1977). These studies on population dynamics of a species entail the quantification and conceptualization of the changes in these elements of population fluxes, including migration (Baki 1986).

The regulation of population size by density-dependent mechanisms is well-documented (Harper 1978; Antonovics and Levin 1980; Turner and Robinowitz 1983; Watkinson 1986; Crawley 1990). Harper (1960, 1961, 1967) noted that plants increased density by either phenotypic plasticity or mortality. According to Keddy (1981), a mortality response includes density-dependent mortality while a plastic response includes density-dependent reproductive traits, including yields. Plant populations display density-dependent or density-dependent mechanisms, acting on either mortality or reproduction (Watkinson and Harper 1978). The effect of density on competition are by characterized density-dependent mortality and reduction in growth (Harper 1977). The pioneering work to investigate the self-thinning phenomenon experimentally was displayed by *M. inodora*, at two densities on fertilized and unfertilized soils, where the high mortality rate associated between high density and fertilized soil prevailed (White and Harper 1970). Yoda *et al.*

(1963) founded the self-thinning phenomenon in overcrowded populations of several species on soils of varying fertility and indicated that the number of surviving plants could be related to their weights as w = c.p -3/2, where p is the density of surviving plants and the value of c varies with the species (White and Harper 1970). White and Harper (1970) cited that the -3/2 power law to be applicable to a mixture of *Rephanus sativus* L. and *Brassica. napus*. with the larger ones displaying domination until an equilibrium between mean weight per plant and the surviving individuals was acquired. Self-thinning changes between species and between populations of the same species grown at different resource levels (White 1985; Waller 1987; Lonsdale 1990). Harper (1977) explained that the mechanism underlying describes the intensity of competition and following self-thinning is dependent on the extent of overlap of resource depletion areas in order to achieve a given plant biomass. Self-thinning was found to be more intense and more consistent in populations grown in shade than in unshaded populations (Hutchings 1957; Westoby and Howell 1981; Lonsdale and Watkinson 1983).

Competition between plants is to a large extent competing for growth. Thus, the method of competition changes plant growth and this is essential to understand the role of competition between plants in nature (Jacob *et al.* 1998). Many studies have attempted to measure the impact of competition on the size of plant growth and in a specified period or periods (Nanda *et al.* 1995; Weiner 1995; Starr *et al.* 1999), which is usually measured in a simple example: the number of securities, the size of the plant, stem diameter.

In a study carried out in 2002 and 2003 on the competition between weeds and rice plant to investigate the density of weeds and their relationship to rice, which showed damage to rice because of the smell of bugs (Tin *et al*. 2005). Results showed that weeds caused a significant decline in the yield of cauliflower, as well as the decline in the average dry weight of the crop (Qasem 2009).

1.1.2 Inter-and intra- plant competitions between crops and weeds

Many ecologists who study plant competition agreed that we need to improve our understanding of mechanisms through which plants compete for resources (Harper 1978; Tilman 1988). Although we know many of the physiological mechanisms involved in resource uptake, these do not translate directly into an understanding of resource competition at the individual, population, or community levels. We still have a long way to go in bridging the gap between physiological mechanisms of a resource uptake and utilization, and the performance of individuals and populations as mediated by competition (Saxena *et al.* 1996).

Plants can grow together with varying numbers of same or different species (Harper 1977; Turkington and Jolliffe 1996). Competing plants are between crops and weeds for space and resources are the most obvious interaction due to the negative effects exerted by weeds on crop growth and yields (Patterson 1995). The control of structure and composition and dynamics of plant communities are by the selection processes between organisms (Harper 1977; Waller 1987; Grace and Tilman 1990; Kropff *et al.* 1993).

Grindal *et al.* (1998) defined competition as the tendency of neighboring plants to utilize the same quantum of light, mineral nutrients, molecule of water, or volume of space. This definition shows the distinction of species in their ability to competition (Kropff *et al.*

1993) who defined competition as the process of capturing and utilizing of resources by the crop and its associated weeds. This definition has been criticized where the supply of the same resources cannot meet the demand of both the crop and its associated weeds and when weeds capture such resources (Kropff *et al.* 1993; Patterson 1995).

Weed competition studies have a long history with some studies focused on identifying the impact of individual types of weeds, for example, couch grass (*Elymus repens*) in potato (Baziramakenga and Leroux 1994), volunteer barley (*Hordeum vulgare*) on oilseed rape (*B. napus*) (Lubigan and Moody 1990), and creeping thistle (*Cirsium arvense*) in spring barley (Kolo and Froud-Williams 1993). Other studies compared the relative competitiveness of a wide range of types of weeds on a particular crop, or relative sensitivity to a range of weed crops (Bond and Burston 1996). Yet other studies have focused on identifying the critical periods of Tashib under traditional systems in broad bean (*Vicia faba*), drilled cabbage (Roberts 1976), beetroot (Hewson and Roberts 1973), sugar beet, drilled lettuce (Robertson *et al.* 2002), rice cultivars in the savannas with weed competition (Friday *et al.* 2009), maize tolerance to weed competition in long-term (Ryan *et al.* 2010), soybean (*Glycine max*) plants grown in the presence of weed competition (Millar *et al.* 2011), and winter wheat and navy bean (*Phaseolus vulgaris*) (Woolley *et al.* 1993).

The competition between crops and weeds are influenced by plant density, the critical period between crop and weed emergence, weather conditions and plant traits such as growth rate, morphological traits like height and leaf area, leaf angle arrangement, seed size, water and or nutrient use efficiency, and photosynthetic rates. Also, the increase in the intensity of competition parallels the increasing taxonomic relationship, between weed and crop species, possibly as a result of increasing niche overlap between weed and crop species (Darwin 1859; Hutchinson 1957).

The main effect of competition between weed and crops is reduction in crop yields (Zimdahl 1988; Smil 2002). Harper (1977) explained that the average yield has been found to be a function of the relative frequencies of the two species involved and the overall density. Many of the studies reported an inverse relationship between cropping intensity and density of weeds (Knake and Slife 1962; Bell and Nelewaja 1968; Smith *et al.* 1988; Lubigan and Moody 1990). Smith *et al.* (1988) studied the effect of three barnyard grass (*Echinochloa cruss-gali L.*) densities of 10, 50 and 350 plants/m^2 on rice yields and found that the rice yields were reduced by 57%, 80%, and 95%, respectively. The effect of weed density and weed competition duration on rice yields has been established for a number of weed species (Smith *et al.* 1988).

Wilson *et al.* (1995) explained the limited competition for weeds in the study on effect of several weed species against winter wheat and indicated that high wheat densities minimized the loss in crop yields. Other studies indicated that reducing crop density had increased weed growth, and consequently increased weed seed production and crop yield losses (Zimdahl 1988; Cousens *et al.* 1984; Wilson *et al.* 1995). On the contrary, others found with increased weed density and increased crop yield density whereby, high weed density reduces the number of branches (Hill *et al*. 1989).

The mean growth rate of shoots and hence the mode of competition between shoots differs among clonal plant species as in non-clonal plants. The mode of competition between individuals (symmetric versus asymmetric, the degree of competitive asymmetry), growth dynamics of individuals, and allocation pattern between organs and spatial pattern of individuals are closely correlated with each other in non-clonal plant populations. Theoretical and field studies based on the diffusion model revealed that plants of height-growth and diameter-growth types, tend to exhibit asymmetric competition and symmetric competition respectively (Hara 1994).

Growth dynamics and size structure during one growing season were investigated at the level of the individual shoot of *Phragmites australis*, a clonal plant (Hara *et al.* 1993). These were based on the diffusion model for three shoot populations, which are described as even-aged sparse (the least crowded), even-aged compressed and uneven-aged compressed (the most crowded). Irrespective of the difference in the degree of crowdedness, these three shoot populations converged to the same size structure in height and weight as they grew. From these size-structure dynamics and from direct estimation of the growth pattern of shoots for the sparse shoot population, two types of shoot growth pattern were inferred for the uneven-aged dense shoot population of *P. australis* which consisted of sprightly brief replacement and old established shoots. In both case's growth of succinct sprightly shoots is guaranteed or supported but not suppressed by large old shoots either stochastically or deterministically, thus leading to little variability in shoot size, even in the uneven-aged crowded stand which can be regarded as an extreme situation of asymmetric competition. This suggests that effective physiological integration between shoots registered at least stochastically in the growth dynamics of shoots in many clonal plant species (and in some clonal species, deterministically as well), or at least in the form of a controlled allocation of remobilized resources from the rhizomes to the successful shoots, especially at the early growing stage. It was also inferred that the stochastic in growth of small shoots plays an important role in the establishment and persistence of clonal plants (Hara *et al.* 1993).

In the effort to understand the demographic rates and vegetative spread of grass *Miscanthus giganteus* in unmanaged arable lands in Illinois to compare with those of large-statured invasive grass (LSIGs) the collected data from 13 *M. giganteus* plantings in Illinois, ranging in age from 1 to 7 years, recording tiller number, plant spatial extent, spikelet production, and the patterns of plant survival over four year were recorded and analysed (Matlaga *et al.* 2012). The invasion risk of *M. giganteus* have been evaluated qualitatively using weed risk assessment (WRA) systems producing somewhat conflicting results. The analyses conducted for Florida (Gordon *et al.* 2011) and California (Barney and Ditomaso 2008) have deemed that *M. giganteus* to be acceptable, largely based on its presumed complete sterility. When *M. giganteus* were evaluated by the same method for introduction into the north central region of the United States, it received a score of ‘‘evaluate further’’ (Raghu and Davis, unpublished observations). The production of sexual reproductive structures and rhizomes capable of lateral extension, fragmentation, and establishment gives the potential to spread via multiple modes (Boland 2006). For perennial rhizomatous grasses that spread laterally over time, growth is an inherently spatial process (Harper 1977).

1.1.3 Life-table

Studies on weed populations involves on life cycle stages and the bank of plant propagules (Mortimer 1983), and these studies are often described in life tables, and can be presented either diagrammatically (Sagar 1974; Sagar and Mortimer 1976) or in a tabular forms (Baki 1986). A life-table helps to delineate the flux that takes place within a population as well as elucidating the periods in the life cycle of a species when population control is occurring

(Baki 1986). There are many detailed studies that work on the dynamics of weed populations (Sagar 1974; Sarukhan 1974; Mortimer 1976, 1983; Werner 1975; Law 1981; Robatnov 1978). Studying weed population dynamics show the role of the factors which regulate the size of weed populations (Sagar and Mortimer 1976) as the understanding of these factors form the basis of strategic planning for weed control (Cousens 1988).

1.2 Growth patterns and the environment

Growth is the irreversible increase in size of plants, their modules and increase in size of organs. Plant development determines the progress changing of a plant from one growth stage to other stages of its life cycle. The most accurate definition is the interaction between development and growth at each stage builds up the potential, and then the actual yield of the crop (Mendham and Salisbury 1995; Khattak and Pearson 2005) or the accumulation of biomass or dry matter.

The growth and development of plants is dependent on abiotic and biotic factors. Abiotic factors include the physical environmental conditions and biotic factors include animals, insects, and diseases. Continued development and growth of the plant following successful germination are dictated by external environmental factors such as photoperiod, temperature, nutrient supply and water and by complex interactions with endogenous growth regulators that collectively called the plant hormones or phytohormones including GA, ABA, cytokinin, brassinosteriods and auxin (Mendham and Salisbury 1995; Yang *et al*. 1996; Gray *et al*. 1998; Thingnaes *et al*. 2003; Zhao *et al*. 2003; Heggie and Halliday 2005). Seedling development is also partly determined by photoreception and circadian clock genes. Because seeds often germinate in the dark, seedlings switch from heterotrophic to photoautotrophic growth when they reach favourable light conditions (Stenoien *et al.* 2002).

Plants are affected by a decrease of sunlight, where the leaves needs to high photon when low photon to less than 40%, because the carbon sequestration becomes weak (Cohen *et al.* 2005). However, plants can adjust to the built environment (Syvertsen and Smith 1984), but the issue of plant responses due to adaptation as follows: a variety of adaptations at physiological and biochemical levels like as alteration of growth rate and plant architecture and finally on morphological characteristics and distribution and also the architecture of plant canopy that can influence the interception, absorption and scattering of solar radiation as passes through the atmosphere of earth to the soil surface (Nasrullahzadeh *et al*. 2007; Faravani and Bakar 2007).

Different environmental factors including light and temperature, and that have a clear impact on the growth of plants (Karlsson *et al*. 1989). Many of studies have showed the manipulation of spectral quality has potential for growth control in a range of ornamental plants and growth response of crops to quality of light spectral can be exploited to deliver a range of agronomically desirable plant traits (Haeringen *et al*. 1998; Khattak and Pearson 2005; Paul and Moore 2006). Plants changing of their growth pattern to adapt themselves to the environment when they encounter and response to environmental stimulants. Solar radiation has a high effect on crop growth, development, survival, reproduction and yield. The solar radiation is one of the major environmental factors influencing growth and distribution of plant species (Boardman 1977; Aleric and Kirkman 2005).

Many crop plants stem and internode elongation are important characteristics, especially in the horticulture by control the temperature and duration of photoperiod (altering day and night length) of the plants growth conditions plant morphology is manipulated routinely (Grindal *et al*. 1998).

Rhizomes are a type of roots where rapid root growth is concentrated after the establishment consisting of vertical extension of the growth, the secondary side of the roots and then deposition of reserves. Most of the studies include only those roots reach drilling, to about 30 cm. Also, found and distributed about 27 to 52% of the roots in the top 20 cm of soil and 1% or less 1 below (Aldrich 1984). Distribution of root close to the maximum at the end of flowering, so earlier flowering *B. rapa* plants the root system and large-scale (Richards and Thurling 1979; Ali *et al.* 2004).

Controlled environmental studies on leaf expansion and duration showed that leaf area development of *B. napus* cultivar Westar followed logistic shape growth functions. There is evidence for an effect of temperature and photoperiod on leaf area development. In addition, found that the optimum temperature range for leaf development in *B. napus* cultivar Westar is 13 to 22 ^{o}C with mean temperature of (17 ^{o}C)(Morrison *et al.* 1992).

An important point in the growth of plants is the composition of flowering commences on the main stem, which becomes the terminal inflorescence or raceme. Once the main stem flower buds are formed, axillary buds lower down will then begin to develop sequentially into the primary branches in a basipetal direction (Diepenbrock 2000; Razzaque *et al*. 2007). The first flowering occurs in the first primary branch and sequence downwards (Bouttier and Morgan 1992). In general, there are four main controls over inflorescence initiation and flowering; a minimum number of leaf initials before initiation takes place, the basic temperature response or plastochron in Cd per leaf, vernalization responses mainly operating before initiation and day length responses operating before both initiation and flowering. Flowering is a result of more than one factor and/or their interactions; hence, the effect of a single factor on flowering is very difficult to identify (Mendham and Salisbury 1995; Razzaque *et al*. 2007).

The rapid growth in length within a few days of anthesis, whereas rapid seed growth occurs after about 20 days of canola (oilseed rape) (Hocking and Mason 1993; Robertson *et al*. 2002). Water and nutrient stress either curtails flowering or limits success rate. A direct relationship was found between the date of last nitrogen application and success rate of flowers (Lewis and Thurling 1994; Mendham and Salisbury 1995). A relationship between the amount of solar radiation intercepted per flower and its likelihood of success was also found. Seed survival until final harvest depends on factors such as supply of assimilates and water (Mendham and Salisbury 1995).

In a study conducted under glasshouse conditions revealed that the critical period for seed abortion is 2 to 3 weeks after flowering (Robertson *et al*. 2002). Also, similar results were found *in-vivo* observations of developing pods using photography of developing pods (Pechan and Morgan 1985). The rate of growth per seed ranged from 0.08 to 0.12 mg day^{-1} and was a function of internal and external factors.

1.2.1 Fertilizer regimes

The concentrations of nitrogen, potassium and calcium in soil are often too low for economic yield of agricultural crops. So it can additions of fertilizers in agricultural soils to maintain the level of fertility for crop growth are essential element in modern agriculture.

However, increases application of fertilizers, particularly N and K, may result in a salinity build up in the soil (Russel 1968). Many of the results showed in lower weed densities, and fewer weed dry matter than did grain sorghum alone because the cowpea intercepted light and used N, P, and K that were then unavailable for weed growth (Abraham and Singh 1984).

Potassium is an essential element for all living organisms. It is often considered to be a nutrient of primary importance for oilseed rape and Indian mustard. The role of K^+ in oilseed rape, is mainly to activate a wide range of enzyme system. The K^+ helped in many of physiological functions (Evans and Sorger 1966 cited by Pettigrew 1999), For example, K^+ is present in unbound form in the cytoplasm and does not enter into the composition of the structural or storage components or plants (Mengel and Kirkby 2004).

Potassium application had no effect on number of seeds per pod but it decreased to reduce 1000-seed weight of oil seed crops. Potassium plays a major part in the enzyme system that controls the metabolism of photosynthesis and their conversion to oil. Potassium fertilizer had no influence on any aspect of fatty acid composition in any of the crop (Mengel and Kirkby 2004). Overall, it is concluded that K^+ has a negligible effect either beneficial or detrimental on the quality, including seed oil content in rapeseed.

In the case of response of Indian mustard to different levels of N^- (0, 25, 50 and 100 kg ha^{-1}) showed that all the yield and seed yield ha^{-1} increased significantly by nitrogen application. The number of branches per plant, dry matter, seed, straw and oil yield ha^{-1} was increased significantly with increasing level of N^-. Nitrogen application (100 kg ha^{-1} at sowing and 50 kg ha^{-1} at post-flowering) enhances substantially growth, photosynthesis, N^- assimilation and yield of mustard following defoliation (Lone and Khan 2007). Plant height, number of branches per plant, number of pod per plant number of seeds per pod, 1000-seed weight, seed and oil yield of Indian mustard improved at 100 % recommended rates of NPK (N-P-K at 80 - 17.2 - 33.2 kg ha^{-1}) + 10 t ha^{-1} farmyard manure compared with 100 % NPK rate (Mandal and Sinha 2004).

Abd El-Gawad *et al*. (1990) determined the effect of NPK fertilization on the yield of rape and reported that although nitrogen application increased seed, straw and oil yield, seed weight per pod and seed index but seed oil concentration decreased with increasing N^- application. Increasing the Phosphate rate to 45 kg^{-1} has increased yield components. However, K_2O application had no significant effect on seed yield components. The highest seed yield was obtained by 60 kg N + 45 kg P_2O_5 + 48 kg K_2O fed^{-1}.

Application of nitrogen at 240 kg ha^{-1} increased total dry matter production and combined seed yield. Seed yield increased mainly due to greater number of pods on the terminal raceme and heavier seed weight, whereas number of seeds per pod was not affected (Asare and Scarisbrick 1995). A high rate of N^- application increases leaf area development improves leaf area duration (LAD) after flowering and increases overall crop assimilation, thus contributing to increased seed yield (Smith *et al.* 1988). Nitrogen rates had significantly effects on plant height, stem diameter, branch/plant and seed yield of *B. napus* (Al-Barrak 2006).

Baki (1988) reported that additions of phosphate appeared to enhance the rate of flowering in *S. grossus.* Alderman (2011) reported that increasing of nitrogen fertilization had an effect on the leaf, stem, rhizome, and root growth and thus caused an increase in the growth of the seedlings (Alderman *et al.* 2011). Similarly, it has been reported that in

Panicum virgatum there was an increase in biomass at harvesting because of the increase in nitrogen in the soil (Jung and Lai 2011).

Saleem *et al*. (2000) studied the effect of NPK application on the seed yield and oil contents of *B. juncea* cultivars and observed that although growth and yield parameters were increased but none of the fertilizers affected the seed oil contents of all the three cultivars of raya (*B. juncea*)(Saleem *et al*. 2000). James *et al.* (2010) reported that on the long-term, NPK addition decreased mortality in the giant cane plant (*Arundo donax*) and observed that periodic burning can increase density and spread of this species. Fertilizing the soil is an important practice in affecting crop production. It is preferred over other methods of application due to the use of lesser amounts of fertilizer, which in turn avoid soil problems, less ground water pollution in addition to its profound effect on plant growth and productivity (Hamayun *et al.* 2011). Hamayun *et al.* (2011) observed that foliar application of NPK increased grain yield in lentils whilst Abdelhamid *et al.* (2011) reported that NPK application alone improved plant growth in cowpea.

Soil nitrogen enrichment and consequent vigorous weed growth are thought to hinder the restoration of tall grass prairie. Adding carbon to the soil may facilitate prairie restoration by inducing immobilization of plant-available nitrogen (Blumenthal *et al.* 2003). Also, high N availability may be particularly problematic in the restoration of native plant communities, where prolific weed growth can delay or even preclude the reestablishment of native species (NRC 1992; Packard and Mutel 1997). For this reason, C addition has been suggested as a method for immobilizing plant-available N and increasing the success of native species (Morgan 1994). By increasing the soil C:N ratio, additions of organic C would be expected to induce soil microbes to immobilize available nitrogen. Decreased N, in turn, might reduce growth of nitrophilic weeds, thereby releasing native species from competitive suppression. At examined these conditions by comparing productivity of 10 weeds and 11 tall grass prairie species under 14 levels of C addition, ranging from 84 to 3346 g C m^{-2}. The results suggest that C addition may be a useful tool for restoring N-limited plant communities (Blumenthal *et al.* 2003).

1.2.2 Soil nutrients and amendments with fertilizer augmentation

Soil types have dramatic impact on plant health (Lamont 1972). Plant selection is very important to minimize soil problem with consideration on the plants' preferences for soil pH, soil texture and soil fertility. Additions of organic matter such as composts yearly and slowly will improve soil fertility, which benefit even the sturdiest plants.

Soil nutrients concentration in a number of soils, especially nitrogen availability, largely determines the relative contribution of proteoid roots to the root systems of two species of *Hakea* (Tian *et al.* 2011). Lamont (1972) reported that the relationship between proteoid and non- proteoid roots depends on four phases as nutrient availability: (a) an increase in proteoid root production as non-proteoid root growth increases; (b) a decrease in proteoid root production as non-proteoid root growth increases; (c) a decrease in proteoid root production as non-proteoid root growth decreases; (d) an absence of proteoid roots as non-proteoid root growth decreases. Soil type is more important than presence or absence of cotyledon on the growth of the oak seedlings and survival of seedlings unaffected by both soil type and cotyledon removal (Kerstin 1994).

The application of sweet corn residue removed, sweet corn residue incorporated, and garland chrysanthemum and edible amaranth treatments increased the yield of cucumber yield (Tian *et al.* 2011). They also stated that this improvement of soil nutrient could be explained by higher microbial biomass, population and diversity. Lora *et al.* (2011) reported that invasive grass species as a group influence nutrient dynamics differently than native grass species as a group. The results indicate species-specific effects on nutrient dynamics.

Recent studies have emphasized the contribution of soil microorganisms in the processes of nutrient release (Duda *et al.* 2003; Silva and Nahas 2002). Accordingly, acknowledging the complexity of the relationships between the soil microorganisms and plant species in a given ecosystem, it is expected that the adaptability characteristics of weeds are influenced directly by soil microorganisms. The edaphic microscopic community is highlighted by an adaptive versatility to changing factors, such as pH, moisture, the concentration of a particular element and temperature, and it is often protected and stimulated by the plant community present (Silva and Nahas 2002). Accordingly, a significant portion of the competition between plants occurs below the soil surface, where the root system plays a key role in the competitive process (Rizzardi *et al.* 2001).

In a study was to evaluate the growth and nutrient accumulation in eight species of weeds and in bean and corn crops grown for 50 days in a substrate fumigated with methyl bromide. Assessments relating to the height, leaf area, leaf number, dry weight of shoots and roots and relative content of nutrients were carried out 50 days after seedling emergence. A positive effect of soil fumigation was observed on the growth, leaf number, leaf area, plant height and accumulation of nutrients in monocot weeds in relation to dicots (Santos *et al.* 2012).

Soil nitrogen enrichment and consequent vigorous weed growth are thought to hinder the restoration of tall grass prairie. Adding carbon to the soil may facilitate prairie restoration by inducing immobilization of plant-available nitrogen (Blumenthal *et al.* 2003). Also, high N availability may be particularly problematic in the restoration of native plant communities, where prolific weed growth can delay or even preclude the reestablishment of native species (NRC 1992; Packard and Mutel 1997). For this reason, C addition has been suggested as a method for immobilizing plant-available N and increasing the success of native species (Morgan 1994). By increasing the soil C:N ratio, additions of organic C would be expected to induce soil microbes to immobilize available nitrogen. Decreased N, in turn, might reduce growth of nitrophilic weeds, thereby releasing native species from competitive suppression. At examined these conditions by comparing productivity of 10 weeds and 11 tall grass prairie species under 14 levels of C addition, ranging from 84 to 3346 g C m^{-2}. Results suggest that C addition may be a useful tool for restoring N-limited plant communities (Blumenthal *et al.* 2003).

1.2.3 Soil moisture and water depth

Soil moisture causes stem elongation resulted in earlier flowering, shorter plants, more lodging, lower grain volume weight, fewer heads unit area and fewer seeds/head than in plants given full irrigation (Day and Intalap 1970).

Soil moisture can be used as an indicator in the Palmer Drought Severity Index (PDSI) which is a measure of surface moisture anomaly for the current month without the consideration of the antecedent conditions that characterize the PDSI. The Z Index can track agricultural drought, as it responds quickly to changes in soil moisture (Karl 1986).

The less frequently used Palmer moisture anomaly index (Z-index) is much less sensitive to changes in the calibration periods, and also has some desirable characteristics which may make it preferable to the PDSI for some agricultural and forest fire applications, i.e., it is more responsive to short-term moisture anomalies (Karl 1986).

Many studies have proved the effects of soil moisture stress on Tillering stem elongation, and grain yield of barley (have been studied by subjecting the plants to periods of stress at different stages of development (Aspinall *et al.*1964). The influence of water stress on grain growth has been investigated under conditions of intermittent stress with pot-grown plants and under longer periods of stress with plants grown in lysimeters. Aspinall (1965) reported that rate of grain growth (in dry weight) in the early stages of development was reduced only by severe water stress. He also observed that spikelet chlorophyll content was also reduced by water stress, particularly in the later stages of grain development.

The water regime of a given habitat is often characterized by the depth (Casanova and Brock 2000). Water level fluctuations can be viewed as disturbance to the plant community and disturbance is sometimes the primary mechanism that facilitates invasions through removing native species and opening niche space for colonizing species (Davies *et al.* 2005; Lockwood *et al.* 2005; Capers *et al.* 2007).

Many scientists have shown that high soil moistures are best suited to help the growth of *Sapium sebiferum* and Survival longer (Jamieson and McKinney 1938; Khan *al et.* 1973; Helm *et al.* 1991). For example, *Myriophyllum aquaticum* (Vell.) is an herbaceous perennial watery plant that is native to South America invades shallow-water bodies that are prone to disturbances, such as repeated and frequent water level fluctuations (Sabbatini *et al.* 1998). In a study to investigate the effects of main maritime environmental factor water depth on its growth of *Ranunculus kadzusensis*. It is an endangered aquatic plant species that commonly reproduces in the rice paddies of Korea and Japan during winter and early spring. The rate of maximum shoot extension was greatest for plants grown at depths of 50 and 100 cm versus those at 20 cm (Jo *et al.* 2010). Furthermore, *M. aquaticus* is an aquatic plant of still or slow flowing waters. In the study, root development and growth response of M. aquaticum to different water levels in a rhizotomy experiment under Central European climatic conditions. *Myriophyllum aquaticum* shows a high tolerance to different water levels, which may be important for future habitat conditions in water bodies and wetlands in Central Europe under the impact of global change with increased water level fluctuations (Hussner *et al.* 2009).

It has been shown that high soil moisture are best suited to help the growth of *S. sebiferum* and Survive longer (reducing the number of deaths) (Khan *et al.* 1973; Hsu 1928; Lin *et al.* 1958; Kuldeep *et al.* 1993). Troy *et al.* (2000**)** reported that infectious mortality of *S. sebiferum* is very high in the sandy soil than clay soil and the length of the plant height was the average length of plants in the sandy soil of less than 20% compared to plants in clay soil. They also showed that growth and the number of seedlings in clay soil beast of sandy soil. *S. sebiferum* growth was also demonstrated in this study. For most soils, growth was substantially greater with frequent watering. It was also indicated that *S. sebiferum* grows most rapidly in wet conditions (Lin *et al.* 1958; National Academy of Sciences 1983). Dou *et al.* (2010) investigated that *Oryza rufipogon* growth and biomass allocation in response to water depth and substrate. They also observed differences in rate average weight, seeds and Root-to-shoot but no significant in biomass allocation for sexual reproduction. In comparative effects of water level variations on growth characteristics of

M. aquaticum. Growth is dependent upon plants emerging from the water column; as water levels increase, this becomes more difficult for plants, as a result of the reduced photosynthetic ability of submerged leaves (Wersal and Madsen 2011).

1.3 Chlorophyll fluorescence, chlorophyll content, growth and architectural models

1.3.1 Chlorophyll content

It is well documented in the literature and in many horticulture and gardening books that leaf chlorophyll content can be indicative of a plant's nutritional status and health primarily due to its importance in the photosynthetic process (Haboudane *et al.* 2002). It is well known that chlorophyll content can be related to the necessary plant nutrient in the soil, particularly that of nitrogen. Chlorophyll is a tetrapyrrole molecule with a nitrogen atom in each of its four pyrrole groups and a magnesium cation in the centre of its ring (Fig. 1.1). It is abundant in leaves which gives a leaf its natural green colour and can make up to 1-2% of the dry weight of leaves. It is involved in the initiation of photosynthesis via the absorption of light energy and converting it to chemical energy initiating a chain of photochemical events that is an integral part of the light reaction of photosynthesis. Thus its presence in the leaves, in the appropriate amount, which vary for different plants, is important for the normal growth of plants. If there is a deficiency of nitrogen in the soil, for example, there will be lower amounts of chlorophyll in the leaves and this lead to a condition known as chlorosis in leaves (Capon 2010). Chlorosis is a condition whereby leaves do not synthesize enough chlorophyll and the leaves appear yellowish green in colour and are termed chlorotic. Plants with this condition can eventually die if prolonged, because they will be unable to carry photosynthesis and produce carbohydrates, lipids and amino acids. However it must be emphasized that a decrease in chlorophyll content could be due to several other factors other than low nitrogen in the soil and some of these include lack of iron, magnesium and soil pH, amongst other factors (Schuster 2008).

Thus one of the ways in which farmers and planters can assess the nutritional status and health of their crops, is to estimate the chlorophyll content in their leaves. This has fairly recently led to the invention of new techniques which can estimate and determine chlorophyll content using non-intrusive and non-destructive methods. Chlorophyll content can now be estimated from afar via remote sensing and a whole plantation of crops and algae in the ocean can be assessed for their nutritional status via satellite (Filella and Pinuelas 1994; Wong and He 2013). It has also led to the development of the leaf chlorophyll content meter or the chlorophyll SPAD (Soil Plant Analysis Development) meter by various companies, notably Hansatech, England and Minolta, Japan respectively (Pinkard *et al.*, 2006; Hawkins *et al.*, 2009; Marenco *et al.*, 2009; Uddling *et al.*, 2007).

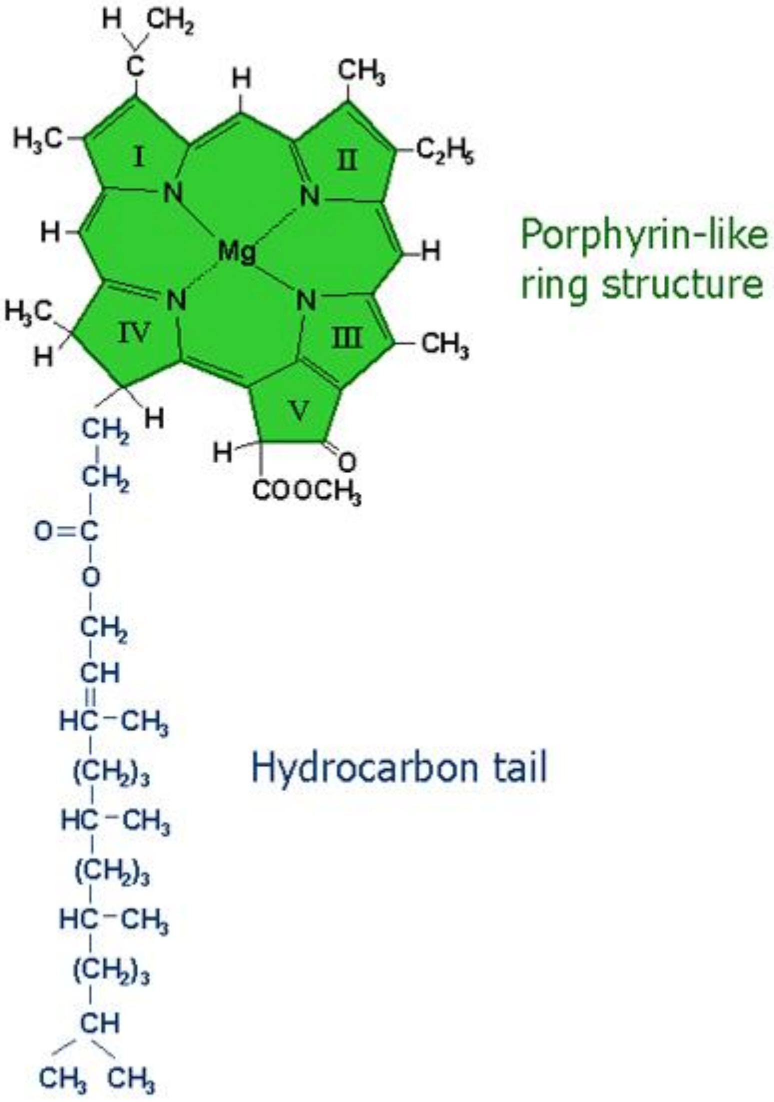

Fig. 1.1 Structure of a chlorophyll a molecule with a magnesium atom coordinated to four pyrrole rings (I-IV) with a hydrocarbon phytol group side chain (Hartzler 2012)

1.3.2 Chlorophyll fluorescence

Chlorophyll fluorescence is another popular technique in plant physiology that has been used to gain detailed information on the state of photosystem II at relatively low cost and in a non-invasive and non-destructive manner. Chlorophyll fluorescence is a phenomena that originates from the absorption of light and the subsequent rapid transfer of its energy across the photosystems to the reactions centre chlorophylls to initiate the early photochemical reactions which lead to photophosphorylation and the production of ATP and reduced NADPH, which are required for the following dark reactions of photosynthesis. Several things can happen to the energy in the excited chlorophyll molecules, in the light harvesting complexes of the photosystems, as they return to ground state. Most of the energy are transferred to neighbouring chlorophyll molecules and onto the chlorophyll *a* pair at the reaction centres to start electron transfer of the light reactions, but a small percentage (2-5%) are emitted as fluorescence (Fig. 1.2). The latter phenomena, sometimes referred to as the signature of photosynthesis, is particularly pronounced in photosystem 2 and has been well studied over several decades in vitro in isolated chloroplasts and thylakoid membranes.

Chlorophyll fluorescence emitted by green plants reflects photosynthetic activity in a complex manner. Nevertheless measurements of chlorophyll fluorescence, when applied with appropriate care, can provide useful information about leaf photosynthetic performance. Recent improvements of fluorescence measuring techniques have made the fluorescence method an important tool in horticulture and agronomy research, in particular the use of fluorescence from intact plant leaves for monitoring photosynthetic events and judging the physiological state of the plant. The improved techniques have facilitated deeper insights into the mechanism of fluorescence emission and thus have resulted in a more precise interpretation of the emitted signals (Maxwell and Johnson 2000; Murchie and Lawson 2013). It was shown previously that chlorophyll fluorescence measurements could be used to estimate, rapidly and non-invasively, the operating quantum efficiency of electron transport through PSII in leaves (Genty *et al.* 1989) and that this PSII operating efficiency was related to CO_2 assimilation (Harbinson *et al.* 1990; Krall *et al.* 1991; Siebke *et al.* 1997) has led to the current widespread use of chlorophyll fluorescence for examining photosynthetic performance in leaves in the laboratory, controlled environment, and field situations.

The relationships between chlorophyll fluorescence parameters and leaf photosynthetic performances have been well studied many times over the years and reviewed in the context of applications of fluorescence measurements to screening programmes, which seek to identify improved plant performance (Baker and Rosenqvist, 2004). An examination of the literature overwhelmingly reveals in excess of 5000 papers on chlorophyll fluorescence, of which about 20% are relevant to eco-physiological performance, and a similar proportion can be considered to have implications for agricultural or horticultural issues. In the last two to three decades a number of reviews on chlorophyll fluorescence have appeared, stressing different aspects of the fluorescence phenomenon and covering most of the relevant literature (Maxwell and Johnson 2000; Murchie and Lawson 2013). Biochemical and physiological implications of fluorescence were covered in the earlier reviews by Krause and Weis (1984), and Krause and Weis (1988)**.** The rapidly growing application of fluorescence in detection and analysis of stress effects on plants, being highly important to ecophysiology was covered by Murata and Satoh (1986). Since then chlorophyll fluorescence has been routinely used for many years to monitor plant photosynthetic performance non-invasively (Maxwell and Johnson 2000; Murchie and Lawson 2013). Kim *et al* (2013) employed chlorophyll fluorescence and leaf temperature measurements as rapid bioassay techniques to assess herbicide resistance in *Echinochloa crus-galli* biotypes.

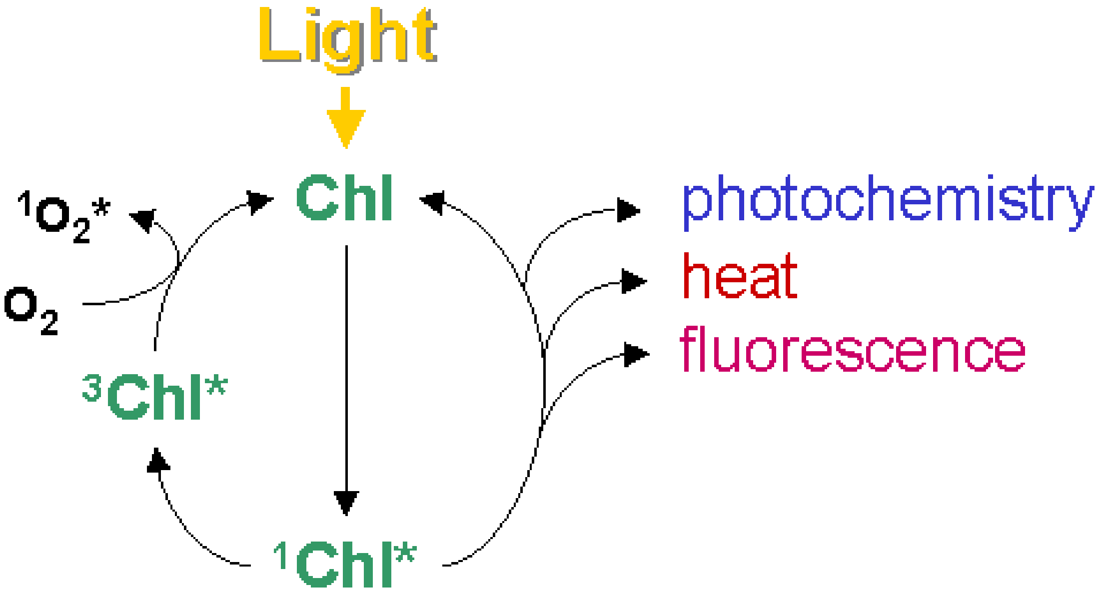

Fig. 1.2 A simple illustration of how an excited chlorophyll molecule can lose its excitation energy (Fracheboud and Leipner 2003).

One of the parameters determined by the technique is variable to maximum fluorescence ratio or F_V/F_M (Fig. 1.3). This ratio, which can be measured within one second, is an indicator of the integrity of the reaction centre and light harvesting complex of PSII and has been found to correlate very well with photosynthetic capacity or performance in plants in well over a hundred studies It is the most widely used chlorophyll fluorescence measuring parameter in the world (DeEll *et al.* 1999). It measures whether or not plant stress affects photosystem ll in a dark adapted state. In general F_V/F_M values vary between the range 0.79 to 0.84 in many plant species and these values are considered to be that of photosynthetically healthy plants, with lower values indicating plant stress (Maxwell and Johnson 2000).

Recently Debrabata and Kumar (2011) studied the influence of submergence on the photosynthetic activity in rice plants using chlorophyll fluorescence to gauge photosynthetic capacity. Prior to that Panda and Sharma (2007) carried out similar studies using chlorophyll fluorescence on rice to investigate submergence tolerance. More recently in 2012 Sone and Sakagami used the same method to characterize submergence survival strategy in rice. Recent studies on wheat and maize have also used chlorophyll fluorescence to gauge photosynthetic capacity in these crops (Roosataei *et al.* 2011; Niu *et al.* 2012) . Thus as with chlorophyll content, chlorophyll fluorescence determination has been widely used by scientists and agronomists over several decades to assess crop health and productivity.

1.3.3 Population models

Previously, agronomists studied the relationship between plant density and yields in monoculture systems in their attempts to minimize seed inputs but maximize harvestable yields (Kropff *et al.* 1993). Large number of experiments gave the researchers the ability to identify the main influences of intra-specific competition in these systems. The he Law of Self-thinning, for example, demonstrates the interactions of density with an average weight of the plant to create an

effect in a major competition. Researcher have revealed that there is an inverse relationship between plant density and its mean weight (Yoda *et al.* 1963; Harper 1977; Baki 1986). Also, weed control in agricultural production systems have been a source of great concern to farmers since the beginning of agriculture, where the task of making it require the help of complex mathematical models. Weed population models can be density independent and dependent on density. The model of density regulation, is dependent on population trends in the short term (Gonzalez *et al.* 2008).

Many research models have been developed to investigate the outcome of competition between crops and their associated weeds (Baki 1992). These models relate crop yield losses to weed density alone (Cousens 1985), weed density and relative time of weed emergence (Cousens 1987). Research models are used in studying competition in monoculture and mixture of species (Kropff and Spitters 1991).

de Wit (1960) pioneered the first worked the hyperbolic yield density function in the analysis of competition in plant mixtures of different species. He introduced the replacement series approach along with design. This design consists of a pure stand of each of the component species and a range of mixture in such a way that the same density is used for each species (Connolly 1988; Snaydon 1991). This design possibly used in ecological and agronomic studies to investigate competition between two plant species (Firbank and Watkinson 1986). Well, this design proves its capability in detecting and measuring the magnitude of competition and in revealing the combination of species densities that maximize yields (Harper 1977). This design has been criticized because of sensitivity of results and its dependence on the density for the experiments (Marshall and Jain 1969; Spitters and Herts 1983; Joliffe *et al.* 1984).

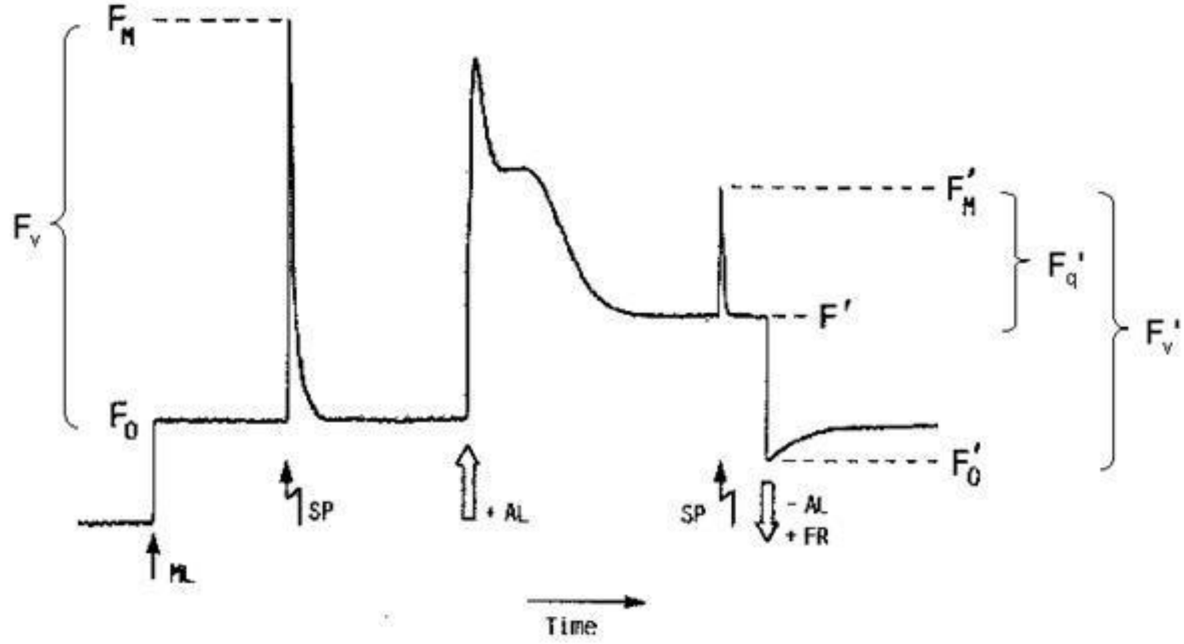

Fig. 1.3 Measurement of chlorophyll fluorescence by the saturation pulse method. Diagram shows initial maximum (F_M) and variable fluorescence (F_V) signals. F_O is minimal dark fluorescence. ML is modulated weak measuring light (6 nmol.m$^{-2\cdot}$sec^{-1}) whilst SP is saturating light pulse (10,000 µmol.m$^{-2\cdot}$sec^{-1})(Guidi and Degl'Innocenti 2011; Van Kooten and Snell 1990).

1.3.4 Architectural models

The plant architecture model greatly assist in the management of weed and choosing an appropriate individual crop plant architecture, integrated with an appropriate crop planting density is an important component of IWM to suppress weed growth (Lemerle *et al.* 2001). Increasingly important of these effects is particularly important in view of the growing interest in reducing the reliance on chemical weed management (Blackshaw *et al.* 2006). The plant architecture is the size, number and spatial arrangement of plant organs upon the plant body. It determines the interaction of a plant with its environment and neighbouring plants (Aphalo and Ballare 1995). A recent advance in the study of biological systems, such as plant architecture and crop–weed competition, is the use of computers to model and simulate such systems. In the last two decades different models have been developed to simulate crop-weed competition (Bastiaans *et al.* 1997; Olesen *et al.* 2004). Having a virtual plant model will help one to see the results of competition over time and combine different cultivars or different planting rules to analyze the competitive ability of that crop plant in silico (i.e. by running a computer simulation). The ability to express branching patterns and to describe relatively complex architectural structures based on rewriting rules makes the L-systems formalism (Lindenmayer 1968) an appropriate candidate for modelling plant architectural development (Prusinkiewicz and Lindenmayer 1996).

1.4 Statistical analysis

1.4.1 The artificial neural network

The artificial neural network (ANN) was developed, trained, and used for classification for three species of broadleaved weeds (common cocklebur, velvetleaf, and ivy leaf morning glory) and two grasses (giant foxtail and crabgrass) that are common in Illinois were studied. The choice of a back propagation ANN as the high–level classifier was based on the fact that ANNs are computing systems whose central theme is borrowed from the analogy of biological neural networks. The main advantage of ANNs is that they can process information in parallel. Multilayer networks trained by the back propagation algorithm are also capable of learning nonlinear decision surfaces. Even though the back propagation algorithm can be trapped by local minima in the error surface, it is one of the most widely used ANN algorithms and has been found to produce excellent results in many real–world applications. With three layers of units, feed forward networks can approximate any function to arbitrary accuracy (Mitchell 1997; Tang *et al.* 2003). Neural network classification was done using Matlab version 4.0 (The MathWorks, Inc., Natick, MA) (Tang *et al.* 1999).

In the general, Artificial Neural Network (ANN) was built by using the Matlab^R neural network toolbox. Multilayer networks trained by the back propagation algorithm are capable of learning nonlinear decision surfaces and thus make efficient and compact classifiers. The ANN was trained until the sum square error of 0.01 being reached as the final learning convergence criterion. The input feature vector matrix had a size 4 by 20 elements, so the network had 4 input layer nodes. The hidden layer consisted of eight nodes. The output layer had two nodes, which corresponded to the two broadleaf and grass classes. The logarithmic sigmoid function was chosen as the threshold unit for all three layers and the learning rate was set to one (Tang *et al.* 1999).

Neural network is used in a classification method in agricultural engineering as well as in other applications. Marchant and Onyango (2003) workers compares a Bayesian classifier with a multilayer feed-forward neural network in a task from the area of discriminating plants, weeds, and soil in colour images. The principles behind and the practical implementation of Bayesian classifiers and neural networks are discussed as are the advantages and problems of each (Marchant and Onyango 2003).

Also neural network used for the classification of hyper spectral data, with the goal of discriminating between different growth scenarios in a cornfield. Where to get the highest accuracy of the data acquired in the classification of data when evaluating neural network (Miao *et al.* 2012).

The application of a neural network describes for classifier to differentiate between 2 and 3 weeks old sunflower plants and common cocklebur weeds of similar size, shape and colour. It is structures with different numbers of hidden layers and neurons in them were tested to find the optimal classifier (Karim *et al.* 2004).

The artificial neural network (ANN) classifier was developed using the neutral network toolbox and Matlab script language in Matlab 4.0 (Tang *et al.* 2003). Also, in another study in artificial neural network is used for classification of image. Where was results showed that the method is capable of performing texture-based broadleaf and grass classification effectively and with 100 percent classification accuracy over 40 sample images with 20 samples from each class (Tang *et al.* 1999).

1.4.2 Response surface analysis

Response surface analysis (RSA) explores the relationships between several explanatory variables and one or more response variables. The method was introduced by (Box and Wilson 1951). It is an effective and commonly-used tool in scientific and engineering investigation, this is design, and analysis of experiments is an effective and commonly used tool in scientific and engineering investigation. A response-surface method consists of an empirical modelling system that evaluates the relationship between a group of variables that can be controlled experimentally and an observed response (Pantone and Baker 1991).The standard RSA can typically be described as consisting of two parts. First, it conducts analysis of data generated from an experiment to screen out unimportant factors. Typically, it is based on a first-order design such as the $2n-k$ fractional factorial designs or Plackett-Burman designs. Second, it conducts a more intensive study of the response surface, typically with fewer factors and over a smaller region (Khuri and Cornell 1996). RSA has been a very effective tool and has seen many successful applications. Its sequential nature can, however, be a disadvantage, especially when the experimental preparation is time-consuming or its duration is long (Shao-Wei and Wu 2001).

The application of statistical methodologies is helpful in defining the effects and interactions of the physiological factors that play a role in ecological processes (Matulis *et al.* 1995). The response-surface model consisted of nonlinear yield-density equations where average per-plant yield was the dependent variable and the densities of the competing plant varieties were the independent variables. The model predicted the maximum yield of an isolated plant, the area associated with the maximum yield per plant, and competitive ability (Dan and John 1991). A response surface technique is utilized in statistical analyses involving densities, duration of interference, interference abilities of different species, and weed growth rates. At high weed densities interfering for long durations, multispecies interference is not additive but at low densities addictiveness is approached (Terry *et al.* 1984). The response-surface model can be used in competition between two species, and this can be analyzed in terms of the changes in their population densities over time, as the species interact with one another (Law and Watkinson 1987).

Competition between wet-seeded rice and barnyardgrass under two distinct environments was analyzed using a two-parameter response–surface model at the International Rice Research Institute in the Philippines. The findings showed that this model could predict crop yield loss due to weed competition over a wide range of crop and weed densities (Hanwen *et al.* 2004). For use the response-surface model correctly we need action prediction requires computation of a simple polynomial equation once the model has been fit (Timothy 1998).

In another study response surface experimental designs, which vary the densities of two competing species independently, offer the advantage of being able to compare the fits of alternative competition models and to estimate model parameters. This kind of experimental design has been relatively little used in ecology to date. I consider the use of response surface designs from two perspectives. The first is the optimal allocation of experimental effort among density treatments, with the goal of distinguishing among alternative models. Second, I compare the ability of six response surface designs to estimate known competition coefficients correctly, using simulated data (Brian 2001). The concentrate on the properties of response surface experimental designs because these designs are well suited for fitting explicit competition models to data. Fitting explicit mathematical models of competition is an important objective for two reasons. First, the use of explicit models allows quantitative prediction of population dynamics, as opposed to qualitative measures of the presence or absence of competition (Peters 1991). Second, fitting explicit models allows one to measure competition in the field using the same units as theoretical models, thus allowing a more direct connection between theoretical and empirical approaches and more rigorous tests of theory (Damgaard 1998) than traditional null-hypothesis tests. Despite the profusion of empirical competition studies, relatively few have calculated the interspecific competition coefficients that are the focus of most theoretical studies of competition (Pfister 1995; Damgaard 1998; Inouye 1999; Freckleton *et al.* 2000). Many of the advantages of response surface experimental designs for investigating competition have been mentioned before (e.g., Goldberg and Scheiner 1993; Gibson *et al.* 2001), but few field studies have actually used these experimental designs, and a thorough review of the ecological application and analysis of these designs is still lacking. Response surface experimental designs are potentially suitable for a wide range of experimental objectives. Their worst shortcoming seems to be that they are overkill for some purposes (Cousens 1991). By using a range of densities for each species, response surface designs can describe intraspecific and interspecific competition without limiting inference to any particular densities. This is important for studies in natural systems, where the densities of the competitors may change over time, and is necessary for studies aiming to predict population dynamics or coexistence. Response surface designs are the only one of the three classes of experimental design considered here that can distinguish among different models and provide parameter estimates for these models. Two-species competition models describe a surface, but substitution and additive designs only provide data along a one-dimensional line under this two-dimensional surface (Brian 2001).

1.4.3 Fractal dimension analysis

For about three decades, spatial analysis has been dominated by a style of model building which has sought high predictive understanding in numerical terms but has paid little attention to the geometry of spatial form. Mandelbrot's concept of a fractal, as one of these fast moving research fronts coupled with concepts of complexity, criticality, and self-organization, extends our usual ideas of classical geometry beyond those of point, line, circle and so on into the realm of the irregular, disjoint and singular. Fractals represent many kinds of patterns, including density, diversity, dendritic stream networks, geometrical shapes, mountainous terrain, and size distributions of islands (Mandelbrot 1983). It has the potential to provide us with a new way to understand and analyze such natural spatial phenomena, which are not smooth, but rough and fragmented to self-similarity or self-affinity at all scales.

The word “fractal” is coined by Mandelbrot to describe sets consisting of parts similar to the whole, and which can be described by a fractional dimension (Mandelbrot 1983). In essence, fractals are mirror images, albeit in smaller dimensions, of the whole plant or organism in question, or time- or space-mediated re-iterations of similar or identical modular construction units (*sensu-stricto* Harper 1977). The values of the complex fractal dimensions can be predicted quantitatively from a renormalization group approach using the quasi-periodic mapping found in (Arneodo 1992). The multifractal dimension spectrum in the presence of disorder can be handled using probabilistic versions of the renormalization group and their development and impact are just emerging (Falconer 1994).

Several attempts have been made to apply the principles of fractal geometry to the description of root systems. Recent studies have included measures of the fractal geometry of landscape and patch pattern analyses in ecological literature, such as, soil and landscape data analysis (Burrough 1981 and 1983; Tyler and Wheatcraft 1990; Bartoli *et al.* 1991; Young and Crawford 1991). In studying images, the analysis was used to collect the data required for determination of three-dimensional and planar fractal dimensions. It was found that the root system has characteristics of a fractal object. The variation of the planar fractal dimension of horizontal and vertical planes intersecting the root system was shown, and their maxima were found to correspond with maximal root proliferation. These results open the way for further application of fractal analysis in root research (Eshel 1998). In another study, fractal geometry applications used of the art and introduce several updated developments in analysis and description of patch patterns and patch dynamics. These topics include geometric fractals, statistical fractals, information fractals, the fluctuation-tolerant fractals of dynamic patch size and shape, patch hierarchical scaling, fractal spatial patterns, multiple scale sampling and data analysis, fractal fragmentation of the landscape habitat into patches, fractal correlation in patchy systems, fractal.

The ontogenetic development of plant root systems involves not only an increase in size, but also an increase in complexity. An increase of the volume of the soil explored by the roots, as a result of continuous branching, goes hand in hand with an increase in root-length-density. Such an increase is not uniform but reflects the plant’s adaptive ability to make best use of unevenly distributed soil resources (Fitter 1987). Great hopes were pinned on application of the principles of fractal geometry to the description of root systems. Since the introduction of these principles by Mandelbrot (1983), they have been applied successfully to various biological systems such as protein molecules (Lewis and Rees 1985). The principles of fractal geometry seem appropriate for the description of root systems because the repetitive branching of roots leads to a certain degree of self-symmetry. Such self-similarity is a fundamental characteristic of fractal objects. Attempts to determine a fractal dimension (*D*) for sections of root systems were successful in showing variation of *D* with genotype (Fitter and Stickland 1992; Lynch and van Beem 1994), with plant age (Fitter and Stickland 1992), and with growth conditions (Eghball *et al.* 1993; Berntson 1994; Lynch and van Beem 1994). Such analyses were applied to roots extracted from the soil and arranged on a flat surface, or grown in a narrow space next to transparent windows.

In 1997, Nielsen *et al.* (1997) have successfully applied fractal analysis to a computer model of bean roots. They have also demonstrated that the true three dimensional fractal dimension (*D*3) is tightly correlated with planar (*D*2) and linear (*D*1) fractal dimensions.

Fractals are conceptual objects showing structures at all spatial scales, with a scale-dependent self-similarity (Mandelbrot 1983 and 1989; Barnsley 1988). The shape of fractals is non-rectifiable, consisting of an infinite sequence of clusters within clusters or waves within waves. In rectifiable objects, increasingly accurate measurements based upon successive scale reductions give series converging to a limit: the true extent of the object. By contrast, in fractals the same procedure generates infinite series, according to the relationship *N*(o)8o-*D*, where *N*(o) is a number measure corresponding to the scale unit o and *D* is the fractal dimension. The length of the object is then *L*(o)8o 1-*D* and *D*\1. The length diverges as 0.0. In a volume of Euclidean dimension *E* the volume occupied by an object of fractal dimension *D* is given by *V*(o)8o*E*-*D*. This parameter exceeds the topological dimension *d* of the object and is generally not an integer, but less than the space dimension of the object, that is, *D*b*d*b *d*-1. For example, the fractal dimension of Koch's snowflake is *D*-log 4:log 3-1.2618. Taylor (1986) suggested that a set should be called a fractal if these different computations aQWll lead to the same value for the index, which we then call the dimension of the set.

Fractals are characterized by so-called 'symmetries' or asymmetries (Li 1986; Li *et al.* 1992), which are invariance under dilations and: or contractions. Hence, the best fractals are those that exhibit the maximum invariance. A fractal invariant under ordinary geometric similarity is called self-similar (Mandelbrot 1983). ‘Self-similar’ has two meanings. One can understand ‘similar’ as a loose everyday synonym of ‘analogous’. But there is also the strict textbook sense of ‘contracting similarity’. It expresses that each part is a linear geometric reduction of the whole, with the same reduction ratios in all directions. Self similar processes are invariant in distribution under judicious scaling of time and space, which are connected with the so-called ‘renormalization group theory’, ‘critical phenomena’, ‘*1:f* noises’, etc. Mathematically, the scaling coefficient or index of self-similarity is a non-negative number denoted H (which is the first letter of the British Harold Edwin Hurst’s last name); a process X- $\{X(t), t\text{-R}\}$ is self-similar with index H if, for any $a\backslash 0$, the finite-dimensional distributions of $\{X(at), t\text{-R}\}$ are the same as those of $\{aHX(t), t\text{-R}\}$ (Samorodnitsky and Taqqu 1994). Self-similarity cannot be compatible with analyticity. Random fractals are self-similar only in statistical sense and to describe them it is more appropriate to use the term ‘scale invariance’ than self-similarity. By ‘scale invariance’ in ecology, we mean that scales are ecologically equivalent so that the same ecological conclusions may be drawn from any scale statistically.

There are many different self-similar processes; however, most studies have considered those that have stationary increment. More recent developments have extended, in particular, to include self-affine, in that the reductions are still linear but the reduction ratios in different directions are different.

Fractals have been used to study nonlinear spatial and temporal phenomena (such as D as a measure of complexity), but they can also be extended to abstract objects developing in a phase space, such as models of dynamic complex systems. Size–frequency distributions describing structured systems can also have a fractal dimension. There are several methods of measuring the fractal dimension which include changing coarse graining level, i.e. box-counting methods, information fractals, etc., using the fractal measure relations, i.e. perimeter: area: volume methods, using the correlation function, i.e. autocorrelations, semivariograms, etc., using the distribution function, i.e. hyperbolic distribution, and using the power spectrum, i.e. Fourier transformation, filters, wavelets, etc. (Li *et al.* 1992). Although the theoretical origins of fractals in measure theory may seem abstruse, the basic ideas of fractal geometry are extremely simple and intuitive, and one can begin to work with them very quickly. Fractal dimensions can be positive, negative (Mandelbrot 1990), complex (Pietronero and Tosatti 1986), fuzzy (Feng *et al.* 1991), and multifractals (Mandelbrot 1989), etc.

Generally, there are three properties of fractal forms: heterogeneity, self-similarity, and the absence of a characteristic scale of length. These geometric features are also characteristic of patch patterns in landscape. The fractal dimension *D* has been shown to be a useful way to characterize the geometric structure of a number of these patchy spatial patterns (Milne 1988).

The fractal concept is also useful for characterizing certain aspects of patch dynamics. Consider a complex process of landscape patch change that cannot be expressed in terms of a simple characteristic rate, but instead is regulated by a self-similar or self-affine mechanism in time. The multiplicity in time scales will be reflected in a power spectrum with a broad profile of responses.

The fractal scaling between variations on different time scales will lead to a frequency spectrum having an inverse power-law distribution. A fractal analysis of a cellular automata model of spatio-temporal response of vegetation to disturbance in the later section is an example.

Levin and Paine (1974) and Paine and Levin (1981) have developed a mathematical model for the spatial and temporal patterns of patch dynamics. However, we try to use fractal theory in dynamic patch size and shape, especially in marine environments. From the fractal viewpoint, change of patch size and shape in space has a multiplicity of spatial–temporal scales and multifractal dissipation. My approach is assuming having self-similarity of patch change and ability of maintaining patch integrity while allowing for a broad spectrum of variations both in space and time. According to some results from fluctuation tolerance fractals in complex physiological structure and processes (West 1990), we similarly obtain the probability distribution of a scale of patch size presented in time t which could be related to the asymptotic statistics of a Levy process, and patch size–frequency distributions. Because the Levy index can be related to the fractal dimension of the underlying process, many studies have shown where there exist some relationships between generalized diffusion equations and fractal random walks (Mandelbrot 1983). In a fractal stochastic process, not only does the process itself display a kind of self-similarity, but also the distribution function characterizes the statistics of the process. If $X(t)$ is a fractal random patch dynamic function, then for constant b\1 and a\1, we have $X(t)$-b-a$X(\mathrm{b}t)$. For example, a given realization $X(t)$ is identical with one that was stretched in time by bt and scaled in amplitude by b-a, where a is related to the fractal dimension. Subject to certain ecological assumptions we can obtain the exponents f for the decay of the power spectrum ($S(f)8f$-f), t for patchsize distributions ($D(s)8s1\text{-}t$), and fractal dimension Df of patch ($s8LDf$), by relating them to the spatial anisotropic exponent z, the usual dynamical scaling exponent z, and the anomalous spatial correlation exponent x.

In addition, some studies show that diffusion limited aggregation (DLA) is the physical origin of fractals (Pietronero 1989). Perhaps these theories could provide us with a possible explanation about formation mechanisms, and ecological and evolutionary consequences of patch patterns and patch dynamics (Li *et al.* 1992).

1.4.4 Topography analysis

Remote sensing and associated spatial technologies provide tremendous opportunity to enhance weed management and improve–protect the environment through judicious use of the most efficacious control methods for a given site (Shaw 2005). Although visual inspection of corneal topography maps by trained experts can be powerful, this method is inherently subjective. Quantitative classification methods that can detect and classify abnormal topographic patterns would be useful. An automated system was developed to differentiate keratoconus patterns from other conditions using computer-assisted videokerat oscopy or Matlab program (Shaw 2005).

Human visual interpretation is essentially subjective, whereas contour information is difficult to analyze quantitatively. An objective assessment of videokeratography is essential for statistical studies of the progression of keratoconus, genetic studies, or screening procedures used for refractive surgery practice. Therefore, the thousands of data points in a color-coded map must be reduced in some fashion to a series of statistically manageable indices (Shaw 2005).

Discriminant analysis was used as a multivariate analysis of these indices. When dependent variables are categorical and the independent variables are di-mensional, discriminant analysis is considered one of the most appropriate statistical techniques. The Keratoconus Prediction Index (KPI) is the index that is proportional to the discriminant cut off value obtained from the discriminant function. Average KPI values for keratoconus were significantly higher than those of any other category. This means that KPI is able to differentiate keratoconus not only from normal corneas but also from keratoplasty, epikeratophakia, photorefractive keratectomy, radial keratotomy, and contact lens-induced warpage. Although one can obtain a system that can perform keratoconus screening with high specificity and high accuracy, discriminant analysis by itself is not sufficient for clinical screening of the keratoconus pattern because of relatively low sensitivity (Shaw 2005). As a result of differences in topography, soils developed from similar parent material may vary greatly within a small area (Foth 1991).

The topographic analysis studies were conducted on many plants, for example (Hamrick and Lee 1987; Shaw 2005) on *Carduus nutans* and *Nassella pulchra* (Dyer 2003). Additionally, this system can be adapted to detact other patterns in corneal topography by developing appropriate quantitative indices sensitive to the unique characteristics of those patterns.

1.5 The Family Cyperaceae

Cyperaceae are plant species belonging to Cyperaceae family of Monocotyledons, consisting of 70 genera with approximately 4,500 species in world. Important genera including noxious weed species are *Cyperus, Eleocharis, Fuirena, Fimblistylis, Scirpus,* and *Scleria,* etc. (Morita 2006). The plant genus *Scirpus* consists of a large number of aquatic, grass-like species in the family Cyperaceae (the sedges), many with the common names club-rush or bulrush. Other common names are deergrass or grassweed (Auclair *et al.* 1976a).

The taxonomy of the genus is complex. Recent studies by taxonomists of the Cyperaceae have resulted in the creation of several new genera, including the genera *Schoenoplectus* and *Bolboschoenus;* others (including *Blysmus, Isolepis, Nomochloa, and Scirpoides*). At one point this genus held almost 300 species, but many of the species once assigned to this genus have at present been re-assigned, and it presently holds an estimated 120 species (Auclair *et al.* 1976a; Day *et al.* 1988). In recent years, most clouted on Cyperaceae have supported a narrow circumscription of the genus *Scirpus*. To weigh this approach, many new combinations are required and several of these are made here. *Actinoscopy* is recognised as a monotypic genus, containing.

It is argued that *Actinoscirpus grossus* L.F. is closely related to, but distinct from, both *Bolboschoenus and Schoenoplectus* in several respects. *Bolboschoenus nobilis* comb. nov. is separated from *B. maritimus* and a key is provided to distinguish between the two Scirpus beccarii is transferred to *Isolepis. S. acaulis* is transferred to *Phylloscirpus* and problems relating to this genus are briefly discussed. Finally, it is suggested that *Amphiscirpus* should be retained as a genus, with its sole species *A. nevadensis* (Goetghebeur and Simpson 1991). The genus *Scirpus* contains several species, including *Scirpus grossus* L. (Table 1.1). The constituent species of the *Scirpus* genus is given in the Appendix 1.

Table 1.1 Some of the species within the genus S*cirpus* with their common names and Bayer codes

Species	Common names	Bayer code*
Scirpus acutus Muhl.	Hardstem bulrush tule	SCPAC
Scirpus americanus Pers.	lney's three square bulrush Olney's three-square Olney bulrush Olney's tule Three-cornered grass Three-cornered sedge Three square sedge Bayonet rush Chairmaker's bulrush	SCPAM
Scirpus articulatus L.	Jie bao shui cong in (pinyin, China)	SCPAR
Scirpus atrovirens Willd.	Woolgrass bulrush	SCPAT
Scirpus australis Murr.	Arabic: Summar English: Cane Grass	SCPAU
Scirpus californicus Camey.	California Bulrush	SCPCA
Scirpus capillaris L.	Densetuft hairsedge in (U.S.)	BULCA
Scirpus ciliaris L.	-	FUICI
Scirpus cognatus Hance.	Kangarei	SCPAG
Scirpus cubensis Poepp. & Kunth.	Cuban bulrush	SCPAU
Scirpus cyperinus L. Kunth.	Wool Grass	SCPAY
Scirpus dichotomus L.	Forked fimbry in (U.S.)	FIMDI
Scirpus diphyllus Retz.	Leafy Bulrush	FIMDI
Scirpus elegans HBK	-	ELDEL
Scirpus erectus Poir.	Sharpscale bulrush in (U.S.)	SCPJU
Scirpus etuberculatus O. Kuntze. ssp. *Nipponicus*	Canby's bulrush in (U.S.)	SCPEN
Scirpus fluitans L.	Floating Club-rush in Australian	SCPFL
Scirpus fluviatilis Torr.	River Bulrush	SCPFV
Scirpus giganteus Kunth.	-	SCPGI
Scirpus grossus L. f.	Clup rush Baki-baki (P. Bis.) Coserse bulrush Giant bur rush	SCPGR
Scirpus hotarui Ohwi.	-	SCPJU
Scirpus juncoides Roxb.	Hard-stemmed bulrush	SCPJU

Table 1.1 (*continued*)

Species	Common names	Bayer code*
	Turdwort	
Scirpus juncoides Roxb.	Hard-stemmed bulrush Turdwort	SCPJU
Scirpus juncoides Roxb.	Hard-stemmed bulrush Turdwort	SCPJO
Scirpus juncoides Roxb.	Hard-stemmed bulrush Turdwort	SCPJO
Scirpus koilolepis Steud.	Mucronate Bulrush	SCPKL
Scirpus komarovii Roshev.	-	SCPSL
Scirpus lacustris L.	Bulrush	SCPLA
Scirpus lacustris L. Gmel.	Bulrush	SCPTA
Scirpus lateriflorus J.F.Gmel.	-	SCPSU
Scirpus lineolatus Franch. & Savi.	-	SCPLI
Scirpus maritimus L. Auct.	Alkali Bulrush	SCPFV
Scirpus maritimus L.	Alkali Bulrush	SCPMA
Scirpus mucronatus L. Auct.	Ricefield bulrush Bog bulrush Roughseed bulrush	SCPTG
Scirpus mucronatus L.	Ricefield bulrush Bog bulrush Roughseed bulrush	SCPMU
Scirpus mucronatus L. robustus	Ricefield bulrush Bog bulrush Roughseed bulrush	SCPTG
Scirpus nipponicus Makino	Shizui in (Japan)	SCPEN
Scirpus olneyi Engelm. & Gray.	Olney's bulrush	SCPOL
Scirpus ovatus Roth.	Ovate spikerush in (U.S.)	ELOOV
Scirpus palustris L.	English: Spike-rush French: des Marais	ELOPA
Scirpus pendulus Muhl.	Rufous Bulrush	SCPPE
Scirpus planiculmis F.R. Schmidt.	-	SCPPL
Scirpus preslii Dietr.	-	SCPTG
Scirpus pungens Vahl.	Threesquare	SCPAM
Scirpus silvaticus (=*sylvaticus*) L.	Bosbies nld Scirpe des bois fra	SCPSI

Table 1.1 (*continued*)

Species	Common names	Bayer code*
	Wald simse deu	
Scirpus smithii A. Gray ssp.	Smith’s bulrush	SCPSL
Scirpus sulcatus Roth.	-	ELOFL
Scirpus supinus L.	Dwarf club-rush	SCPSU
Scirpus tabernaemontani Gmel.	Grey club-rush “Albescens”	SCPTA
Scirpus triangulatus Roxb.		SCPTG

Table 1.1 (*continued*)

Species	Common names	Bayer code*
Scirpus triqueter (= *triquetrus*) L.	Lisca trigona	SCPTR
Scirpus validus Vahl.	Great Bulrush**,** Soft Stem Bulrush	SCPVA
Scirpus wallichii Nees		SCPWA
Scirpus wichurai Boeck.	Abura-gaya in (Japan)	SCPWI
Scirpus wichurai Boeck.	Abura-gaya in (Japan)	SCPWI

***** Bayer, (1992).

1.6 *Scirpus grossus* L.*f.* syn. *(Schoenoplectus grossus* L.*f.)*

The genus *Scirpus* belongs to the Cyperaceae family. Some of the species of this genus are weeds commonly found in wetlands and moist soil, some species adapts well in saline, marshy environments such as intertidal mud-flats while others grow well in ponds or lake-sides and river-beds. Their leaves look like grasses with flower clusters of small brown spikelets. Some species (e.g. *S. lacustris*) can grow up to 3 m high, while others (e.g. *S. supinus*) are much smaller, only reaching 20-30 cm tall (Auclair *et al.* 1976a; Day *et al.* 1988). *Scirpus* species are usually planted to prevent soil erosion and also to provide an environmental alternative and food chain for other wildlife such as the birds and wild ducks. *Scirpus grosus* is popularly harvested in the wetlands area to specifically balance the ecosystem (Auclair *et al.* 1976a).

Scirpus grossus is one of the economic weeds abundantly found in Malaysia and elsewhere in the tropical Asia; particularly in Malesia, Oceania, South east Asia, South Asia and Far- east (Baki 2004). It is also known as 'rumput menderong' in Malaysia. Some of these pest species are classified as scheduled under the 1976 Act for the Protection and Plant Quarantine list in 1981. The weed is also found in rice fields as reported in a survey on the major weed flora of rice fields in Muda Kedah. (Begum *et al.* 2008). *S. grossus* is one from many common sedgesin Malaysia. It is very common in Sarawak and Sabah, and common in Peninsular Malaysia (Baki 2005).

1.6.1 Description of plant

Scirpus grossus is a perennial sedge weed plant with leaves like grass (Fig. 1.4). Stems are triangular in shape with concave sides, septate, smooth or slightly scabrid apically, can grow up to 1.5-2 m high, lower part triangular to deeply sulcat, septate, in cross-section; upper part shallowly sulcate with flat, very acute tip, margins scabrid, bristly; sheaths broad, spongy, straw-coloured. Leaves are basal, often half as long as the stem, the width are 1-2 cm wide, the leaf-like bracts subtending the in florescence, spreading and broad, 30-60 cm long. In florescence a terminal, irregular, compound umbel of corymbose, axils scabrid, minutely bristly, 10-18 cm long; flowers consist of numerous spikelets, solitary, sessile or peduncled, ovoid to oblong ovoid, acutish, densely many-flowered, 4-10 x 3.5-4 mm; rechilla persistent, not winged; glumes helically arranged, membranous, appressed,

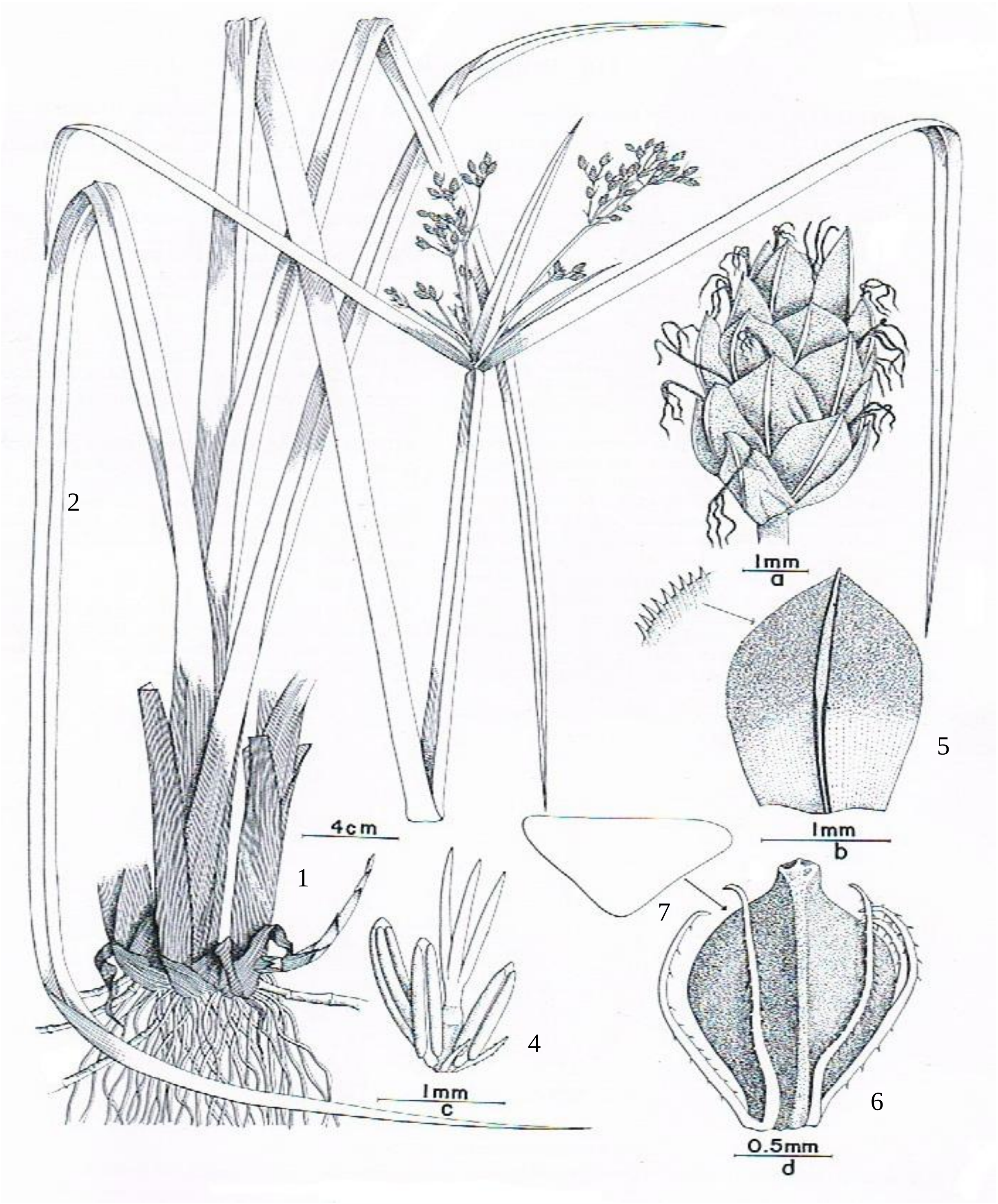

Fig. 1.4 *Scirpus grossus*: 1. Habit; 2. Portion of culm with leaf sheath; 3. Portion of inflorescence; 4. Flower; 5. Glume; 6. Achene with bristles; 7. Same, cross section (After Baki 1988; 2006).

concave, broadly oval, reddish brown with green midrib in color, glabrous to more or less hairy, minutely ciliate, shortly mucronulate, 2.5-3 x 1.75-2 mm; the lower 1-3 glumes often empty. Flowers bisexual. Perianth of 5(4-6) filiform, hypogynous bristles, sparsely covered with minute hairs pointing downwards, as long as or somewhat longer than the nut, tip incurved. Stamens 3, anthers linear; connective slightly protruded. Style short, glabrous, not separated from the ovary, with 3 stigmas. Nut obovoid, apiculate, smooth, brown, trigonous. The phenology of *S. grossus* usually flowering April to July and sometimes through to October (Dassanayake 1983; Soerjani *et al.* 1987; Kostermans *et al.* 1987; Pancho 1995).

1.6.2 Distribution

Scirpus grossus is a true indigenous of South-east Asia (Baki 2005). The species is well distributed in India, South China, South East Asia, Malaysia, Laos, Australia (Northern Territory, Queensland and Western Australia), Borneo, Bhutan, Cambodia, Myanmar, Pakistan, Sri Lanka, Thailand, Vietnam, Japan, Taiwan, the Bonin Islands and throughout Indonesia (Kostermans *et al.* 1987; IUCN 2011). The scourge grows well in swampy or inundated places, pools, ditches, marshes; locally abundant water especially in the lowlands; up to 850 m alt and in lowland-irrigated and tidal rice fields (Barnes 1990). The plant has the capability to dominate rice fields and wetlands, and it pose a major threat to rice fields in Malaysia that incorporate the direct seeding methods (Azmi 1994) (Table 1.2 and Fig. 1.5).

Scirpus grossus is very widespread and very important in Malaysia, and widespread and important in Myanmar, important locally in Vietnam and Philippine and present, but not important in another counters (Waterhouse 1993).

Table 1.2 The distribution of *Scirpus grossus* in Malesia, India, China and the Far-east

Country	Vernacular Names	Crops/Habitat	References
Australia (Northern Territory, Queensland and Western Australia)	-	Drains, ditches and marshes	(Gupta 2011 In IUCN 2011)
Cambodia(Khmer)	Meum plong and Kak chrung	The rice fields/ in swampy or inundated places, pools, ditches and marshes/ Fresh water.	(Barnes 1990) (Waterhouse 1993)
India	Bundung, Reduk and Kesari	The rice fields/ General Habitat in marshy fields, in swampy and inundated places, pools, ditches, and marshes and the lowlands.	(Waterhouse 1993) .
Indonesia (Sunda Island, the Moluccas, Jawa, Kalimantan, Sulawesi and Sumatera)	Mensiang,Walingi, Wlingi, Lingi and Wlingen	Rice fields/ in the lowlands; up to 850 m alt. Lowland – irrigated and lebak/ Fresh water.	(Barnes 1990) (Waterhouse 1993)
Japan (Ogasawara)	-	Drains, ditches and marshes	(Gupta 2011 In IUCN 2011)

Table 1.2 (*continued*)

Country	Vernacular Names	Crops/Habitat	References
Laos	Hua haeo yaeng	The rice fields/ in swampy or inundated places, pools, ditches and marshes/ Fresh water. Present, but not important	(Barnes 1990) (Waterhouse 1993)
Malaysia	Rumput menderong Mensiang, Masiang, Murong and Menurong	The rice fields/ in swampy or inundated places, pools, ditches and marshes/ Fresh water. Very common in Sarawak and Sabah, and common in Peninsular Malaysia.	(Barnes 1990), (Waterhouse 1993) (Baki 2007) (Baki 2005)
Myanmar	-	Widespread and important	(Waterhouse 1993)
Pakistan	-	The rice fields/ in swampy and inundated places, pools, ditches, and marshes and the lowlands/ Fresh water.	(Barnes 1990)
Philippines	Agás, Bungkuang and Ragiudiu.	The rice fields/ in swampy and inundated places, pools, ditches, and marshes and the lowlands/ Fresh water.	(Waterhouse 1993)
South China	-	Drains, ditches and marshes	(Gupta 2011 In IUCN 2011)
Taiwan	-	Drains, ditches and marshes	(Gupta 2011 In IUCN 2011)
Thailand	Kok, Kok prue, Kok samlien and Ta kraab	The rice fields.	(Barnes 1990) (Waterhouse 1993)
Vietnam	Lac her, Chi c[os]i d[uf]i	The rice fields.	(Barnes 1990) (Waterhouse 1993)

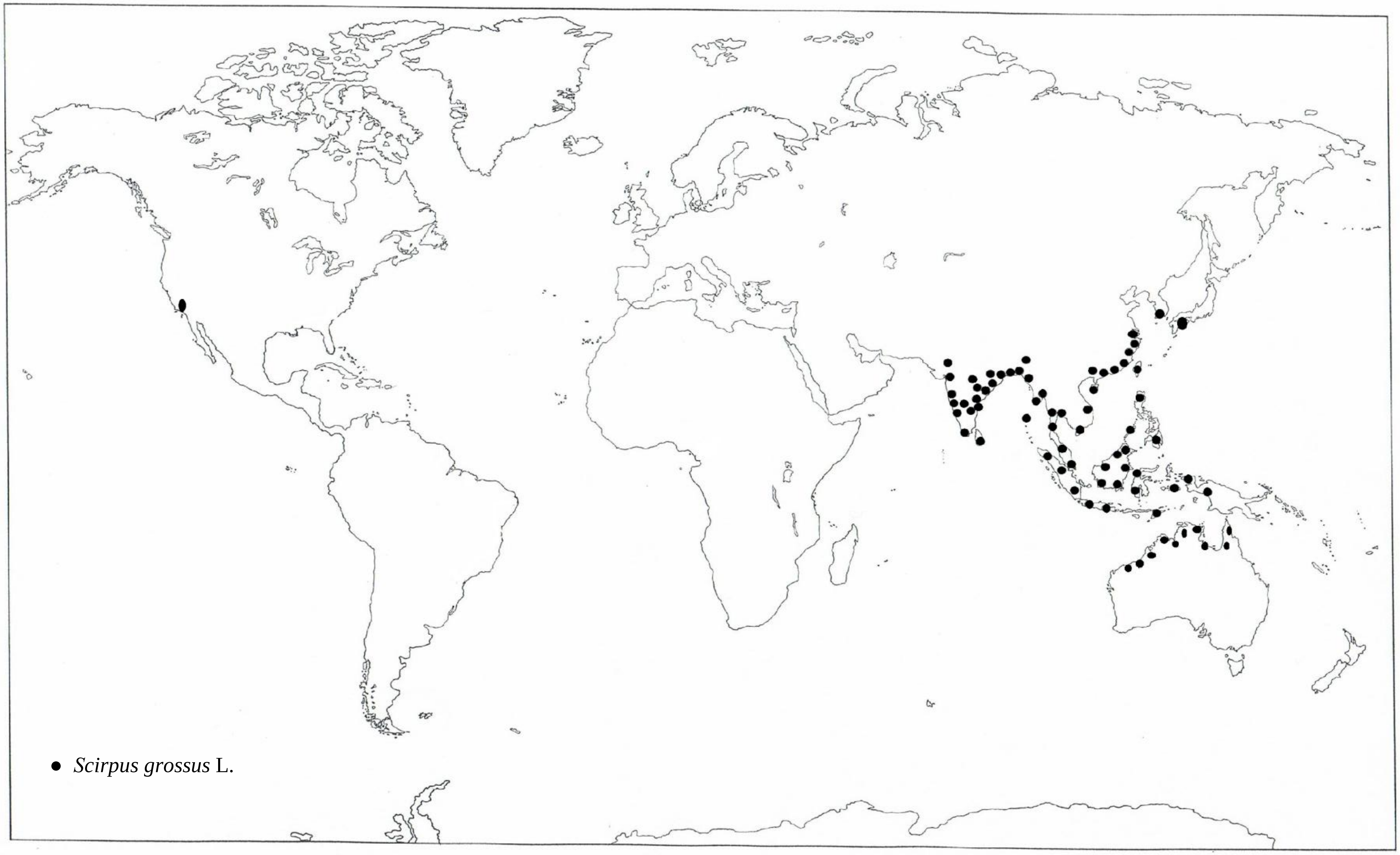

Fig. 1.5 Dispersion of *Scirpus grossus* in the world where it has been reported as a noxious weed (Barnes 1990; IUCN 2011).

1.6.3 Economic importance and management

Weeds are considered undesirable plants, or troublesome plants, or plants out of place, or plant with negative value, or any plant that is growing in a place where a man wants a different kinds of plant or no plants at all. All definitions of weeds are predicated on relationship of the plant to activities or desires of mankind. A large number of weed grow both wild and in cultivated habitats. It means that a number of weeds grow with wild plant species in primary habitats. Thus, it is rather difficult to distinguish weeds and wild plants. Of course, obligate weeds have never been found in wild stage (Kim *al et.* 2007). In Malaysia, plants hitherto classified and perceived as weeds at one point in time and place, can be viewed as useful resources when their potential have been properly harnessed for the benefit of mankind and improve their immediate environments, serving as alternative source for food, alternative medicines, animal fodder, materials for slope management and landscaping, or simply as decorative plants with aesthetic values in home gardens and parks (Baki 2007).

Many parts of *Scirpus* species are also used in some herbal treatments. For example, young shoots and lower stem are edible raw including the growing tips of the rhizome. Flattened dried stems of *S. grossus* can be used making baskets or mats. Herbage for green manure (Baki 2007). Essential oil can be extracted from the rhizomes. Dried rhizome can be shriveled to eliminate the fibers and grounded into flour. Fresh rhizomes can be seethed into gruel which is used in making pancakes or breads. Young rhizomes can be crushed and boiled to make sweet syrup. Pollen can be added in the making of cake or mixed with other flours. Seeds can be ground into fine meal. Sweet dried sap that exudes from the stem can be rolled into balls for food storage (Mahfuza *et al*. 2008). The parts uses of *S. grossus* are rhizomes in astringent, and is given to check diarrhea and vomiting. Also, against infection, burning sensatives, fevers and gonorrhea and diuretic. In India, sap extracted from leaves and stem of *S. grossus* is mixed with garlic, and the paste applied topically for cattle wounds. Also, made basketry from Stems, dried and flattened (Barnes 1990).

Researchers have shown that *S. grossus* significantly improved the effluent quality in removing pollutants from the wastewater by the submerging plant system. The results suggested that harvesting prolonged the benefits of the plants of the system and the generation of a renewable biomass with potential economic value. (Tanaka *et al.* 2006) Harvesting *S. grossus* also successfully removed pollutants from domestic wastewater under tropical conditions (Jinadasak *et al.* 2006). The plant too has the capacity to reduce CR ions from textile waste water at moderate level (Taufik 2008). In a study conducted at 15 sites at Tasik Cini to assess the concentration of heavy metals in plant species, it was found that the highest concentration of heavy metal was discovered form the roots of *S. grossus* (Ebrahimpour 2007).

In view of the distribution of *S. grossus* in rice fields, it is essential to study the weed species in rice fields specifically *S. grossus* in term of their biological needs in order to improve the management of padi fields. The high competition of weed species with rice produce an impact on the rice production in Malaysia, reducing the grain yield to 35%. (Karim *et al.* 2004). Repeated use of herbicides in the rice fields have resulted the increase of some weed species population including *S. grossus* but a recent study showed that bensulfuron plus 2, 4-D dimethlamine was effective against *S. grossus*. (Tse- Seng 2006) Therefore it is important to study this plant in weed management system that is environmental friendly and cost-effective.

The management protocols of sedges in *Padi Sawah* rice culture, be it direct-seeded or transplanted, form part of the in situ overall weed management operation. Knowingly or unknowingly, many *Padi Sawah* farmers in Malaysia have been practicing some form of Integated Weed Management of sedges and other weed invasives in their rice filed (Azmi 1994; Baki 2005). Following routine pre-tillage sprays with glyphosat or glufosiate ammonium at the respective rates of 2-3 kg ae ha^{-1} or 0.5-1.5 kg a.i. ha^{-1} with the knap-sac (small-scale farmers) or boom sprayers (large-scale cooperative ferming), *Padi Sawah* farmers usually practice open burning of the weed vegetation, despite the Malaysia government's mandatory orders to do away with such practice to prevent haze. Two or three rounds of dry-or wet tillage followed by land leveling are done to ensure good crop establishment while keeping weeds including sedges at bay (Baki 2006).

While good land preparation practices will control most sedge and other weeds, species with extensive sub-terranean stolons like *S. grossus* with their cut fragments as ramets can escaped herbicidal treatment are aggravated by enhanced bud break, hence increased sprouting and generating more plantlets after burning (Azmi, M., *pers. comms*.). There are a host of herbicides available to farmers for pre- or early post-emergence control of sedges in *Padi Sawah* culture. Azimsulfuron applied at 10-15 DAT controls a number of sedge species (Baki and Azmi 1992). Other herbicides efficacious against several species of sedges at 2-3 leaf stage in durect-seeded or transplanted rice include benthiocarb, 2,4-D amine/ester, MCPA (4-chloro, 2-methyphenoxyacetic acid), cyclosulfamuron, cyhalofop-butyl, flufenacet, imazapyr and molinate when applied as early post-emergence. The emergence of 2,4-D resistant biotypes of *F. miliacea* in Muda rice granary in Kedah following continuous use of the herbicide, of course, is a cause of concern among rice farmers, farm operators, weed scientists, policy makers and extinction workers alike in Malaysia (Watanabe *et al.* 1999).

Among the herbicides used, propanil and propanil-based herbicides are the most widely used Grass-killers, especially aiming at suppressing the populations of *Echinochloa crus-galli*, the most troublesome grass weeds in lowland rice cultivation in Sri Lanka (Marambe *et al.* 1997; Marambe and Amarasinghe 2002). While MCPA is the most widely used herbicide for the control of sedges and broadleaf weeds. Howere, the over-dependence on herbicides and the continuous use of the sameherbicide have resulted in negative impacts on the environment, shift in weed flora and development of resistant weed species (Marambe *et al.* 1997; Marambe and Amarasinghe 2002). Thus, there is a growing interest among Sri Lanka rice farmers for more effective weed control strategies. Kathiresan and Bhowmik (2006) from India remembered the primary methods of control adopted by farmers are either hand weeding or use of popular pre-emergence herbicides. Hand weeding has been effective against annual sedges but is often ineffective in controlling perennial sedge species. Cultural practices like planting pattern, intercropping, raising green manure in the off-season, continuous submergence, integration of other farming elements such as fishes and poultry in the farming system have also been used in controlling sedges.

In Thailand, the most popular herbicide is 2,4-D which is also the cheapest herbicide in the market. It is recommended to spray at 15-20 days after sowing rice. Pre-emergence herbicides are applied as a single or ready mixed with other herbicides to obtain broad spectrum of weed control (Chanya and Jumroon 2006). Baltazar *et al.* (2006), Also, In China used the shift of sedge weeds was influenced greatly by sulfonylurea herbicides application with high percentage in paddy fields (Sheng 2006). Finally, in Indonesia for control of sixteen common weed species in irrigated and rainfed lowland rice fields can be achieved by using pure seeds, good land preparation, flooding with >5 cm water depth to effective to control the species (Hamdan 2006).

1.7 Research Objectives

The principal objectives of the present research work were to: (a) study of the general growth patterns, structural demography and photosynthetic capacity of *S. grossus* as fertilizer application, soil types, soil moisture content, water depths, organic matter and their interactions; (b) assess spatio-temporal dynamics of sub-terranean rhizomes as influenced by selected agro-environmental factors; (c) undertake population modeling of aerial population modules and sub-terranean rhizomes based on fractal and response surface analyses mediated through fertilizer applications and soil types; and (d) assess directionality and dispersion pattern of growth of subterranean rhizomes of *S. grossus.*

1.8 Thesis structure

The work embodied in this thesis is reported in six chapters. Chapter 1 encompasses General Introduction and literature review. Chapter 2 describes general growth patterns of *S. grossus* in two different locations of different soil types with or without fertilizer applications and different water level and NPK concentrations. Chapter 3 focuses on chlorophyll florescence response of *S. grossus.* in two different locations of different soil types with or without fertilizer applications and different water levels and NPK concentrations. Chapter 4 reports on the population models of aerial ramets with emphasis on response surface, fractal dimension, gray-level analyses of vertical and lateral growths of *S. grossus.* Chapter 5 reports on the architectural models of subterranean rhizomes with emphasis on dispersion and directionality analyses, fractal dimension, box analyses of vertical and lateral growths of *S. grossus*. Chapter 6 embodied the general discussion.