CHAPTER 2

GENERAL GROWTH PATTERNS OF *SCIRPUS GROSSUS* L.

2.1.1 General growth patterns

Rhizomatous plants grow and reproduce clonally by rhizomes. Clonal branches are formed from the reiteration of the basic units, while inflorescence and inflorescences come from the reiteration of units bearing modified leaves (Harper 1977; Horn 1978). The population dynamics of many rhizomatous plants is dominated more by the flux of clonal modules. The ability of a single genotype to form fragmented phenotypes is just one of the variants in the life patterns of a modular organism (Harper and Bell 1979; Alderman 2011). The process of new growth is often subjected to different pressures, including the change in soil nutrients, and resource capture ability among individual plants and their modules. Remobilization of internal nutrient helps to support new growth and is a key mechanism to explain the improved performance of nutrient-loaded plants (Salifu *et al.* 2008). For example NPK fertilizer has been shown to be effective for growth in several *Senecio* sp.; *S. madagascariensis* actually has increased competitive advantage over oats with increasing nitrogen and phosphorus levels (Sindel and Michael 1992). The sawdust mulch and NPK 20:10:10 fertilizer affects rates on weed flora composition and growth in plantain and was more abundant in mulched plots, while the gramminaceous species (19%) were mostly found in bare plots (Hol 2010).

It has been well documented in the literature that nitrogen, potassium, and phosphorous are important macroelements for healthy plant growth, in addition to other macro-and microelements (Daughtry *et al.* 2000). N has been shown to increase the strength of competitive interactions in plants and were far better predictors than growth in the field (Levi *et al.* 2011). 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). They also observed that foliar application of NPK increased grain yield in lentils. Abdelhamid *et al.* (2011) reported that NPK application alone improved plant growth in cowpea.

Fertilizer applications strategies that promote nutrient loading during seedling nursery culture have been recommended to increase the performance of transplanted seedlings (Timmer and Aidelbaum 1996; Salifu *et al.* 2008). NPK fertilizer applications usually exhibit superior survival, growth, and competitive ability over non-loaded cohorts when transplanted in a variety of habitats (Oliet *et al.* 2009a). It has been reported that NPK fertilizer levels had a significant effect on weed population dynamics in onion bulb crop (Patel *et al.* 2011). Another study conducted for 8 years, during which the use of several different tests to improve the quality of NPK fertilizer was made, the results showed that the fertilizer application resulted in lower mortality rate and longer survival of plants (Oliveira *et al.* 2011). The effect of tillage and fertilizer types on soil properties increased significantly leaf area, vine length and tuber yield (39%) in sweet potato (*Ipomoea batatas*) (Agbede 2010).

Many studies in the literature on seedling nutrient status and transplanting performance has focused on N. New studies have shown how other macronutrients, like P, are involved in planting response under Mediterranean conditions, probably through promoting root growth (Villar-Salvador *et al.* 2004; Oliet *et al.* 2005,2009a). Other studies have shown the positive effects of fertilizer application on nutrient loading in nursery seedlings (South and Donald 2002; Rikala *et al.* 2004; Islam *et al.* 2009) and

subsequent outplanting performance (South and Donald 2002; Puértolas *et al.* 2003; Boivin *et al.* 2004).

NPK fertilizer applications of Holm oak seedlings in the nursery can improve early field survival and growth after planting (Villar-Salvador *et al.* 2004; Oliet *et al.* 2009b). However, some of the studies indicate that raising rates or using exponential regimes of fertilizer applications do not considerably improve the nutrient status of Holm oak seedlings, mostly due to its episodic growth through multiple flushes during nursery culture, which does not match any continuous fertilizer applications regime (Terradas and Save 1999). In Pakistan, NPK are nutrients required for plant growth and development. Many researchers have shown that micro-nutrients have a promising effect on the growth and development of crop plants and the use of micronutrients can improve the quality and quantity of agricultural produce (Rafique and Rashid 2006). During two years of study, on the effects of NPK fertilizer on the growth and yield of wheat (*Triticum aestivum*) it was shown that NPK increased shoot dry biomass and grain yield (Javaid and Shah 2010). In another study which tested six organic fertilizers it was found that liquid anaerobic digestate (LAD) was equally good as NPK fertilizer for barley when equal amounts of mineral N were applied (Haraldsen *et al.* 2011).

The impact of water level on wetland macrophyte communities, particularly emergent and submerged species, are well documented in the literature (Casanova and Brock 2000; Richardson *et al.* 2002; van der Valk 2005; Maltchik *et al.* 2007), Similar effects have been reported for amphibious species as well (Casanova and Brock 2000; Maltchik *et al.* 2007). Casanova and Brock (2000) reported the deepest depth in their study was 60 cm, on the influence of water depth on macrophyte establishment. They also, reported differences in *Myriophyllum aquaticum* total shoot length, shoot biomass, root biomass and total biomass, over a limited range of water levels. *M. aquaticum* is

capable of growing in deeper water depths, however the direct effects of deeper water levels on growth characteristics are still unknown (Hussner *et al.* 2009). Another study investigated the comparative effects of water level variations on growth characteristics in *M. aquaticum* to determine it is growth response, particularly of biomass and plant length, and its individual structures under increasing water depths (Wersal and Madsen 2011). Similarly, the biomass, plant height, crown diameter, flower number and days of blooming of *Begonia xelatior* under the effect of different watering frequencies and fertilizer amounts was studied (Sun and Zhang 2011). The results of main factor analysis indicated the effect of fertilizer amount was greater than that of watering frequency, and the value of watering frequency and fertilizer amount matching the optimal indexes was determined as well. The effects of water content and fertilizer on the growth index and quality indexes of *B. xelatior* was obtained by single factor analysis (Sun and Zhang 2011). The same results were obtained with regard to the biomass of *Lactuca sativa* L. under the effects of NPK fertilizer and water content (Xu *et al.* 2011).

2.1.2 Objectives of study

In this study the effects of different concentrations of NPK, different water depths and soil types on the growth patterns of *S. grossus*, and important weed in rice fields and waterways, was investigated.

MATERIALS AND METHODS

2.2.1 Plant materials and experimental sites

Planting materials consisting of young ramets at 2-3-leaf stage of *Scirpus grossus* (uniform-age cohorts) were obtained from rice fields of Tanjung Karang, Selangor. The ramets were used on the same day of collection. Synthetic populations of *S. grossus* were established on peat soils at the Malaysian Agriculture Research Development Institute (MARDI) Research Station, Jalan Kebun, Klang (N 2.98^{o} / E 101.50^{o}), Malaysia for 24 weeks commencing on 24 February 2010 (Figs. 2.1, Fig. 2.2) While experiments on paddy soil of the Jawa series was conducted in (MARDI) Research Station, Tanjung Karang, Selangor (N 3.28^{o} / E 101.08^{o}), Malaysia for 24 weeks commencing on 26 October 2010 (Figs. 2.1, and 2.3). The pot experiments was conducted in the experimental field at Universiti Putra Malaysia (N 03.00536^{o} / E 101.70259^{o}), Malaysia for 16 weeks commencing on 3 June 2011 (Figs. 2.1, and 2.4).

Fig. 2.1 Location of experimental sites at (i) ★ MARDI Station, Jalan Kebun, (ii) ■ MARDI Station, Tanjung Karang, and (iii) ● Universiti Putra Malaysia, Serdang Selangor, Malaysia.

Fig. 2.2 Plot site for *Scirpus grossus* in the first month of experimentation at MARDI Research Station, Jalan Kebun, Selangor, Malaysia.

Fig. 2.3 Plot site for *Scirpus grossus* in the first month of experimentation at MARDI Research Station, Tanjung Karang, Selangor, Malaysia.

Fig. 2.4 Pot arrangement for *Scirpus grossus*, in the first month of experimentation at Universiti Putra Malaysia, Serdang Selangor, Malaysia.

The weather data on rainfall and ambient temperatures at the experimental sites are shown in Figs. 2.5 and 2.6 where it can be seen the rainfall ranged from 3.9 mm - 10.8 mm and the temperature ranged from 26.5-28.6 ^{o}C. (Meteorology Department Malaysia). The weather data for Universiti Putra Malaysia is shown in Fig. 2.7.

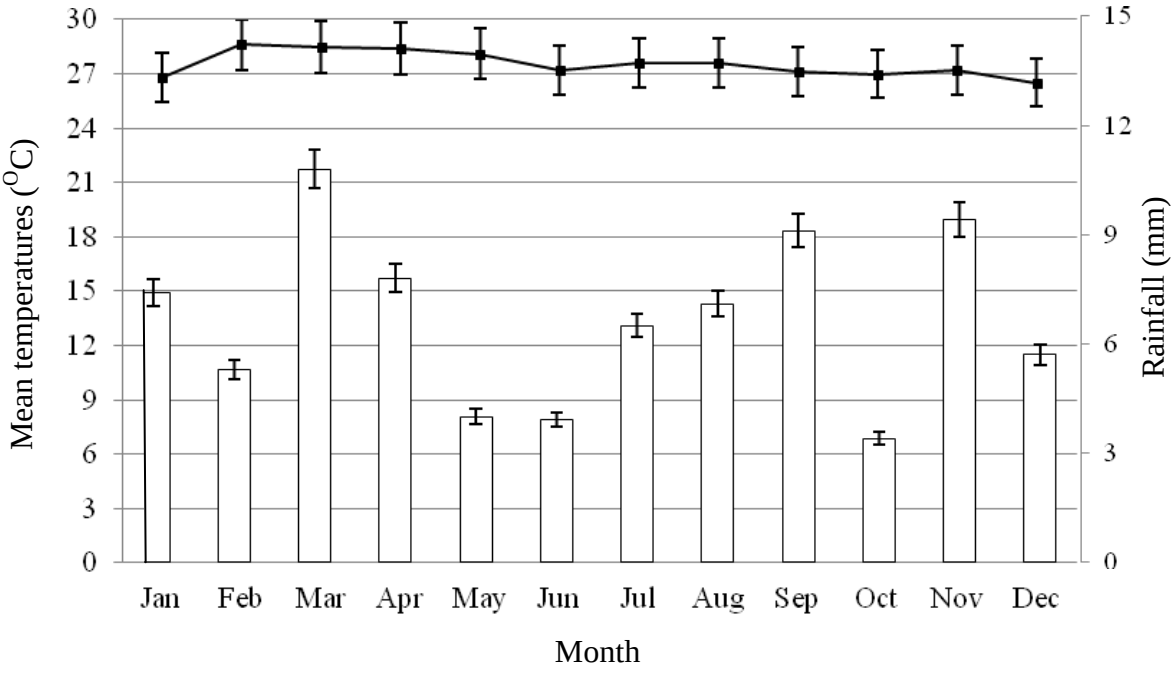

Fig. 2.5 Mean monthly □ rainfall (mm) and ■ temperature (^{o} C) readings (2010-2012) in MARDI Research Station, Jalan Kebun, Selangor, Malaysia. Bars represent highest and lowest rainfall and temperature readings.

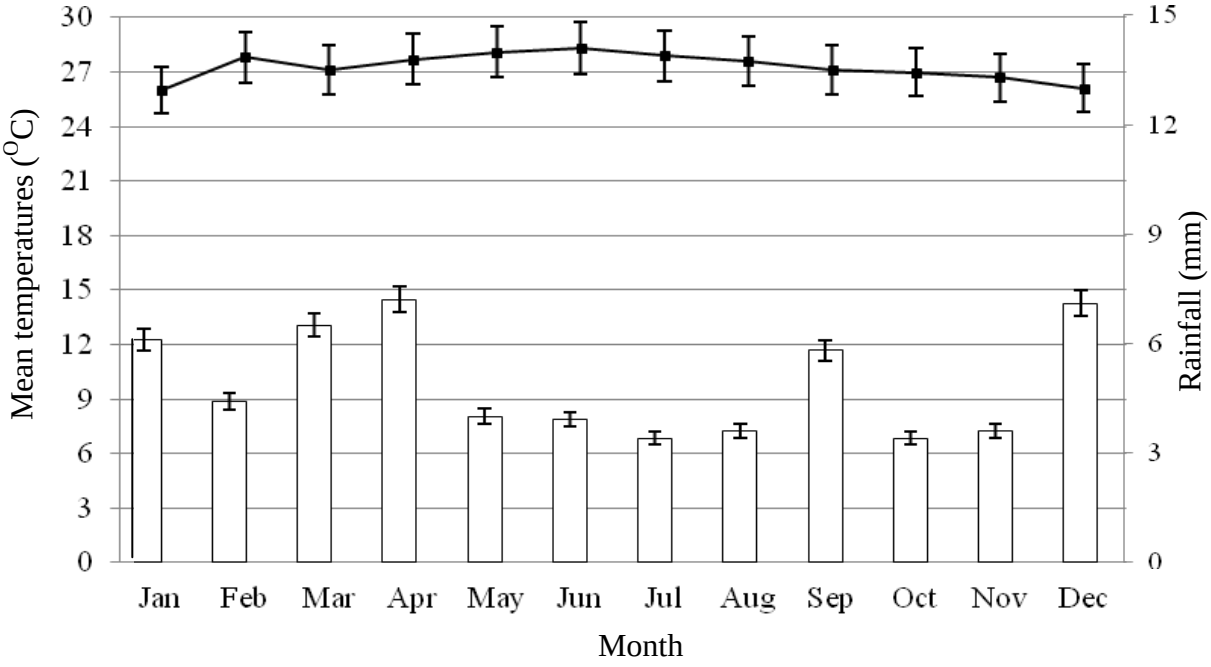

Fig. 2.6 Mean monthly □ rainfall (mm) and ■ temperature (^{o}C) readings (2010-2012) in MARDI Research Station, Tanjung Karang, Selangor, Malaysia. Bars represent highest and lowest rainfall and temperature readings.

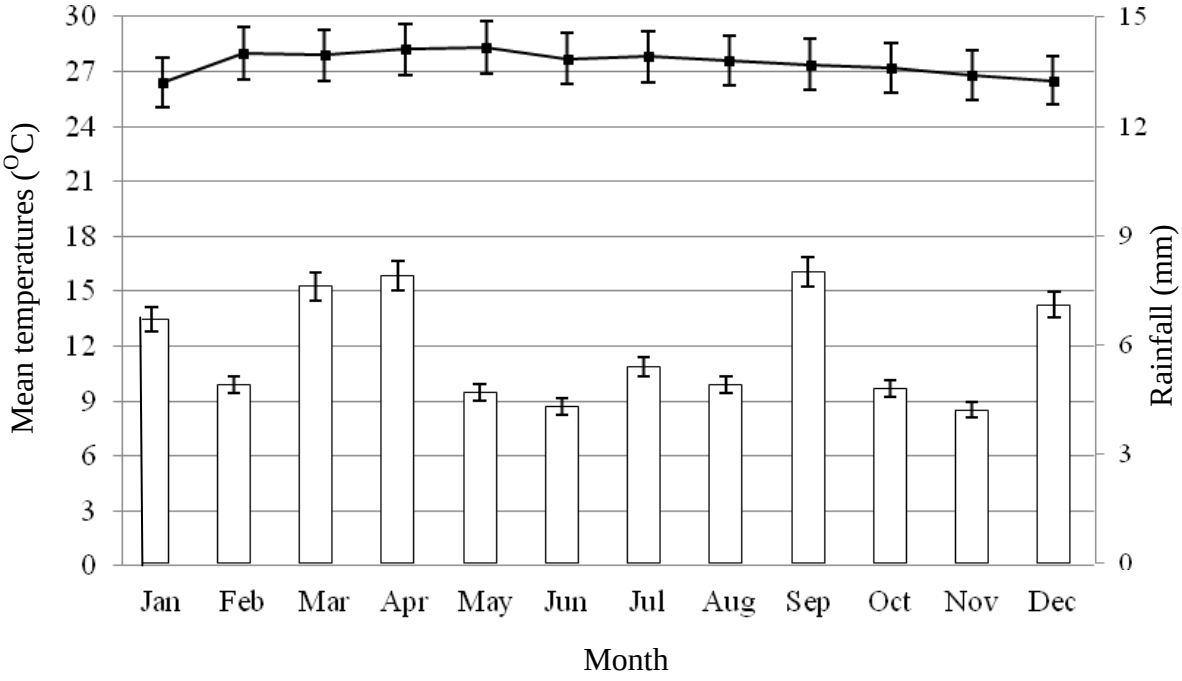

Fig. 2.7 Mean monthly □ rainfall (mm) and ■ temperature (^{o} C) readings (2010-2012) in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia. Bars represent highest and lowest rainfall and temperature readings.

2.2.2 Experimental design

Both field and pot experiments were executed following the completely randomized design (CRD) (Fig. 2.8).

2.2.3 Field experiments: Effects of soil types and fertilizer applications on the growth of *Scirpus grossus*

Each ramet was planted in the centre of a plot measuring 2m x 2m, previously demarcated and lined with 5 cm x 5 cm grids and sub-plots on peat soil (on 24 February 2010). Fertilizer applications with Nitrophoska Blue Special NPK fertilizer at the rate of 100:30:30 were made one week prior to planting. A set of 3 replicated plots with fertilizer application was allocated while another 3 sets devoid of fertilizer application served as control. Watering of the plots was made twice daily, one in the morning and the other in the late afternoon using a fine rose fitted water hose. No weeds were allowed to grow in the plots during experimentation (Fig. 2.8).

The experiment was repeated on paddy soil of the Jawa series at MARDI Station, Tanjung Karang in 26 October 2010.

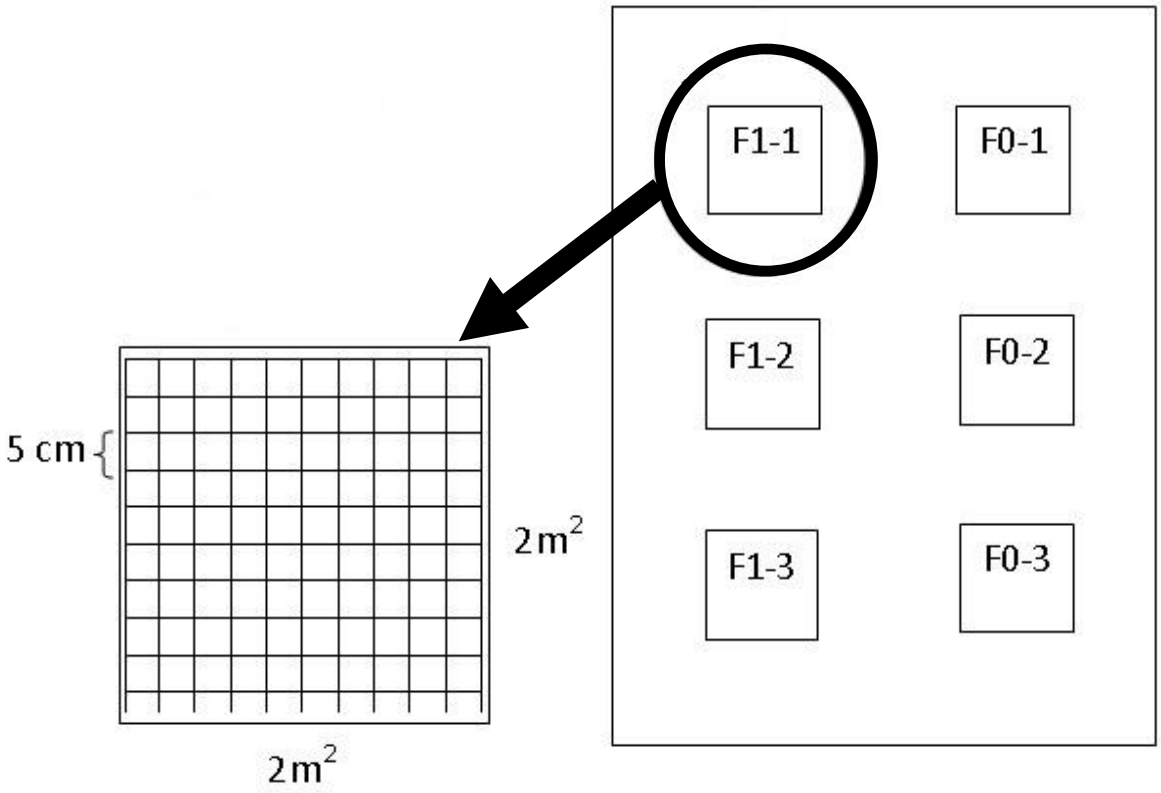

Fig. 2.8 Experimental design and quadrat arrangement at MARDI Research Station, Jalan Kebun, Selangor, Malaysia. Key: F0 = No fertilizer application; F1 = NPK applied.

2.2.4 Field census of ramet population fluxes, subterranean rhizomes, rhizome length and their precise locations of emergence

The number of emerged aerial ramets and their relative positions in the 5cm x 5 cm micro-grids within the 2m x 2m macro-grids were recorded weekly for 24 weeks for each replicated mother plant or plot. These emerged ramets were then grouped according to their time of emergence as weekly cohorts and labeled as such in different colures to denote their distinct or different time of emergence. In the event of death of any of the cohorts, they were likewise recorded at weekly recordings and their positions were marked accordingly. Jointed maps of emerged ramets for each corresponding mother plant were constructed at weekly basis, again marked in different colures. Eventually, at the end of experimentation, maps of ramets emergence (natality) and death (mortality) and probable jointed rhizome maps for each replicated mother plant were generated. The maps of the resultant populations and their corresponding data were utilized to model and analyzed the aerial ramets population fluxes and dynamics of *S. grossus.* The details of such analyses and assessments forms the body of Chapter 4 (pp. 226 - 240).

As for the assessment on the time-mediated ramification and growth of sub-terranean rhizomes of *S. grossus* and spatial dynamics, the aerial plant parts were dismembered leaving the rhizomes intact. The soils were subjected to powerful rose of water to expose the subterranean rhizomes. These jointed rhizomes generated from each mother plant were mapped and their lengths were measured, and compared with the probable maps described earlier. The growth of rhizome at weekly basis (based on the probable maps), spatial dynamics of rhizomes and their growth for the 24 weeks of experimentation were analyzed to generate architectural models of subterranean

rhizomes of *S. grossus.* The detailed analyses of those jointed rhizomes and the architectural models that were generated are presented in Chapter 5 (pp. 284 - 294).

2.2.5 Plant height, leaf number per ramet (plant) and phenology of ramet populations

For each replicated mother plant or plot, a set of 15 emerged aerial ramets were selected for plant height measurement at weekly basis. The number of leaves that were produced per ramet was also recorded, again at weekly basis until the end of experimentation. The results of leaf number per ramet of matured *S. grossus* plants are presented in Chapter 3 (pp. 155 - 163).

As for the phenology recordings, the time of emergence of each inflorescence for each surviving emerged ramet in each plot were noted up to the end of experimentation.

2.2.6 Determination of physico-chemical characteristics of fertilized and unfertilized peat and paddy soils and nutrient status of matured *Scirpus grossus* plants

After 24 weeks of growth peat and paddy soil samples from Jalan Kebun and Tanjung Karang, respectively, were taken for physico-chemical analysis. The soil samples were sent to a laboratory in the Malaysian Agriculture Research and Development Institute (MARDI) for analysis. The analyses focused on the major elements, moisture, total nitrogen and soil pH and moisture.

The results of nutrient status analysis of matured *S. grossus* plants are presented in Chapter 3 (p. 180).

2.2.7 Pot experiment: Effect of water depth and different concentration of fertilizer application on the growth of *Scirpus grossus*

Paddy soil of Jawa series taken from Tanjung Karang of been placed in the lower part of pots at depth of 20 cm. While the top part for water depth with 4 levels of water depth (D1 = 0 cm water depth (control); D2 = 5 cm; D3 = 10 cm; D4 = 20 cm) by making some holes at the required level. In the same experiment different fertilizer concentrations were applied. Four levels of NPK fertilizer concentrations (F2, F3, F4, F5), were used with F0 as control, and F2 = 50 g/500 ml; F3 = 75 g/750 ml, F4 = 100 g/1000 ml, F5 = 125 g/1250 ml. Each young ramet of *S. grossus* was planted in the center of the pots measuring 20x 40x cm in size, on paddy soil type from the MARDI Station of Tanjung Karang. A set of 3 replicates were allocated (R1, R2, R3), encompassing 60 plots in a randomized complete block design (RCBD) (Fig. 2.9).

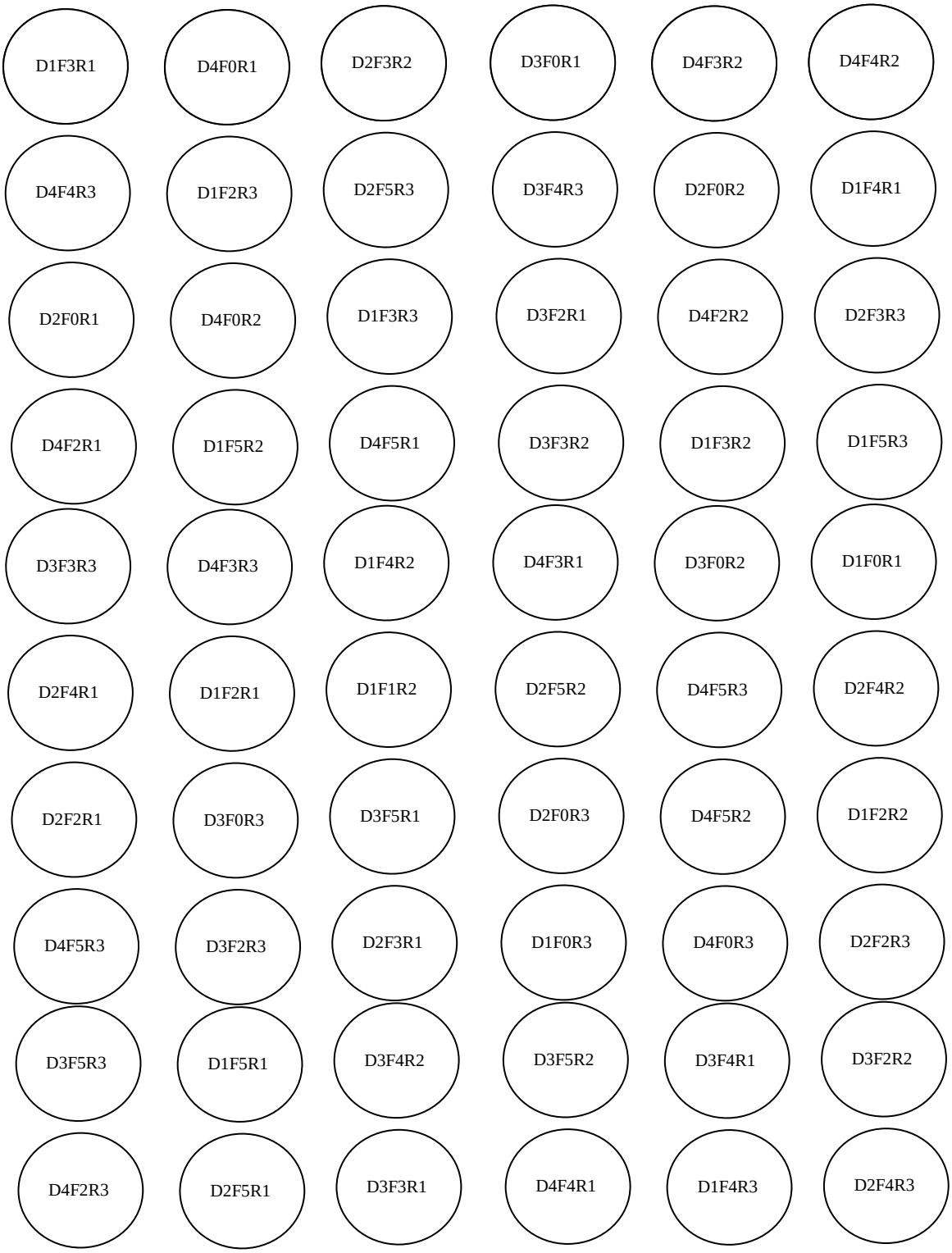

Fig. 2.9 Experimental design and treatment combinations of pots with different water depths and different concentrations of fertilizer application on *Scirpus grossus* D1 (control)(0 cm), D2 (5 cm), D3 (15 cm), D4 (20 cm); F0 (control)(without fertilizer), F2 (50g/500 ml), F3 (75g/750 ml), F4 (100g/1000 ml), F5 (125g/1250 ml); R, replicates.

2.2.8 Data Analysis

The data of population fluxes of ramets, inflorescence number and height plants were transformed to $\log^{+1}$ or log prior to statistical analysis and subjected to ANOVA and Tukey's HSD tests wherever appropriate, using the SAS Computer Programs. Further analyses were made to determine the significance of planting in fertilized soil and unfertilized soils, planting in different soils (peat and paddy soils) and weekly differences in the rate of increase or recruitment of any parameter, e.g. leaf number, rhizome length, ramet number, mortality number, plant height, flower number by regressing the recruitment values of the $\log^{+1}$ or log of transformed data against time. The relative rates of increase or recruitment for each appropriate parameter were calculated using the equation:

$$R = log_e \ N_2 \ - log_e \ N_1 / (t_2 - t_1)$$

where R= relative rate of increase or recruitment of the values (N_1, N_2) of each parameter at t_1 *and* t_2, respectively.

In all experiments, ANOVA and Tukey's HSD tests were carried out to compare treatment means. In first set of experiments the results were subjected to one-way ANOVA and Tukey's HSD tests for fertilizer application and timing factors from the 1st week to the 24th weeks. Subsequently two-way ANOVA was employed comparing fertilizer application with timing factors. In second set of experiments one-way ANOVA and Tukey's HSD tests was used for fertilizer application concentrations, water depths and timing factors from the 1st week to the 16th weeks. Two way ANOVA was used to compare fertilizer application concentrations and water depths with timing factors. Similar analyses have been used in many previous studies (Baki, 1986 &1988; Ministry of Forestry and Range, 2007; Juan *et al.*, 2010; Levi *et al.* 2011).

RESULTS AND DISCUSSION

2.3.1 Field experiments

2.3.1.1 Aerial ramet dynamics and general clonal growth patterns of *S. grossus* in grown in fertilized and unfertilized peat and paddy soils

Scirpus grossus reiterated by subterranean rhizomatous growth and branches from a single mother plant producing different-age cohorts. It is through this rhizomatous growth at the nodes that aerial ramets proliferate above ground displaying phalanx (*sensu stricto* Baki 1986) growth strategy in concordat with lateral proliferation of rhizomes through soil layers or lattices in search of space for further exploration and intake of nutrients in nutrient pools. It is not possible at this juncture to speculate whether there is some forms of trade-offs between the production of aerial ramets (as a means of resource capture of light and above- ground space) and the subterranean growth of rhizomes and roots through soil lattices (as a means of lateral exploitation and exploration of space, water and nutrients). From previous studies by John L. Harper and his school (Sagar 1974; Harper 1977; Baki 1986, 1988; Faravani and Bakar 2007), among others, indicated a mechanism generally known as the "integration of modules" prevailed in modular plants, where trade-offs occurs among modules in the partitioning of resources, made more readily available to young growing points (leaves, roots, etc.) compared with older modules, to enable the former to grow in anticipation of resource capture for ensuing growth.

These latter display of growth strategy mimicking the guerilla (*sensu stricto* Baki 1986) tactics of the clandestine communist guerilla army in search of the enemy during the war of attritions comparable to the conventional warfare among phalanx of armies of tactical divide. In actual field situations, phalanxes or phalanges of aerial

ramets of *S. grossus* when growing sympatrically with crops or other weed species are actually competing for space, while the subterranean rhizomes are competing for space in the soils in search for nutrients.

As shown in Table 2.1, the highest clonal growth rate in peat soil, in general, was between 10-18 weeks. The best period of clonal growth in fertilized peat soil was at week 12 while in unfertilized soil it was at week 13. An outcome similar to the results reported previously by Baki (1988) (for increased in plant number between weeks). At the end of the 24 weeks of study period, when the plots are completely filled with *S. grossus* plants, the total average gross number of emerged ramets in fertilized soils were 126.75 ramets m^{-2} and 117.83 ramets m^{-2} in unfertilized soils, respectively, although these readings were not significantly different at $p<0.05$. (HSD tests). The values per week at end of 24^{th} week were 0.00, 0.29, 1.42, 1.67, 2.67, 4.92, 7.17, 10.50, 15.92, 26.17, 38.33, 50.92, 64.08, 74.17, 86.83, 95.50, 102.17, 105.25, 107.67, 109.83, 113.08, 116.83, 117.83, 117.83, respectively, in unfertilized soils. The parallel figures for fertilized were 0.33, 0.75, 1.08, 1.67, 2.92, 4.42, 7.58, 11.17, 17.67, 26.75, 36.25, 53.92, 69.25, 81.42, 91.25, 101.67, 110.17, 115.67, 117.25, 120.17, 124.67, 125.17, 126.25, 126.75, respectively.

As shown in Table 2.2, the highest clonal growth rate in paddy soil, in general, was between 10-18 weeks. The best period of clonal growth in fertilized soils was at week 15 while in unfertilized soils it was at week 14. At the end of the 24 weeks of study period, the total average gross number of emerged ramets in fertilized soils was 97.08 ramets m^{-2} and 83.67 ramets m^{-2} in unfertilized soils, and these were not significantly different at $p<0.05$, (HSD tests). The values per week at end of 24^{th} week were 0.00, 0.08, 0.33, 0.50, 0.83, 1.00, 1.58, 2.33, 3.75, 4.92, 11.08, 15.83, 18.08, 34.42, 43.67, 48.00, 51.58, 54.67, 60.00, 63.92, 69.92, 74.67, 78.92, 83.67,

respectively, in unfertilized soils, while in fertilized soils these were 0.00, 0.75, 1.33, 2.00, 2.58, 3.92, 5.25, 6.75, 8.25, 10.58, 19.00, 25.83, 29.42, 43.83, 59.42, 64.92, 69.33, 72.33, 77.00, 80.83, 84.08, 88.08, 93.17, 97.08, respectively.

Mortality of aerial ramets set in 8 weeks after planting of the mother plant with eventual plunging of net populations in the ensuing weeks up to the 24th week, especially in the unfertilized plots. Mortality of aerial ramets also set in the fertilized plots, albeit at a slower rates and lower in numbers (Figs. 2.10a and 2.10b). The numbers of dead ramets recorded were 30.33 ramets in unfertilized peat soils and 8.67 ramets in fertilized soils after 24 weeks (Table 2.1), while the net population of ramets were 87.5 ramets m^{-2} in unfertilized soils was significantly lower at p>0.05, (HSD tests) *vis-a-vis* 116.08 ramets m^{-2} in fertilized soils (Figs. 2.10a and 2.10b), indicating higher turn-over of aerial ramets in the unfertilized peat soils compared with those in the non-fertilized plots. At the end of experimentation, scores of aerial ramets still emerged outside the 2 m x 2 m plots, but these were not taken into account in the analysis. The values per week at end of 24th week were 0.00, 0.00, 0.00, 0.00, 0.25, 0.25, 0.25, 0.25, 0.75, 1.25, 1.50, 1.92, 1.92, 2.83, 3.92, 5.42, 7.75, 9.08, 9.83, 13.17, 15.83, 18.33, 22.25, 30.33, respectively, in unfertilized soils, while in fertilized soils these were 0.00, 0.00, 0.00, 0.00, 0.25, 0.25, 0.25, 0.33, 0.33, 0.58, 0.75, 0.83, 1.00, 2.42, 2.83, 3.83, 5.00, 5.08, 5.17, 5.25, 5.50, 5.50, 6.67, 8.67, respectively. The differences in the mortality number of *S. grossus* were not significantly different in F1 and F0 plots in Jalan Kebun in the first 14th week after planting, but show significantly different in the ensuing weeks.

At 24th week of experimentation, the mortality number recorded was 8.58 ramets m^{-2} in unfertilized paddy soils and 5.67 ramets m^{-2} in fertilized paddy soils (Table 2.2), while the net population were 75.09 ramets m^{-2} in unfertilized soils and 91.41 ramets m^{-}

^{2} in fertilized soils (Figs. 2.10a and 2.10b), and were significantly different from each other at $p>0.05$, (HSD tests). Mortality set in on 10th week at 0.17 ramets m^{-2} in unfertilized soils. The parallel values for the ensuing weeks were 0.50, 0.83, 1.33, 1.33, 1.92, 2.17, 2.75, 3.25, 3.58, 4.42, 4.92, 5.83, 7.00, 8.58 ramets m^{-2}, while in fertilized set in on 11th week at 0.08 ramets m^{-2} . The parallel values for the ensuing weeks were 0.17, 0.33, 0.42, 0.58, 0.67, 1.08, 1.42, 1.75, 2.33, 3.17, 4.25, 4.92, 5.67 ramets m^{-2}. The differences in the mortality number of ramets of *S. grossus* in F1 and F0 plots were not significantly different from each other in Tanjung Karang in the first 23 weeks after planting, but show significant values from each other only in the 24th weeks.

In this experiments two factors that were investigated are 2 fertilizers (with and without) and time factor of 24 weeks (after transplanting) on the plant population characters of interest which are plant number, mortality number and net population.

ANOVA was carried out on each variable follows the split-plot model with fertilizer as the main-plot and time factor in weeks as the subplot. The main-plot treatments follow the CRD design model.

For the three variables gross population, mortality number and net population data was first transformed before analysis. Gross no and net population used log of the variable plus one, while mortality no used the square root of the variable plus one. Results of the ANOVA are summarised in Appendices 4 and 5 (pp. xlvii and xlviii). The table highlighted the effects (significant or otherwise) on each of the factors tested and their interactions.

Application of fertilizer had a significant impact on the overall growth performance of *S. grossus*, particularly with regard to mortality number, but not on the overall gross populations and net populations as well. The addition of NPK fertilizer at

a concentration of (100:30:30) had a significant effect on clonal growth with dramatically increase in the population fluxes of the weed. Similarly, the NPK fertilizer reduced mortality of ramets, and this was similar to the findings of Baki (1988), who studied the structural demography and growth patterns of *S. grossus* under paddy soils of the Bungor series.

Interestingly, the insignificant week-to-week increment in gross population and net population number of ramets in F0and F1 plots, generally 17-18 weeks onwards after planting explains the increasingly limited space available for further growth within the 2m x 2 m perimeter plots. Sometimes, ecologist, like economists would see these phenomena as the law of diminishing returns operating on population number with time, with or without additions of fertilizer. It is well documented in many previous studies that the application NPK fertilizer can improve the clonal growth of crop plants, such as wheat and many others (Ognjanovic *et al.* 1994; Biberdzic *et al.* 2011).

In studies on the effects N and P dynamics on the growth of root, results have shown a significant increase in root growth patterns as affected by N and P in Holm oak (*Quercus ilex*) (Juan *et al.* 2010). Allocation patterns of shoot N and K, and root K were unaffected by both the rate and timing of autumn fertilizer applications although shoot P concentration of autumn fertilized plants significantly increased, and root P concentration was enhanced by applying fertilizer at either the highest rate or during early autumn. This revealed a different nutrient dynamics during autumn that was dependent on the specific nutrients and plant components. These results confirmed that root growth potential was positively correlated to nursery root P concentration (Juan *et al.* 2010). These studies show that the application of fertilizers had a positive impact on plant growth.

Some of the above mentioned studies used bare root stock where no limits to root expansion exists. These studies reported that root growth responded positively to additional fertilizer supply during autumn (Oliet *et al.* 2009b). Another study has shown that decreasing N and K in the soil to the lowest rates of fertilization, had a significant impact only when N was reduced (Boivin *et al.* 2004). Significant differences in N concentration by fertilizer applicationsfor root, but not for shoot, indicated that N uptake and storage in roots responded to different concentrations of N in the growing media, but N translocation to shoots was almost nil as no differences in N concentration, based on treatments, were observed (Folk and Grossnickle 2000). While for P, its concentration in roots was significantly affected by fertilizer rate and timing, with the highest concentration values observed when maximum fertilizer rate applied in early autumn (Folk and Grossnickle 2000).

Low N- and K- uptake capacity must be explained mostly by a weak sink demand. N uptake has been shown to be greatly dependent upon ontogeny (Imsande and Touraine 1994), and lower N uptake amounts are expected during hardening (Silla and Escudero 2003). In other studies, the relationship between fertilizer applications and root growth potential (RGP) it has been shown that P concentration in roots is positively correlated to new root proliferation (Oliet *et al.* 2009b).

Previous studies have also shown a significant effect of fertilizer application on root growth potential, although this effect could not be associated to any nutrient in particular. Mortality after planting showed a significant and negative relationship with root P concentration (Villar-Salvador *et al.* 2004; Molla *et al.* 2006), namely that fewer seedlings died when roots had a higher P concentration. Findings from this study agree with those of Villar-Salvador *et al.* (2004). The response of root growth and survival after planting to P concentration in roots has been observed in earlier studies with other

Mediterranean species, like *Acacia salicina* and *Pinus halepensis* (Oliet *et al.* 2005, 2009a) and also with Holm oak (Sardans *et al.* 2006a). However, the mechanisms by which P could promote root extension after planting are still debated (Folk and Grossnickle 2000; Landis and Van Steenis 2004).

Higher N levels in spring have also been shown to accelerate bud burst of *Picea abies* (Floistad and Kohmann 2004). The time duration of the study has shown that a longer study time will reveal more impacts and results on plants and herbs **(**Oliveira *et al.* 2011). In a study conducted over 8 years, during which the use of several different tests improved the quality of NPK fertilizers, the results showed that fertilizers decreased mortality rate and prolonged the survival of plants **(**Oliveira *et al.* 2011). James *et al.* (2010) reported that in 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. Their study was conducted between 2000 and 2002, whereby field experiments were carried out to evaluate the effect of sawdust mulch and NPK fertilizer at 20:10:10 fertilizer rates on weed flora composition and growth in plantain/cocoyam intercrop. Elsewhere sawdust mulch promoted the formation of a high composition (81%) of broadleaved/ herbaceous weeds which were more abundant in mulched plots, while the graminaceous species (19%) were mostly found in bare plots (Hol 2010). In another study, during a two year period between 2005 and 2006 NPK fertilizer applications on the growth and yield of wheat (*Triticum aestivum*), there was 137% increase in shoot dry biomass over control in wheat crops supplied with the recommended dose of nitrogen-phosphorus-potassium (NPK) fertilizer, where there was 96% increase in grain yield over the control (Javaid and Shah 2010). We could argue that increased N application would have resulted in the higher ramer populations (equivalents of bud bursts at the cambium levels) of *S. grossus.* Serial anatomical

studies under binocular microscope would show this cambium burst to produce more ramets following N-application in the sedge. These studies serve another line of research under developmental biology of weeds or crops under investigations.

Table 2.1 Mean gross and mortality number and net populations of ramets (m^{-2}) of *Scirpus grossus* plants grown in fertilized (F1) and unfertilized (F0) peat soil at MARDI Research Station, Jalan Kebun, Selangor, Malaysia [#]

Weeks after planting	Ramets gross number		Ramets mortality number		Net population	
	F0	F1	F0	F1	F0	F1
1	0.00 g	0.33 j	0.00 i	0.00 g	0.00 l	0.33 l
2	0.92 g	0.75 ij	0.00 i	0.00 g	0.92 k	0.75 k
3	1.42 fg	1.08 hi	0.00 i	0.00 g	1.42 jk	1.08 jk
4	1.67 fg	1.67 ghi	0.00 i	0.00 g	1.67 jk	1.67 jk
5	2.67 efg	2.92 ghi	0.25 i	0.25 g	2.42 ij	2.67 ij
6	4.92 efg	4.42 ghi	0.25 i	0.25 g	4.67 hi	4.17 hi
7	7.17 defg	7.58 fghi	0.25 i	0.25 g	6.92 gh	7.33 gh
8	10.50 defg	11.17 efgh	0.25 i	0.33 g	10.25 fg	10.84 fg
9	15.92 cdef	17.67 defgh	0.75 hi	0.33 g	15.17 ef	17.34 ef
10	26.17 bcdef	26.75 cdefg	1.25 ghi	0.58 g	24.92 de	26.17 de
11	38.33 abcde	36.25 bcdef	1.50 fghi	0.75 g	36.83 cd	35.50 cd
12	50.92 abcd	53.92 abcde	1.92 efghi	0.83 fg	49.00 bcd	53.09 bcd
13	64.08 abcd	69.25 abcd	1.92 efghi	1.00 efg	62.16 abc	68.25 abc
14	74.17 abc	81.42 abc	2.83 defghi	2.42 efg	71.34 ab	79.00 ab
15	86.83 abc	91.25 ab	3.92 cdefgh	2.83 defg	82.91 ab	88.42 ab
16	95.50 ab	101.67ab	5.42 cdefg	3.83 defg	90.08 a	97.84 a
17	102.17 ab	110.17 ab	7.75 bcdef	5.00 defg	94.42 a	105.17 a
18	105.25 a	105.67 ab	9.08 bcde	5.08 cdef	96.17 a	100.59 a
19	107.67 a	117.25 ab	9.83 abcde	5.17 cde	97.84 a	112.08 a
20	109.83 a	120.17 ab	13.17 abcd	5.25 bcd	97.66 a	114.92 a

Table 2.1 (*continued*)

21	113.08 a	124.67 a	15.83 abc	5.50 abc	97.25 a	119.17 a
22	116.83 a	125.17 a	18.33 ab	5.50 ab	98.50 a	119.67 a
23	117.83 a	126.25 a	22.25 ab	6.67 a	95.58 a	119.58 a
24	117.83 a	126.75 a	30.33 a	8.67 a	87.50 a	118.08 a

[#]Figures in a column with same lowercase letters are not significantly different at $p<0.05$ (HSD tests).

Table 2.2 Mean gross and mortality number and net populations of ramets (m^{-2}) of *Scirpus grossus* plants grown on fertilized (F1) and unfertilized (F0) paddy soil at MARDI Research Station, Tanjung Karang, Selangor, Malaysia[#]

Weeks after planting	Ramets gross number		Ramets mortality number		Net population	
	F0	F1	F0	F1	F0	F1
1	0.00 j	0.00 m	0.00 m	0.00 m	0.00 l	0.00 l
2	0.00 j	0.75 l	0.00 m	0.00 m	0.08 k	0.75 k
3	0.00 j	1.33 kl	0.00 m	0.00 m	0.33 jk	1.33 jk
4	0.00 j	2.00 jk	0.00 m	0.00 m	0.50 ij	2.00 ij
5	0.50 ij	2.58 ijk	0.00 m	0.00 m	0.83 hij	2.58 hij
6	1.00 hij	3.92 hij	0.00 m	0.00 m	1.00 ghi	3.92 ghi
7	1.58 ghi	5.25 ghi	0.00 m	0.00 m	1.58 fgh	5.25 fgh
8	2.33 fgh	6.75 fgh	0.00 m	0.00 m	2.33 efg	6.75 efg
9	3.75 fg	8.25 fg	0.00 m	0.00 m	3.58 ef	8.25 ef
10	4.92 f	10.58 f	0.17 lm	0.00 lm	4.42 e	10.58 e
11	11.08 e	19.00 e	0.50 klm	0.08 klm	10.25 d	18.92 d
12	15.83 e	25.83 e	0.83 jkl	0.17 jkl	14.50 d	25.66 d
13	18.08 de	29.42 de	1.33 jk	0.33 jk	16.75 cd	29.09 cd
14	34.42 cd	43.83 cd	1.33 ij	0.42 ij	32.50 bc	43.41 bc
15	43.67 bc	59.42 bc	1.92 hij	0.58 hij	41.50 ab	58.84 ab
16	48.00 abc	64.92 abc	2.17 ghi	0.67 ghi	45.25 ab	64.25 ab
17	51.58 abc	69.33 abc	2.75 fgh	1.08 fgh	48.33 ab	68.25 ab
18	54.67 abc	72.33 abc	3.25 fg	1.42 fg	51.09 ab	70.91 ab
19	60.00 ab	77.00 ab	3.58 ef	1.75 ef	55.58 ab	75.25 ab
20	63.92 ab	80.83 ab	4.42 de	2.33 de	59.00 a	78.50 a

Table 2.2 (*continued*)

21	69.92 ab	84.08 ab	4.92 cd	3.17 cd	64.09 a	80.91 a
22	74.67 ab	88.08 ab	5.83 bc	4.25 bc	67.67 a	83.83 a
23	78.92 ab	93.17 ab	7.00 ab	4.92 ab	71.17 a	88.25 a
24	83.67 ab	97.08 a	8.58 a	5.67 a	75.09 a	91.41 a

[#]Figures in a column with same lowercase letters are not significantly different at $p<0.05$ (HSD tests).

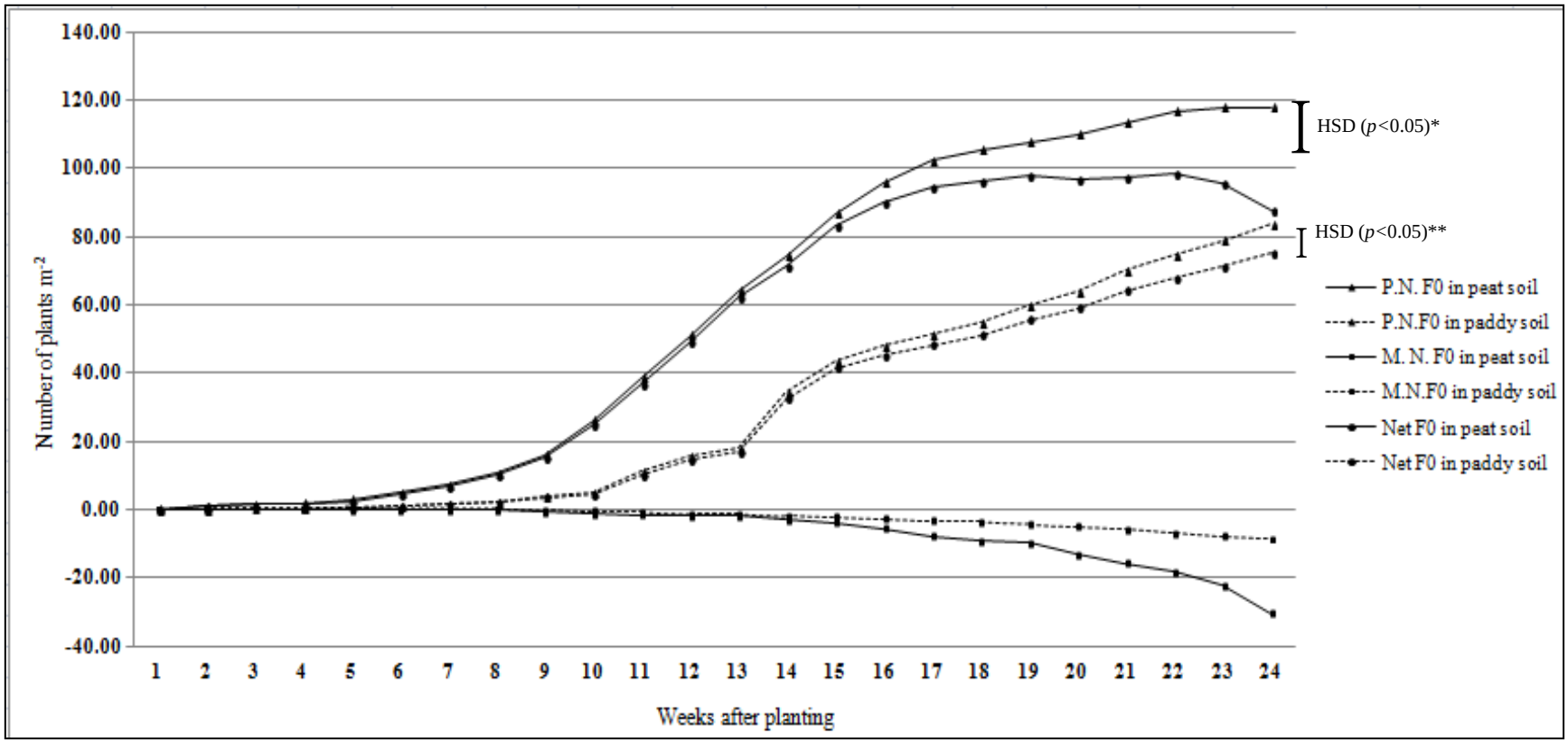

Fig. 2.10a Population fluxes of *Scirpus grossus* grown on unfertilized peat and paddy soils. Natality (▲), Mortality (■), Net population (●).* In peat soil, **In paddy soil.

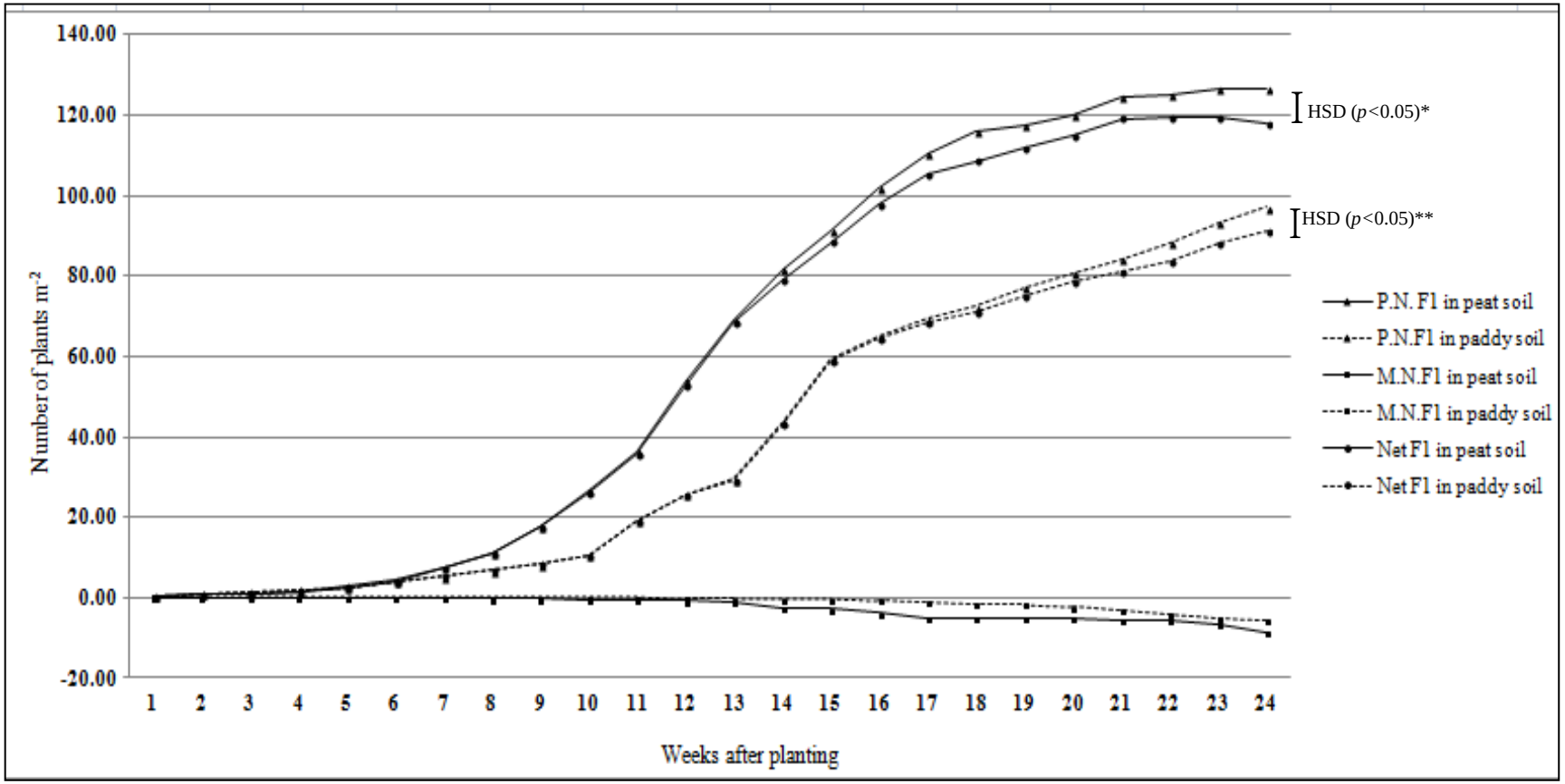

Fig. 2.10b Population fluxes of *Scirpus grossus* grown on fertilized peat and paddy soils. Natality (▲), Mortality (■), Net population (●).* Peat soil, **Paddy soil.

2.3.1.2 Plant height of *Scirpus grossus* grown on fertilized and unfertilized peat and paddy soils

Subsequent recruitment of aerial ramets appeared convergent (Table 2.3 and Fig. 2.11), where the highest average plant (ramet) height in unfertilized peat soils was 161.67 cm while in fertilized peat soils this was 160.67 cm, after 24 weeks of growth. This was not significantly different at $p>0.05$. The highest average plant (ramet) height in the ensuing starting at week 1 were 1.17, 14.00, 18.67, 23.00, 26.17, 28.00, 29.00, 30.67, 31.83, 35.83, 40.00, 43.83, 51.00, 59.67, 75.33, 93.00, 113.67, 124.67, 134.67, 135.00, 141.67, 156.33, 156.33, 161.67 cm, respectively, in unfertilized soils, while in fertilized soils these were 2.67, 11.67, 17.33, 23.50, 26.00, 26.83, 27.17, 29.67, 34.33, 40.67, 50.50, 63.17, 76.67, 92.33, 103.67, 121.33, 128.33, 143.33, 143.33, 143.33, 149.33, 153.00, 157.67, 160.67 cm, respectively.

The results for subsequent recruitment of aerial ramets appeared convergent (Table 2.3 and Fig. 2.11) where the highest mean plant height in unfertilized paddy soils was 172.67 cm, while in fertilized counterparts it was 175.33 cm, not significantly different at $p> 0.05$. The values mean highest average plant (ramet) height per week were 15.33, 17.67, 18.83, 19.67, 23.17, 27.83, 30.83, 34.33, 42.30, 47.67, 55.07, 67.43, 76.67, 101.67, 116.00, 120.67, 127.67, 135.83, 137.83, 142.00, 150.17, 155.33, 163.17, 172.67 cm, respectively, in unfertilized soils, while in fertilized these were 18.83, 21.67, 24.33, 27.83, 31.33, 34.50, 38.83, 48.67, 57.40, 76.00, 82.67, 95.27, 103.47, 118.67, 138.83, 144.33, 147.67, 154.33, 156.33, 158.83, 161.33, 165.67, 169.17, 175.33 cm, respectively. The ANOVA are summarised in Appendices 4 and 5 (pp. xlvii and xlviii).

The continuing increase in plant height can be explained by the phalanx nature of aerial growth of individual ramets although less in number with time but bigger in size of tussocks, all competing for light or the phenomenon of phototropism, This case

is not uncommon in grasses and sedges, or even broadleaves as their growth strategy to maximize exploitation of resources, in this case light and vertical space. (e,g. *Vulpia membranacea* by Watkinson 1975; *Carex acuta*. as observed by White 1984; *Ischaemum rugosum* by Nabi and Jog 1999, *Melastoma malabathricum* by Faravani *et al*. 2008; or *B. juncea* var. Ensabi by Toosi *et al*. 2010).

Table 2.3 Mean plant height (ramet) of *Scirpus grossus* plants grown in fertilized (F1) and unfertilized (F0) peat soil at MARDI Research Station, Jalan Kebun, Selangor, Malaysia, and paddy soil at MARDI Research Station, Tanjung Karang, Selangor, Malaysia[#]

Observation	Plant height (cm)			
Weeks after planting	Peat soil		Paddy soil	
	F0	F1	F0	F1
1	1.17 k	2.67 k	15.33 j	18.83 j
2	14.00 jk	11.67 jk	17.67 j	21.67 j
3	18.67 jk	17.33 jk	18.83 ij	24.33 ij
4	23.00 ijk	23.50 ijk	19.67 ij	27.83 ij
5	26.17 ijk	26.00 ijk	23.17 ij	31.33 ij
6	28.00 ijk	26.83 ijk	27.83 hij	34.50 hij
7	29.00 ijk	27.17 ijk	30.83 hij	38.83 hij
8	30.67 ijk	29.67 ijk	34.33 ghij	48.67 ghij
9	31.83 hijk	34.33 hijk	42.30 fghij	57.40 fghij
10	35.83 hij	40.67 hij	47.67 fghi	76.00 fghi
11	40.00 ghij	50.50 ghij	55.07 efgh	82.67 efgh
12	43.83 ghi	63.17 ghi	67.43 efg	95.27 efg
13	51.00 fgh	76.67 fgh	76.67 def	103.47 def
14	59.67 efg	92.33 efg	101.67 cde	118.67 cde
15	75.33 def	103.67 def	116.00 bcd	138.83 bcd
16	93.00 cde	121.33 cde	120.67 bc	144.33 bc
17	113.67 bcd	128.33 bcd	127.67 abc	147.67 abc
18	124.67 abc	143.33 abc	135.83 abc	154.33 abc
19	134.67 abc	141.33 abc	137.83 abc	156.33 abc
20	135.00 abc	143.33 abc	142.00 abc	158.83 abc
21	141.67 ab	149.33 ab	150.17 ab	161.33 ab
22	156.33 a	153.00 a	155.33 ab	165.67 ab
23	156.33 a	157.67 a	163.17 ab	169.17 ab
24	161.67 a	160.67 a	172.67 ab	175.33 a

[#]Figures in a column with same lowercase letters are not significantly different at $p<0.05$ (HSD tests).

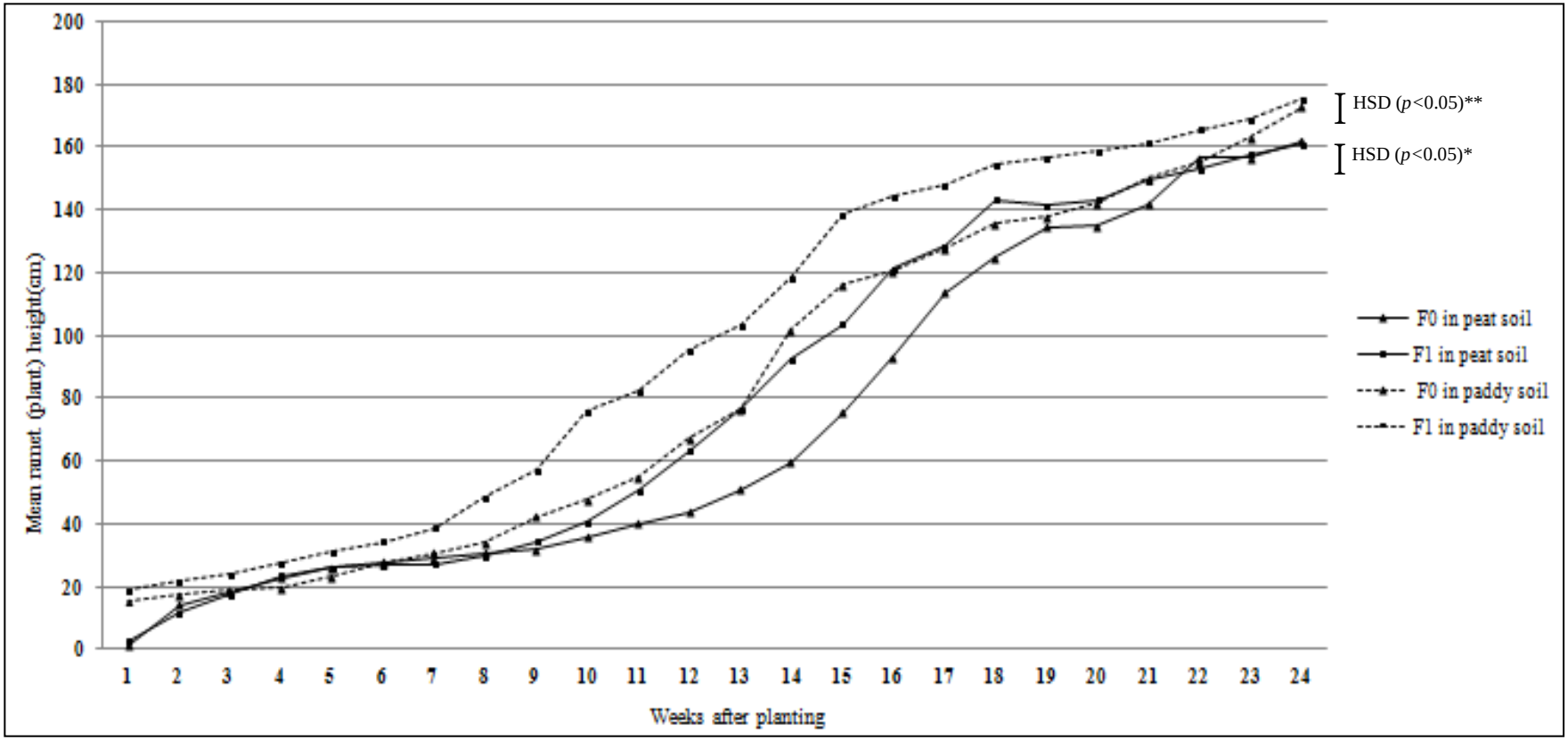

Fig. 2.11 Mean ramet (plant) height of *Scirpus grossus* plants grown on fertilized (F1) and unfertilized (F0) peat soil at MARDI Research Station, Jalan Kebun, Selangor, Malaysia, and paddy soil at MARDI Research Station, Tanjung Karang, Selangor, Malaysia (●).* Peat soil, **Paddy soil.

2.3.1.3 Phenology of *Scirpus grossus* plants on fertilized and unfertilized peat and paddy soils

The NPK fertilizer, which contained 30% of phosphate, is known to boost flowering in plants, increased the flowering number of the weed. A similar observation was reported by Baki (1988) for *S. grossus*. Aerial ramets growing in unfertilized soils started to flower 16 weeks after transplanting, while in fertilized peat soils, *S. grossus* started to flower at week 13. At the end of the 24 weeks study period, the average number of flowering ramets in unfertilized peat soils stood at 38.75 ramets m^{-2} *vis-a-vis* 51.58 ramets m^{-2} for those with fertilizer (Table 2.4 and Fig. 2.12). However, time-mediated measurable differences were observed in the number of flowering ramets between those receiving fertilizers compared with those non-augmented with fertilizer application. It was not significantly different at $p>0.05\%$. Flowring set in on 16^{th} week at 2.67 ramets m^{-2} in unfertilized soils. The parallel values for the ensuing weeks were 7.83, 12.25, 15.92, 20.92, 25.42, 28.92, 35.25, 38.75 ramets m^{-2}, while in fertilized set in on 13^{th} week at 0.17 ramets m^{-2}. The parallel values for the ensuing weeks were 2.08, 5.75, 13.08, 16.83, 20.08, 24.33, 29.83, 36.42, 41.50, 47.00, 51.58 ramets m^{-2}.

In the case of plants growing in unfertilized paddy soils, they started to flower 16 weeks after transplanting, while in fertilized paddy soils, *S. grossus* started to flower at week 13. At the end of the 24 weeks study period, the average number of flowering ramets in unfertilized paddy soils stood at 16.42 ramets m^{-2} *vis-a-vis* 23.67 ramets m^{-2} for those fertilizer application (Table 2.4 and Fig. 2.12). It was not significantly different at $p>0.05\%$. Flowring set in on 11^{th} week at 0.08 ramets m^{-2} in unfertilized soils. The parallel values for the ensuing weeks were 0.16, 0.50, 1.33, 3.83, 5.67, 7.83, 8.83, 9.58, 10.33, 11.25, 12.08, 13.83, 16.42 ramets m^{-2}, while in fertilized set in on 10^{th} week at 0.25 ramets m^{-2}. The parallel values for the ensuing weeks were 0.67, 1.25,

2.58, 4.58, 6.67, 8.50, 10.50, 12.08, 13.50, 14.58, 15.83, 17.50, 19.58, 23.67 ramets m^{-2}. The ANOVA are summarised in Appendices 4 and 5 (pp. xlvii and xlviii).

The results show that the use of fertilizer had impact on the phenology and number of flowering of *S. grossus*. It is well documented in the literature that the addition of N and P to the soil can play an important and significant role in increasing plant growth and development (Levi *et al.* 2011). Kolb *et al.* (2002) reported that the exotic annual weed *Lolium multiflorum* grew at a faster rate and increased its competitive effectiveness more than the perennial native weed *Hordeum brachyantherum* in the presence of N. Abraham *et al.* (2009) also reported that the growth performances of exotic and native plant species, with annual and perennial life histories, increased with N availability and reported species-specific results. Although the effect of P has been less studied than that of N, it has been shown that its deficiency limited the growth of *Bromus tectorum* in the field (Miller *et al.* 2006; Gundale *et al.* 2008; Levi *et al.* 2011) whereby *B. tectorum* tended to invade patches of high P availability (Bashkin *et al.* 2003) because of the high concentrations of both N and P in the soil.

Table 2.4 Mean inflorescence number of *Scirpus grossus* plants grown in fertilized (F1) and unfertilized (F0) peat soil at MARDI Research Station, Jalan Kebun, Selangor, Malaysia, and paddy soil at MARDI Research Station, Tanjung Karang, Selangor, Malaysia. [#]

Observation	Inflorescence number m^{-2}			
Weeks after planting	Peat soil		Paddy soil	
	F0	F1	F0	F1
1	0.00 f	0.00 f	0.00 j	0.00 k
2	0.00 f	0.00 f	0.00 j	0.00 k
3	0.00 f	0.00 f	0.00 j	0.00 k
4	0.00 f	0.00 f	0.00 j	0.00 k
5	0.00 f	0.00 f	0.00 j	0.00 k
6	0.00 f	0.00 f	0.00 j	0.00 k
7	0.00 f	0.00 f	0.00 j	0.00 k
8	0.00 f	0.00 f	0.00 j	0.00 k
9	0.00 f	0.00 f	0.00 j	0.00 k
10	0.00 f	0.00 f	0.00 j	0.25 k
11	0.00 f	0.00 f	0.08 j	0.67 jk
12	0.00 f	0.00 f	0.17 ij	1.25 ij
13	0.00 f	0.17 f	0.50 hi	2.58 hi
14	0.00 ef	2.08 ef	1.33 gh	4.58 gh
15	0.00 def	5.75 def	3.83 fg	6.67 fg
16	2.67 cdef	13.08 cdef	5.67 ef	8.50 ef
17	7.83 bcde	16.83 bcde	7.83 def	10.50 def
18	12.25 bcd	20.08 bcd	8.83 cde	12.08 cde
19	15.92 abc	24.33 abc	9.58 bcd	13.50 bcd
20	20.92 abc	29.83 abc	10.33 bcd	14.58 bcd
21	25.42 ab	36.42 ab	11.25 bc	15.83 bc
22	28.92 ab	41.50 ab	12.08 abc	17.50 abc
23	35.25 a	47.00 a	13.83 ab	19.58 ab
24	38.75 a	51.58 a	16.42 a	23.67 a

[#]Figures in a column with same lowercase letters are not significantly different at $p<0.05$ (HSD tests).

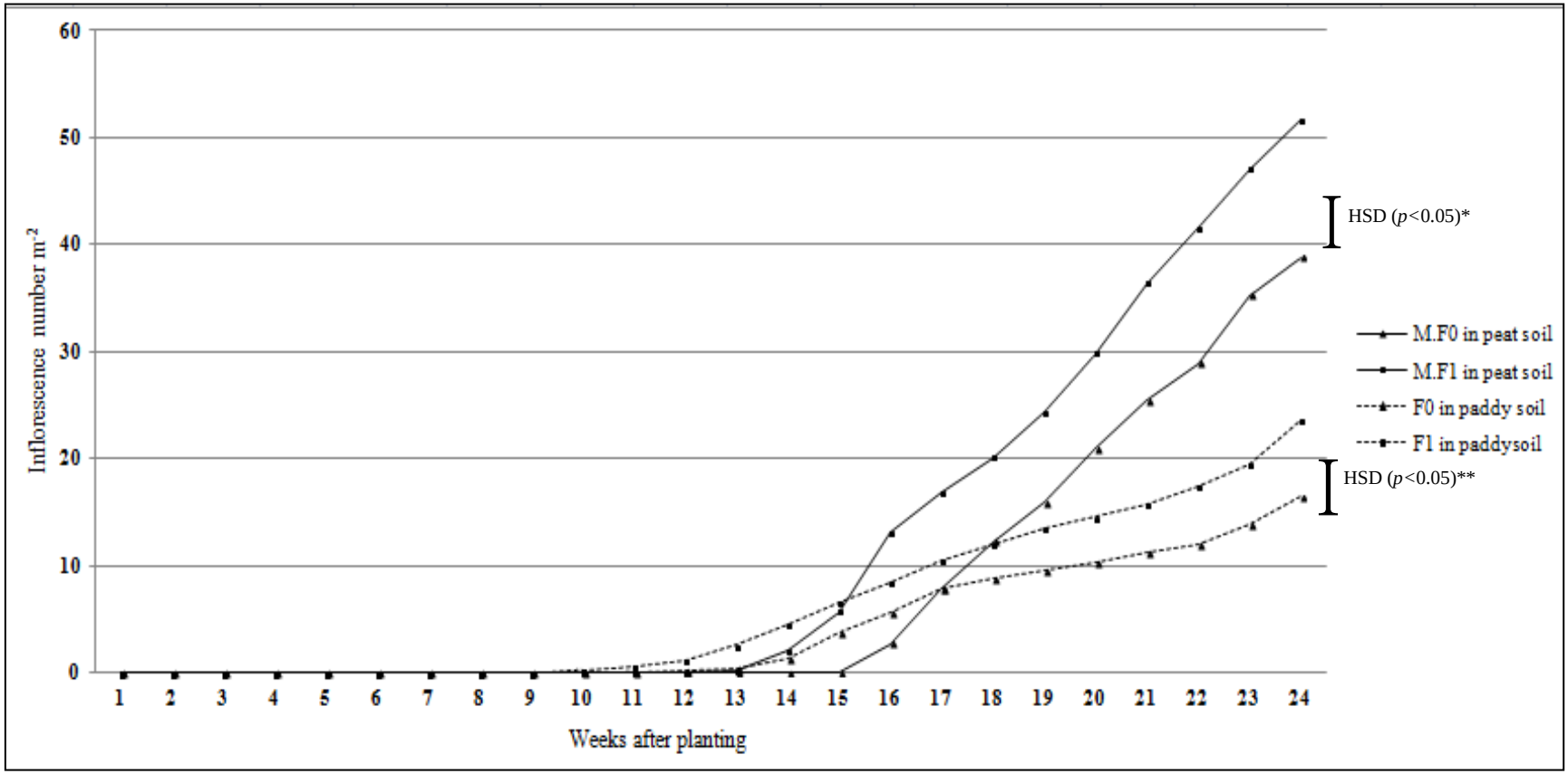

Fig. 2.12 Mean inflorescence number of *Scirpus grossus* plants grown on fertilized (F1) and unfertilized (F0) peat soil at MARDI Research Station, Jalan Kebun, Selangor, Malaysia, and paddy soil at MARDI Research Station, Tanjung Karang, Selangor, Malaysia (●).* Peat soil, **Paddy soil.

2.3.2 Pot Experiment: Effect of water depth and different concentration of fertilizer application on the growth of *Scirpus grossus*

2.3.2.1 Aerial ramet dynamics and general clonal growth patterns of *Scirpus grossus* in grown at different water depths and fertilizer regimes in paddy soil

Scirpus grossus grows in moist soils or under inundated or water-logged conditions. It is these conditions that may impact on the growth performance of this sedge, particularly when subjected to wet and dry soil fluxes or when subjected to different depths of inundation under the natural environment in drainage and irrigation canals, abandoned rice fields, or even as a weed in rice crops. There are evidences from the experiment conducted that plants of *S. grossus* have a remarkable ability to alter their development in response water depth regimes. This phenotypic plasticity allows them to continually adapt to their local environment, a necessity for plants as sessile organisms. For example, devoid of fertilizer application (F0) and not inundated, *S. grossus* plants with mean monthly population counts up to 16 weeks, taken at 4-weekly intervals were as follows: 61.33, 67.33, 75.33, and 117.00 plants m^{-2}. With fertilizer applications, the parallel counts for F2 (64.67, 71.00, 80.33, and 34.33 plants m^{-2}),), F3 (65.33, 72.67, 68.33, and 32.00 plants m^{-2}), F4 (71.67, 72.00, 71.67, 6.33 plants m^{-2}), F5 (79.33, 74.67, 52.00, and 0.00 plants m^{-2}), denoting increased mortality of ramets with increased fertilizer applications.

Irrespective of fertilizer application, a host of environmental cues can be interpreted by *S. grossus* ramets including light, temperature and nutrients, and these inputs are integrated and translated into a range of developmental outputs from shoot elongation, regulation of root gravitropism, altered flowering time, growth cessation of leaves, and bud breaks. In the case of increased water depths, the population increase of

ramets were severely curtailed with parallel increase in mortality (Tables 2.5, 2.6; Fig. 2.14a – Fig. 2.14e).

Ramet mortality of *S. grossus* decreased with the greater depths of the water level. The results are shown in Table 2.6 and Fig. 2.14a, after 16 weeks of ramets mortality readings were as follows; (0 cm depth = 48.33 plants m^{-2}, 5 cm depth = 40.67 plants m^{-2}, 10 cm depth = 40.00 plants m^{-2}, 20 cm depth = 46.00 plants m^{-2}) respectively. All results were significantly different at $p<0.01$ (HSD tests).

Ramet mortality of *S. grossus* decreased with increasing NPK concentrations as shown in the results displayed in Table 2.6 and Figs. 2.14b, 2.14c, 2.14d and 2.14e The mean monthly ramets mortality at the different NPK concentrations were as follows; F0 (48.33, 40.67, 40.00, 46.00 plants m^{-2}), F2 (42.67, 39.67, 33.00, 13.00 plants m^{-2}), F3 (30.00, 31.33, 27.00, 8.33 plants m^{-2}), F4 (26.00, 30.00, 23.67, 2.67 plants m^{-2}) and F5 (16.33, 14.00, 11.67, 1.67 plants m^{-2}), generally in decreasing trends with higher NPK concentrations. The results were significantly different at $p<0.01$ (HSD tests). The ANOVA are summarised for all results in Appendix 6 (pp. xlvix).

Table 2.5 and Fig. 2.13a showed the clonal growth of *S. grossus* continued until 16 weeks for all the treatments at 0 cm, 5 cm, 10 cm, and 20 cm water depths, taken at monthly intervals. As can be seen in Fig. 2.18 the results illustrated the effect of water depth level on clonal growth, where plant number increased with increasing water depths. After 16 weeks of clonal growth the readings were as follows; (0 cm depth = 61.33, 5 cm depth = 67.33, 10 cm depth = 75.33, 20 cm depth = 117.00) respectively. All results were significantly different at $p<0.01$ (HSD tests). A similar study with similar results, on the growth and biomass of *Myriophyllum aquaticum* was reported by Wersal and Madsen (2011). It has also been reported previously that biomass allocation

to emergent shoots was greater when *M. aquaticum* was grown in water depths of less than 0.5 m (Sytsma and Anderson 1993a).

As shown in Table 2.5 and Figs. 2.13b, 2.13c, 2.13d and 2.13e the results showed that between the different NPK concentrations used, the highest plant number that emerged was after 16 weeks in all the F0, F2, F3, F4, F5 treatments. The results also showed that plant number and growth rate showed an increasing trend with increasing NPK concentrations, at water depths of 5 and 10 cm. The monthly population counts with regard to mean plant number up to 4 months, were as follows: F0 (61.33, 67.33, 75.33, and 117.00 plants m^{-2}), F2 (64.67, 71.00, 80.33, and 34.33 plants m^{-2}), F3 (65.33, 72.67, 68.33, and 32.00 plants m^{-2}), F4 (71.67, 72.00, 71.67, 6.33 plants m^{-2}), F5 (79.33, 74.67, 52.00, and 0.00 plants m^{-2}). It should be noted that for plants growing under water depths of 20 cm, the F2, F3, F4 and F5 fertilizer concentrations, caused a marked reduction in mean plants m^{-2}. The results were significantly different at $p<0.01$ (HSD tests).

Flooding events with partial to complete inundation of plants, can have severe effects on the abundance and distribution of wild plant species in natural ecosystems (Franco and Silvertown 1996; Voesenek *et al.* 2004) and on the productivity of crops (Bailey-Serres and Voesenek 2008). An aqueous environment is stressful to terrestrial plants because of 10^4 -fold slower rates of gas diffusion compared with air. The consequent limited exchange of gases such as CO_2 and O_2 dramatically limits photo-synthesis and respiration, respectively. Ultimately, an imbalance between the production and consumption of carbohydrates coupled with an accumulation of toxic metabolic end products proves fatal for most non-adapted terrestrial plants (Bailey-Serres and Voesenek 2008). Some plants have evolved traits to avoid and ameliorate the problems associated with complete submergence. Rapid acceleration of shoot

elongation growth enables some plant species to outgrow flood waters and thus maintain fast gas exchange and re-establish aerial photosynthesis (Bailey-Serres and Voesenek, 2008). Employment of an effective flooding survival strategy, either quiescence or escape, is thus crucial for plant competitive vigour and survival. Physiological studies have revealed that the gaseous plant hormone ethylene, which rapidly accumulates within flooded organs attributable to the reduced gas exchange underwater, is one of the main drivers regulating both strategies. Indeed, ethylene is considered to be the most reliable and earliest indicator of the flooded status of a plant (Voesenek and Sasidharan 2013) because, as also shown here, internal oxygen levels can be quite high in submerged photosynthetic tissues, especially when sufficient illumination is present (Mommer *et al.* 2007). Ethylene can either stimulate or suppress growth, depending on the species (Voesenek *et al.* 1993a; Pierik *et al.* 2006; Nagai *et al.* 2010), and was also shown to be relevant in submergence survival strategies of rice (*Oryza sativa)* (Xu *et al.* 2006; Hattori 2009). It is a long shot to speculate which of the above-listed mechanisms that would have played their roles either individually or in concert on the growth patterns displayed by *S. grossus* when subjected to different depths of inundation and different fertilizer regimes. Notwithstanding, these drivers that may regulate growth strategies of *S. grossus* will serve venues for further research on the scourge.

There is no concrete evidence from the experimental data that *S. grossus* instituted such escape or quiescence strategy to increase population number of ramets, enhanced biomass production or increased plant height with increased water depth. In fact, with increased depths of inundation, population number of ramets decreased, irrespective of fertilizer regimes (Tables 2.5, 2.6). Such an escape strategy is energetically expensive because it requires considerable amounts of carbohydrates to

fuel the rapid growth toward the water surface (Setter and Laureles 1996). Therefore, escape growth is beneficial only if the flooding event is not too deep to outgrow and if the growth investment is rewarded by restored gas exchange and aerial photosynthesis as the leaves emerge above the water surface (Pierik *et al.*, 2009). If the water surface is not reached, survival of escape-driven plants is severely reduced. Deep or transient flood conditions favour species with growth-suppressing behavior upon submergence by limiting carbohydrate consumption and elongation growth, the so-called quiescent strategy (Fukao *et al.* 2006; Akman *et al.* 2012). This situation seems prevalent *S. grossus* population subjected to increased depth of flooding or inundation, where mortality rates were increased accordingly.

In this study, *S. grossus* was subjected to varying depths of water levels up to 20 cm and a flood duration of 16 weeks. The plants responded quickly to inundation. However *S. grossus* plants grown in deeper water levels were unable to grow to the water surface or emerged as such. This observation was similar to the study on *M. aquaticum*, but the response might have been different, if the duration of flooding was reduced to a shorter period (Cook and Johnson 1968), suggesting that this species does not grow well under sustained deep flooded conditions. Light transmittance was 25% in all treatments, which was sufficient to promote submerged plant growth. However, in this study a significant decline in biomass of *S. grossus* and plant length was observed as water levels increased, suggesting that submerged leaves alone cannot sustain growth for long periods of time.

The decrease in growth rates of *S. grossus* at water depth of 20 cm could be due to several reasons. Firstly it has been reported that qptimal photosynthetic rates in *M. aquaticum* occur in its emergent form and therefore it cannot remain as a submerged plant for long periods of time as the photosynthetic rate of the submerged leaves will

not be sufficient to support plant growth in the long term (Salvucci and Bowes 1982). Secondly, it is contended that submerged plant growth is transient and only utilised for short overwintering periods, times of reduced light and temperature (Sytsma and Anderson 1993a), or to survive disturbances in the growing environment. Prolonged exposure to adverse growing conditions will result in reductions in growth and eventually plant mortality. Thirdly as has been suggested in one study, the presence of algae leads to reduced hydrocarbon content, and works as a light insulator and thus prevents the growth of weed (Deng *et al.* 2012). Similar conditions of heavy growth of algae may have helped to reduce the growth of *S. grossus* in our experiments.

Table 2.5 Mean plant number of ramets (m^{-2}) of *Scirpus grossus* plants grown under different NPK concentrations and water depths on paddy soil in Universiti Putra Malaysia, Serdang, Selangor, Malaysia[# *]

F0 (Control)				
Weeks after Planting	Water depth (cm)			
	D1	D2	D3	D4
1	0.33 g	0.67 i	0.33 g	0.33 i
2	2.67 f	4.00 h	3.33 f	3.33 h
3	7.00 f	7.00 g	6.67 f	6.00 gh
4	13.00 e	12.67 f	15.00 e	10.00 g
5	27.00 d	24.67 e	26.00 de	20.67 f
6	35.00 cd	40.00 d	35.67 cd	39.67 e
7	36.33 bcd	40.67 d	37.67 bcd	44.33 de
8	37.00 bcd	42.00 d	38.67 abcd	51.67 cde
9	38.67 bcd	43.33 d	40.67 abcd	59.67 bcde
10	42.67 abcd	46.33 cd	44.67 abcd	65.67 bcde
11	45.67 abcd	50.67 cd	47.33 abcd	73.00 abcd
12	50.00 abcd	55.00 bcd	50.33 abcd	77.00 abc
13	52.00 abc	58.00 abcd	52.67 abc	80.33 abc
14	56.33 ab	62.67 abc	62.67 abc	96.67 ab
15	58.67 a	64.67 ab	72.67 ab	112.67 a
16	61.33 a	67.33 a	75.33 a	117.00 a
F2				
Weeks after Planting	Water depth (cm)			
	D1	D2	D3	D4
1	0.00 f	0.33 e	0.33 f	0.00 a
2	2.67 e	3.00 de	3.00 ef	2.00 a
3	5.67 d	4.33 cde	4.33 def	2.33 a
4	8.67 cd	9.00 bcde	9.67 cde	1.33 a
5	26.33 bc	20.67 abcd	21.33 bcd	1.00 a
6	29.33 ab	26.33 abc	29.33 abc	1.67 a
7	30.00 ab	30.00 abc	30.67 abc	2.33 a
8	31.67 ab	34.00 ab	33.00 abc	3.67 a
9	33.33 ab	39.33 ab	36.33 abc	4.00 a
10	41.00 ab	45.00 ab	44.67 ab	8.67 a
11	44.67 ab	50.33 ab	53.33 ab	15.00 a
12	51.67 ab	57.33 ab	59.67 ab	16.67 a
13	53.00 ab	63.33 a	66.00 a	18.67 a
14	58.00 a	67.33 a	71.00 a	23.33 a
15	63.00 a	69.33 a	78.00 a	32.67 a

Table 2.5 (*continued*)

16	64.67 a	71.00 a	80.33 a	34.33 a
		F3		
Weeks after Planting		Water depth (cm)		
	D1	D2	D3	D4
1	0.33 d	2.00 e	0.33 k	0.00 b
2	3.00 c	5.33 de	2.33 j	0.00 b
3	7.67 c	7.67 cd	4.33 ij	0.00 b
4	15.00 c	19.00 bc	5.67 hij	0.33 ab
5	29.00 b	35.67 ab	7.67 ghi	0.33 ab
6	36.00 ab	43.67 ab	11.00 fgh	1.00 ab
7	36.33 ab	45.00 ab	14.00 efg	2.67 ab
8	37.67 ab	47.33 ab	16.67 def	2.67 ab
9	39.33 ab	48.33 ab	20.33 cdef	3.00 ab
10	44.33 ab	53.33 a	28.00 bcde	7.33 ab
11	48.67 ab	57.33 a	36.00 abcd	11.00 ab
12	53.33 ab	61.67 a	43.00 abc	13.00 ab
13	54.33 ab	64.00 a	49.67 ab	14.33 ab
14	60.00 a	66.33 a	58.33 ab	25.33 a
15	63.67 a	70.00 a	65.00 a	29.33 a
16	65.33 a	72.67 a	68.33 a	32.00 a
		F4		
Weeks after Planting		Water depth (cm)		
	D1	D2	D3	D4
1	0.00 j	0.00 f	1.33 g	0.67 a
2	3.00 i	3.00 e	4.67 fg	2.33 a
3	8.33 h	7.00 e	6.33 ef	2.33 a
4	15.67 g	15.00 d	9.67 def	2.00 a
5	27.33 f	23.33 c	12.00 cdef	3.67 a
6	39.67 e	37.33 bc	26.00 bcde	3.67 a
7	40.67 e	38.67 b	27.00 bcde	3.67 a
8	42.00 de	39.67 ab	28.33 bcd	4.33 a
9	44.00 cde	41.67 ab	30.67 abcd	4.33 a
10	45.00 cde	45.00 ab	38.00 abc	3.67 a
11	50.00 bcde	47.33 ab	45.00 ab	3.33 a
12	54.67 abcd	49.67 ab	51.67 ab	3.67 a
13	56.67 abc	53.67 ab	54.33 ab	3.67 a

Table 2.5 (*continued*)

14	62.67 ab	64.33 ab	63.00 a	5.33 a
15	68.00 a	69.33 ab	67.33 a	5.67 a
16	71.67 a	72.00 a	71.67 a	6.33 a
		F5		
Weeks after Planting		Water depth (cm)		
	D1	D2	D3	D4
1	1.00 e	2.00 f	0.00 h	0.33 b
2	4.33 d	5.00 ef	1.33 h	2.00 b
3	7.67 c	7.67 e	1.33 gh	2.00 ab
4	16.00 c	15.67 de	1.33 gh	1.00 ab
5	31.67 b	28.67 cd	2.00 fg	0.67 ab
6	38.00 ab	36.33 bcd	3.33 efg	0.67 ab
7	38.33 ab	37.67 abc	5.00 efg	0.67 ab
8	38.67 ab	40.00 abc	6.67 def	0.67 ab
9	40.67 ab	42.00 abc	9.67 cde	0.67 ab
10	47.00 ab	48.00 abc	15.00 bcd	0.67 a
11	50.33 ab	53.00 abc	21.33 abc	0.33 a
12	55.33 a	59.33 ab	27.33 ab	0.33 a
13	62.33 a	64.67 ab	33.67 ab	0.33 a
14	68.33 a	69.00 ab	40.67 a	0.00 a
15	75.67 a	73.00 ab	47.33 a	0.00 a
16	79.33 a	74.67 a	52.00 a	0.00 a

[#]Figures in a column with same lowercase letters for each fertilizer concentration and each water depth are not significantly different at $p<0.01$ (HSD tests).
*F0 (control) (without fertilizer); F2 (50g/500 ml); F3 (75g/750 ml); F4 (100g/1000 ml); F5 (125g/1250 ml).

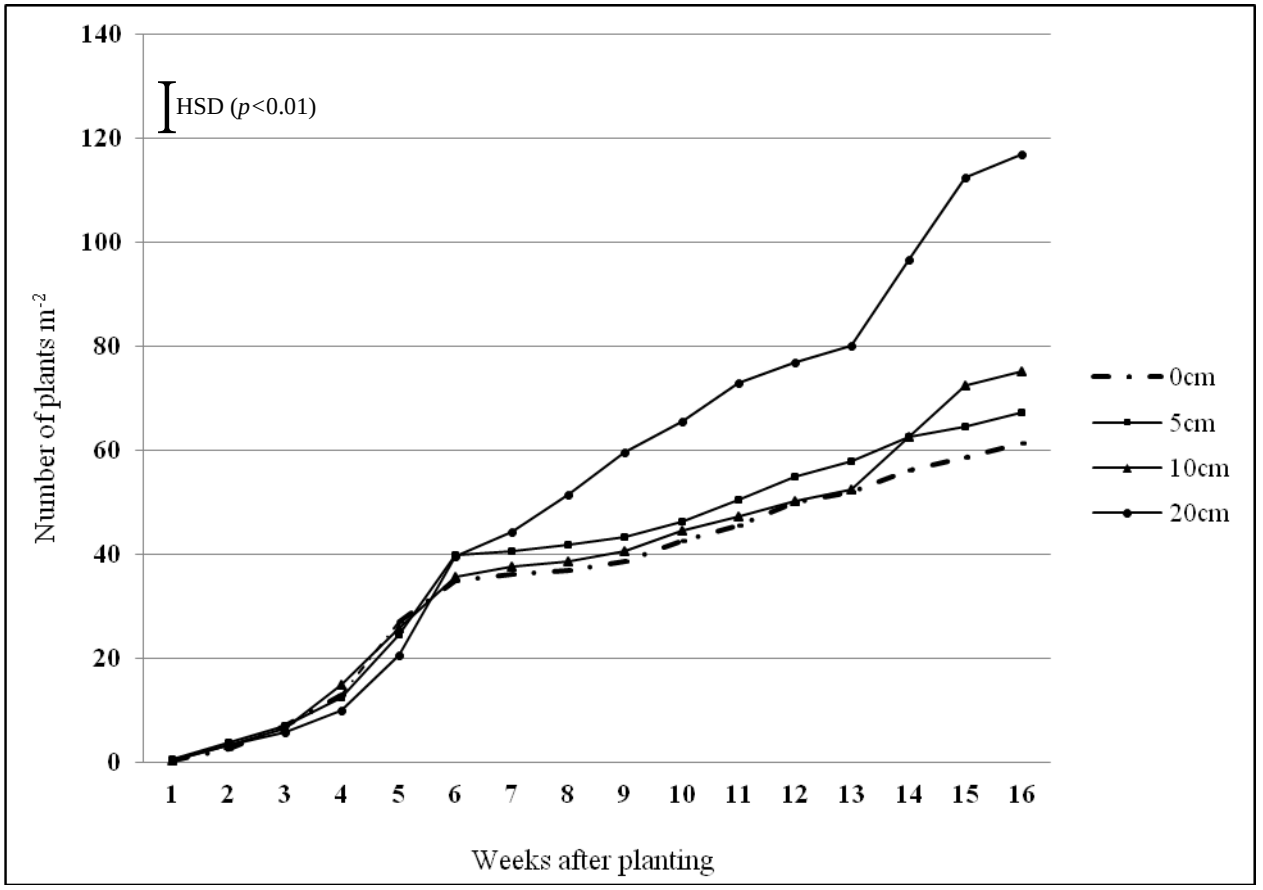

Fig. 2.13a Plant number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), without NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

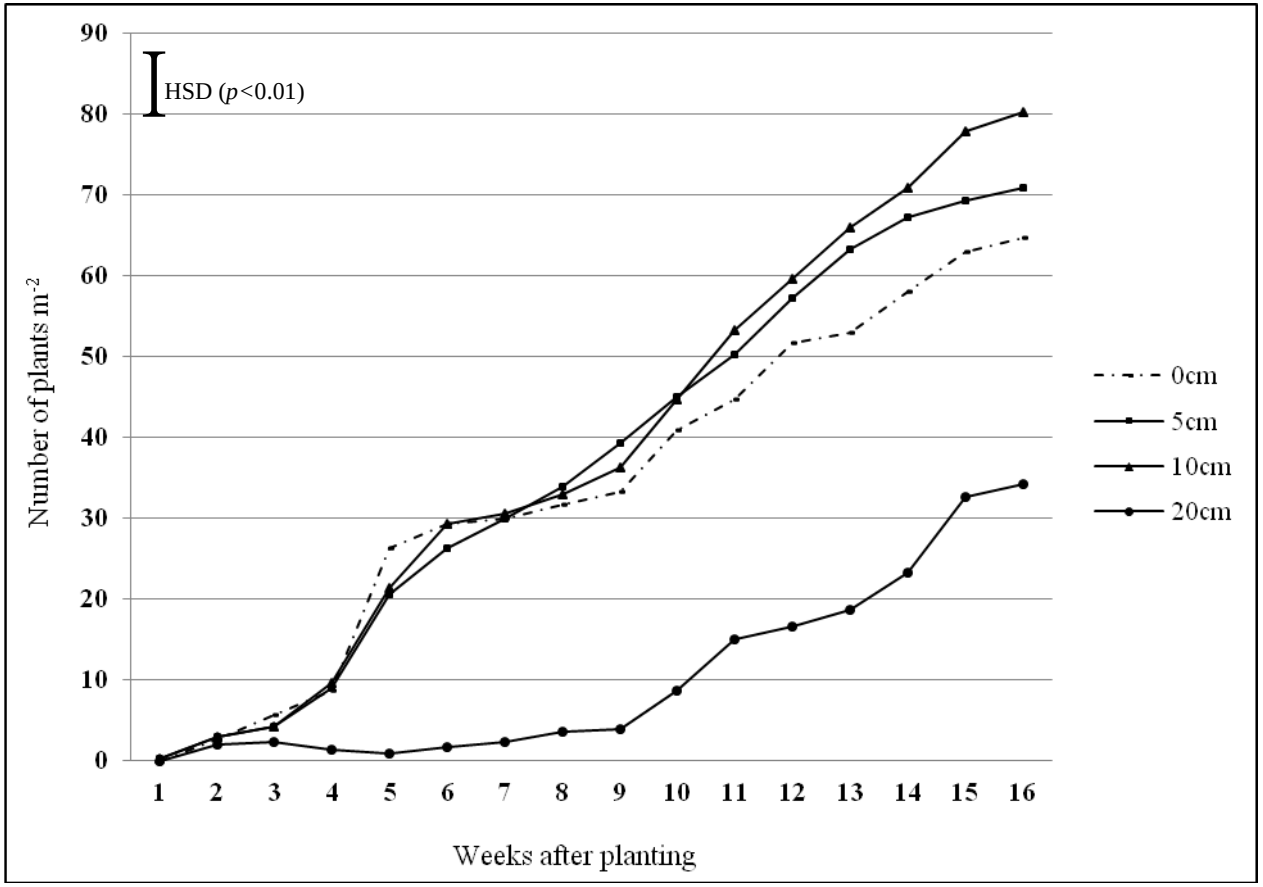

Fig. 2.13b Plant number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 50 g/ 500 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

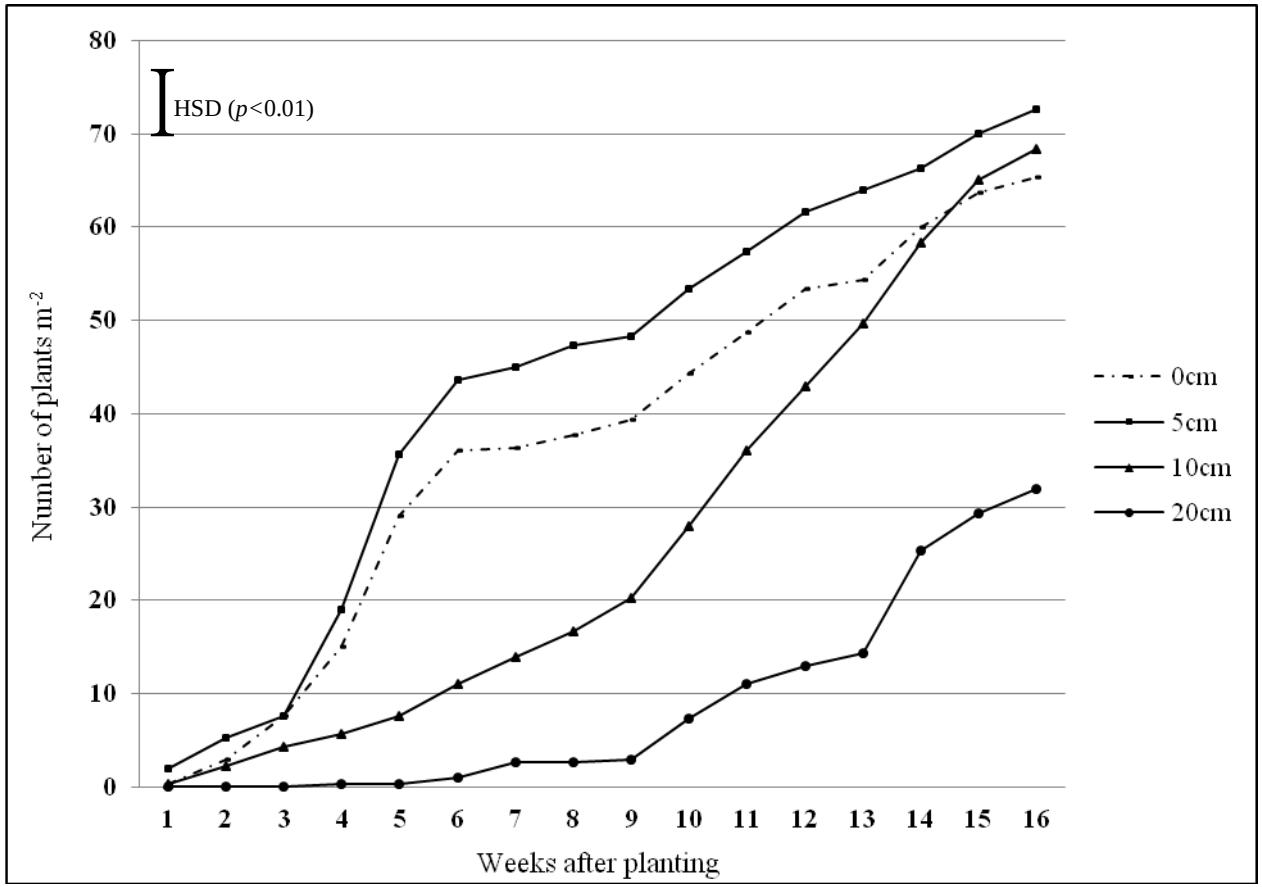

Fig. 2.13c Plant number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 75 g/ 750 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

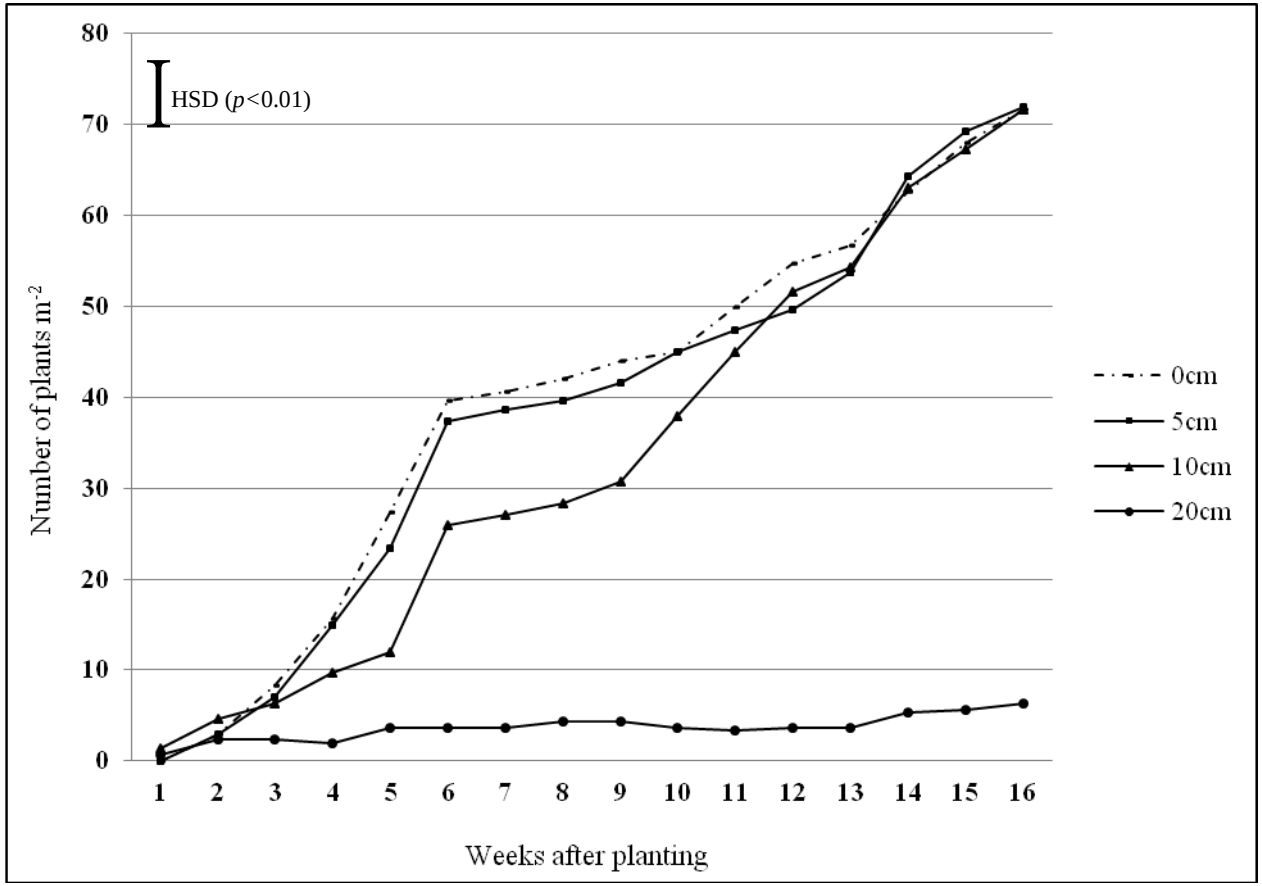

Fig. 2.13d Plant number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 100 g/ 1000 ml NPK application in paddy soils in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

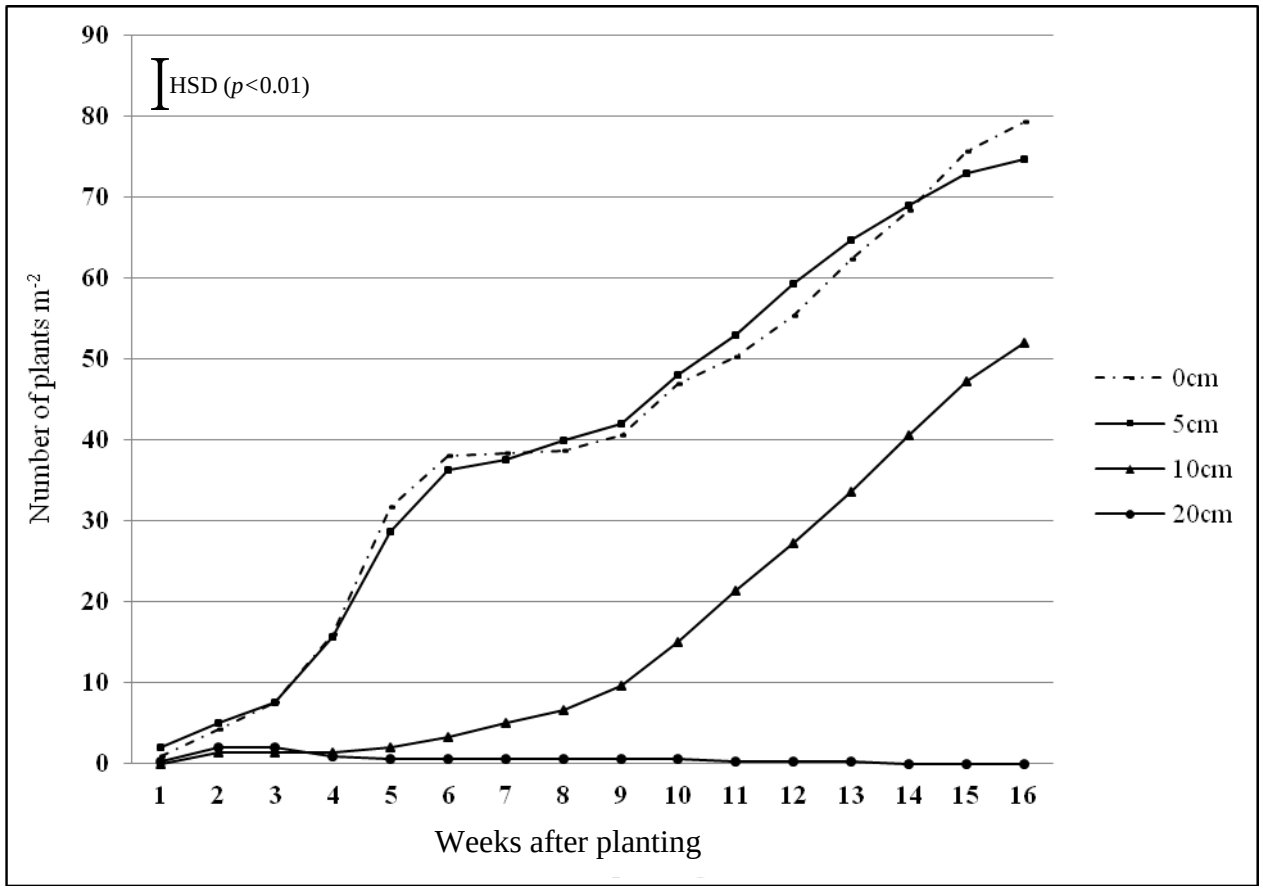

Fig. 2.13e Plant number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 125 g/ 1250 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

Table 2.6 Mean mortality number of ramets (m^{-2}) of *Scirpus grossus* plants grown under different NPK concentrations and water depths in paddy soil in Universiti Putra Malaysia, Serdang, Selangor, Malaysia[# *]

F0 (Control)				
Weeks after Planting	Water depths (cm)			
	D1	D2	D3	D4
1	0.00 g	0.00 j	0.00 h	0.00 l
2	0.00 g	0.00 j	0.00 h	0.00 l
3	0.00 g	0.00 j	0.00 h	0.00 l
4	0.00 g	0.67 j	0.00 h	0.00 l
5	0.00 g	2.33 ij	1.00 h	1.00 kl
6	0.33 g	4.33 hi	2.33 gh	2.67 jk
7	1.67 g	6.67 gh	4.67 fgh	5.33 ij
8	4.67 fg	9.67 fg	8.33 efg	8.67 hi
9	10.00 ef	12.00 fg	10.67 def	11.67 gh
10	15.67 de	15.00 ef	15.33 cde	16.00 fg
11	21.33 cd	20.33 de	19.33 bcd	19.00 ef
12	26.67 bcd	25.33 cd	23.33 bc	23.67 de
13	32.67 abc	29.00 bcd	27.00 abc	27.33 cd
14	39.00 ab	33.33 abc	30.00 ab	33.00 bc
15	42.67 a	38.67 ab	34.33 ab	39.00 ab
16	48.33 a	40.67 a	40.00 a	46.00 a
F2				
Weeks after Planting	Water depths (cm)			
	D1	D2	D3	D4
1	0.00 j	0.00 k	0.00 h	0.00 a
2	0.00 j	0.00 k	0.00 h	0.00 a
3	0.00 j	0.00 k	0.00 h	0.00 a
4	0.00 j	0.00 k	0.00 h	1.00 a
5	2.33 i	0.33 k	0.00 h	1.33 a
6	8.00 h	2.33 j	0.67 h	1.33 a
7	11.67 g	4.00 ij	2.33 g	2.33 a
8	15.00 fg	6.67 hi	3.33 g	3.33 a
9	19.00 ef	9.00 gh	7.00 f	4.00 a
10	22.33 de	11.67 fg	9.67 e	5.33 a
11	26.33 cd	14.33 ef	12.33 e	6.33 a
12	29.33 c	18.00 de	15.67 d	7.67 a
13	32.67 bc	22.33 cd	19.33 c	9.00 a
14	37.33 ab	28.00 bc	24.67 b	10.33 a
15	40.00 a	34.33 ab	28.33 b	10.67 a

Table 2.6 (*continued*)

16	42.67 a	39.67 a	33.00 a	13.00 a
		F3		
Weeks after Planting		Water depths (cm)		
	D1	D2	D3	D4
1	0.00 h	0.00 i	0.00 h	0.00 c
2	0.00 h	0.00 i	0.00 h	0.00 c
3	0.00 h	0.00 i	0.00 h	0.00 c
4	0.00 h	0.00 i	0.00 h	0.00 c
5	0.00 h	0.00 i	0.00 h	0.00 c
6	0.67 h	0.33 i	0.33 h	0.00 c
7	1.67 gh	3.00 hi	1.67 gh	0.00 c
8	4.00 fg	5.00 gh	2.67 gh	0.33 c
9	7.67 ef	7.33 fg	4.00 fg	1.00 bc
10	10.67 de	10.33 ef	7.67 ef	1.33 bc
11	14.33 cd	13.67 de	9.33 de	2.00 abc
12	16.67 bc	16.67 cde	12.33 cde	4.00 abc
13	19.67 bc	20.33 bcd	15.67 bcd	5.00 abc
14	23.33 ab	24.00 abc	19.67 abc	6.33 ab
15	27.67 a	27.00 ab	22.67 ab	7.33 ab
16	30.00 a	31.33 a	27.00 a	8.33 a
		F4		
Weeks after Planting		Water depths (cm)		
	D1	D2	D3	D4
1	0.00 e	0.00 j	0.00 i	0.00 c
2	0.00 e	0.00 j	0.00 i	0.00 c
3	0.00 e	0.00 j	0.00 i	0.00 c
4	0.33 e	0.00 j	0.00 i	0.33 bc
5	1.33 e	0.00 j	0.33 hi	0.33 bc
6	2.67 de	2.00 i	1.33 ghi	0.33 bc
7	3.67 de	4.00 h	2.67 fghi	0.67 abc
8	5.00 cde	6.67 h	4.00 fghi	1.00 abc
9	6.67 cde	9.67 g	5.33 efgh	1.00 abc
10	8.67 bcde	12.00 fg	6.67 defg	1.33 abc
11	10.33 abcde	15.33 ef	9.00 cdef	1.67 abc
12	13.33 abcd	17.67 de	12.00 bcde	2.33 ab
13	16.33 abc	20.67 cd	14.33 abcd	2.33 ab
14	18.67 ab	23.67 bc	17.00 abc	2.67 a

Table 2.6 (*continued*)

15	22.33 ab	26.33 ab	20.00 ab	2.67 a
16	26.00 a	30.00 a	23.67 a	2.67 a
		F5		
Weeks after Planting		Water depths (cm)		
	D1	D2	D3	D4
1	0.00 f	0.00 f	0.00 g	0.00 a
2	0.00 f	0.00 f	0.00 g	0.00 a
3	0.00 f	0.00 f	0.00 g	0.00 a
4	0.00 f	0.00 f	0.00 g	0.33 a
5	0.00 f	0.00 f	0.00 g	1.00 a
6	0.00 f	0.00 f	0.00 g	1.33 a
7	0.00 f	0.00 f	0.33 fg	1.33 a
8	0.33 ef	0.00 f	0.33 fg	1.67 a
9	1.00 ef	0.67 f	1.00 efg	1.67 a
10	2.00 def	1.67 ef	2.00 defg	1.67 a
11	3.67 cdef	4.00 de	3.33 cdef	1.67 a
12	5.67 bcde	5.67 cd	4.00 cde	1.67 a
13	8.00 abcd	7.67 bcd	5.33 bcd	1.67 a
14	10.33 abc	10.33 abc	7.33 abc	1.67 a
15	12.67 ab	12.33 ab	9.67 ab	1.67 a
16	16.33 a	14.00 a	11.67 a	1.67 a

[#]Figures in a column with same lowercase letters for each fertilizer concentration and each water depth are not significantly different at $p<0.01$ (HSD tests).
*F0 (control)(without fertilizer); F2 (50g/500 ml); F3 (75g/750 ml); F4 (100g/1000 ml); F5 (125g/1250 ml).

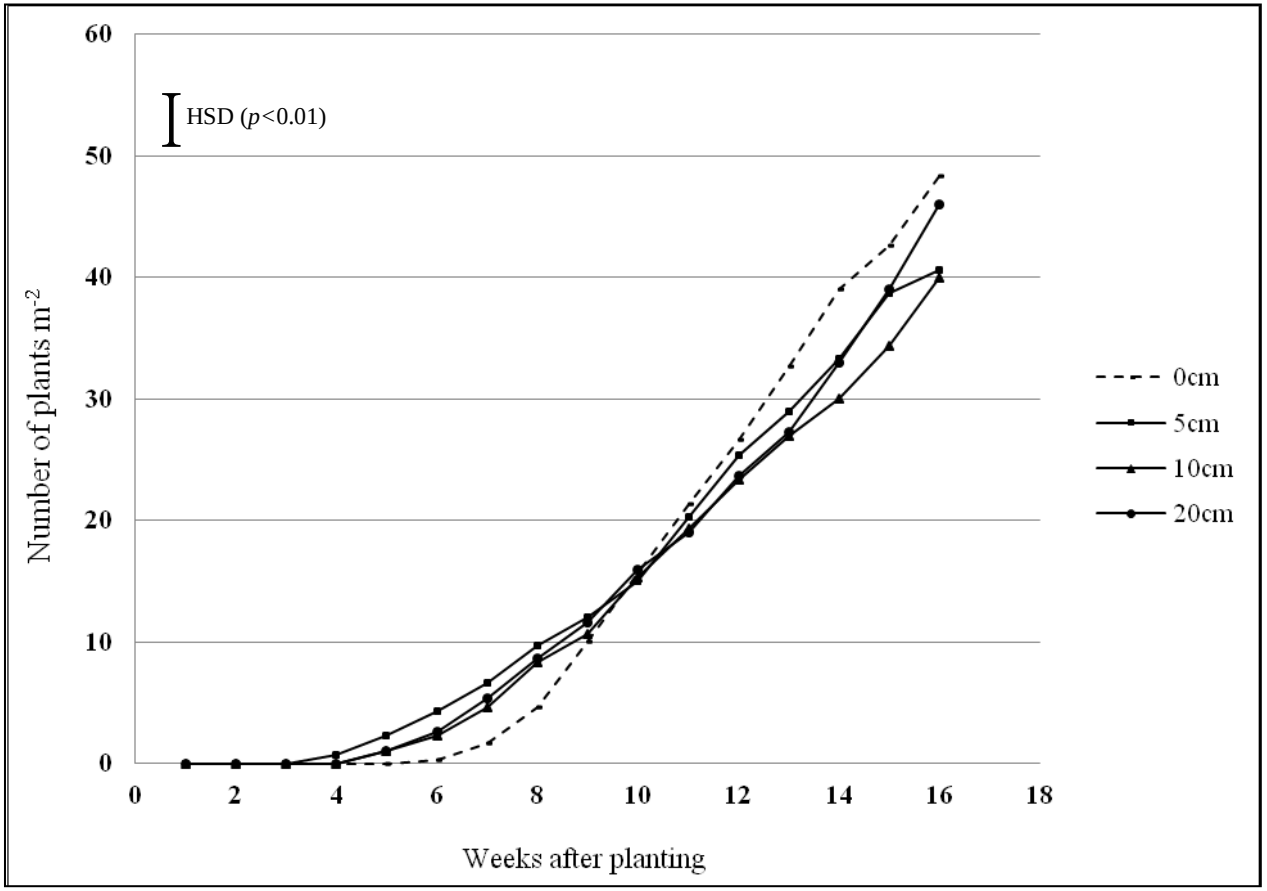

Fig. 2.14a Mortality number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), without addition of NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

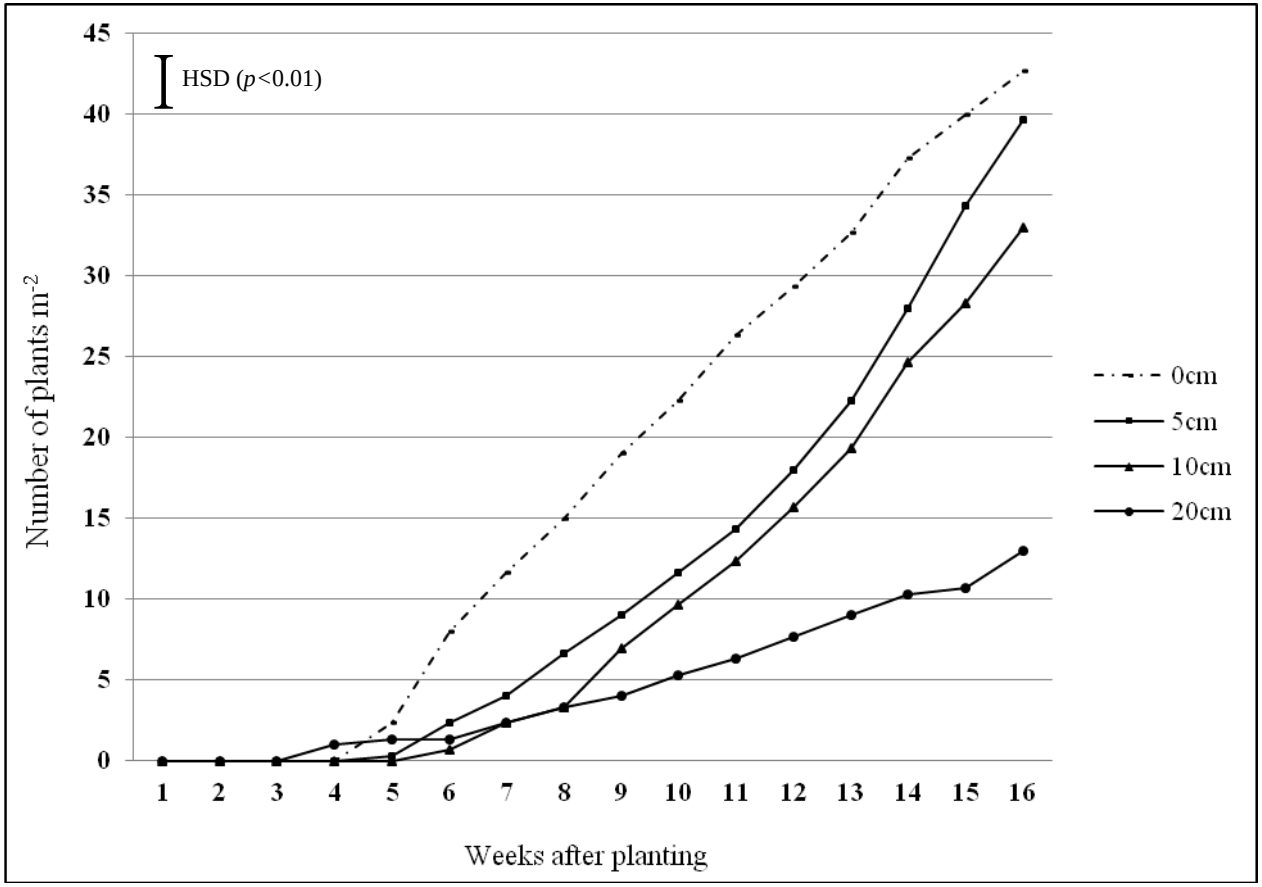

Fig. 2.14b Mortality number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 50 g/ 500 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

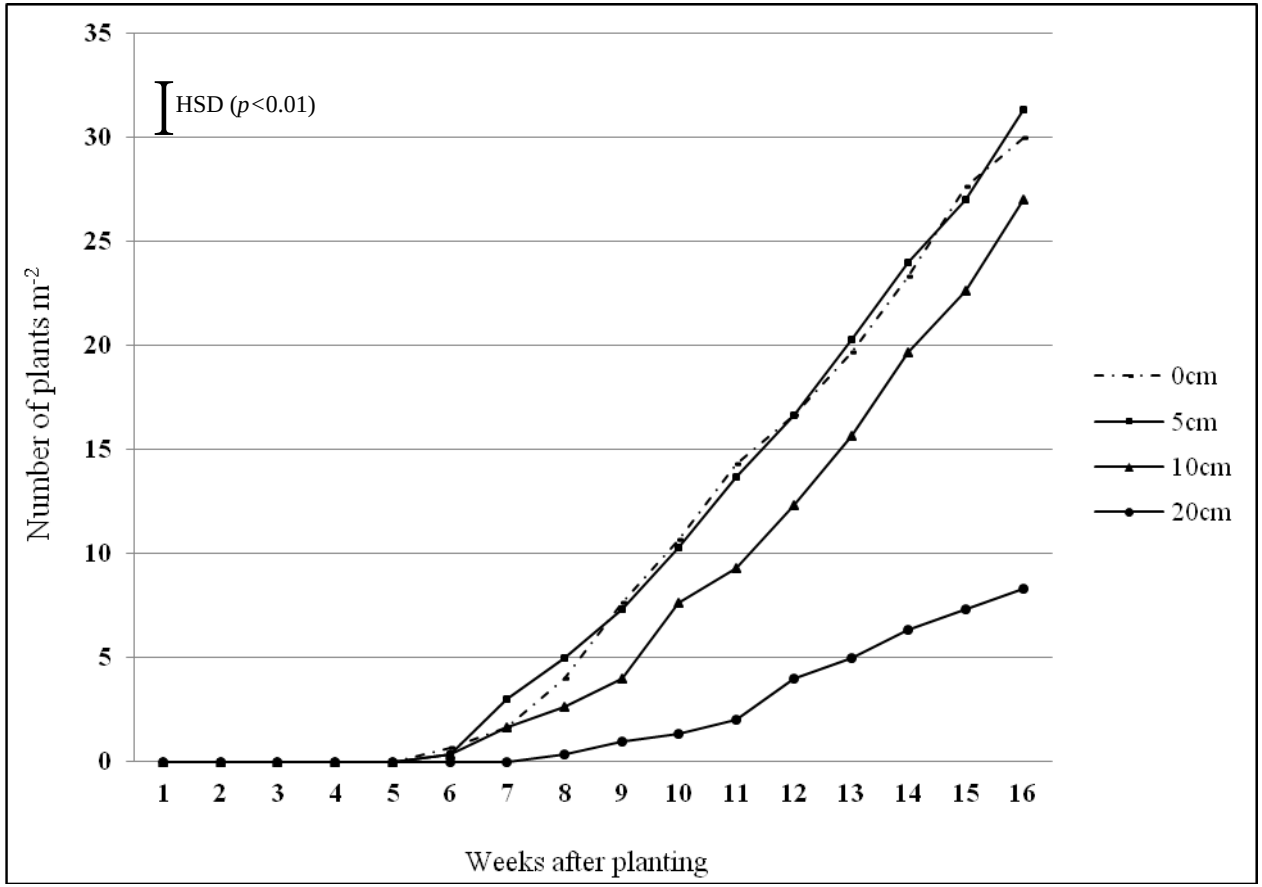

Fig. 2.14c Mortality number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 75 g/ 750 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

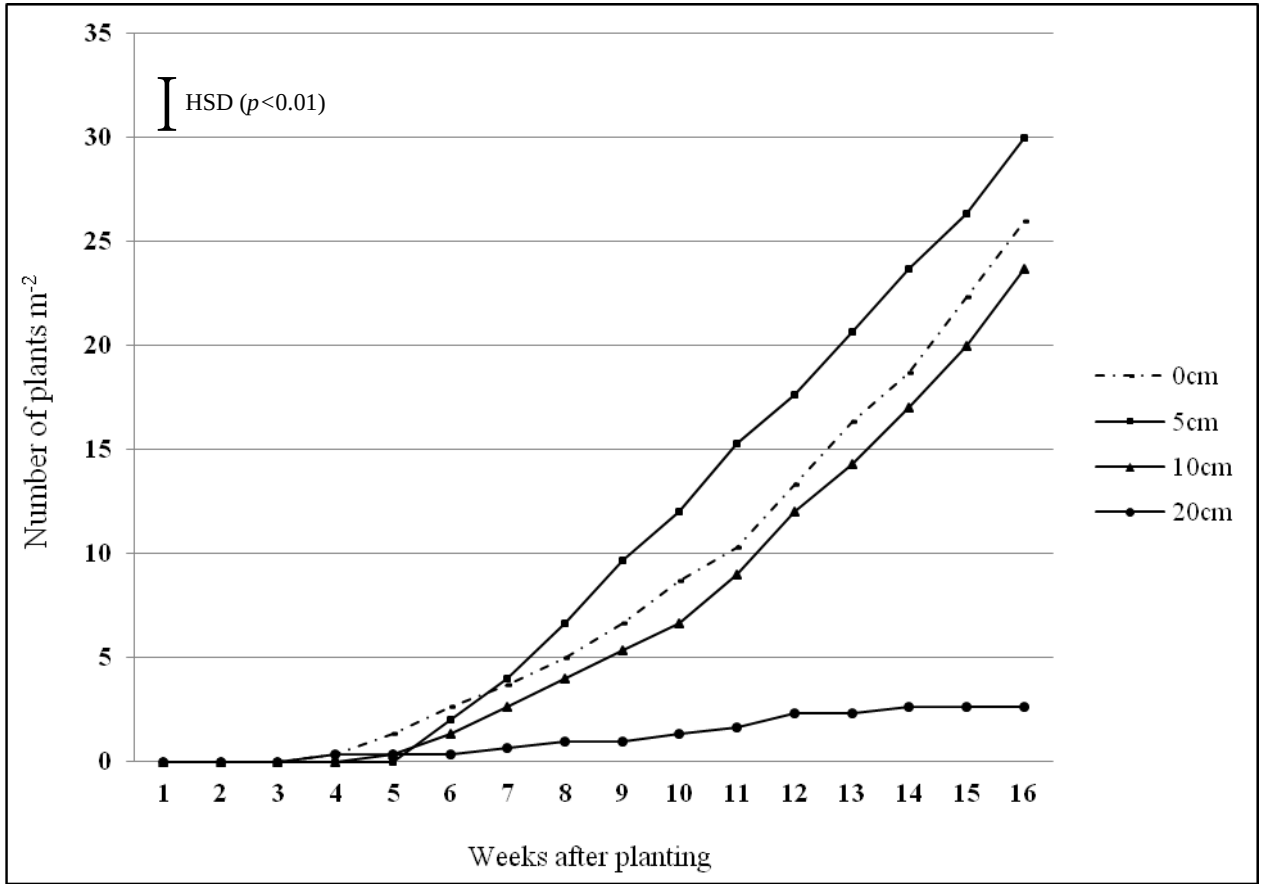

Fig. 2.14d Mortality number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 100 g/ 1000 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

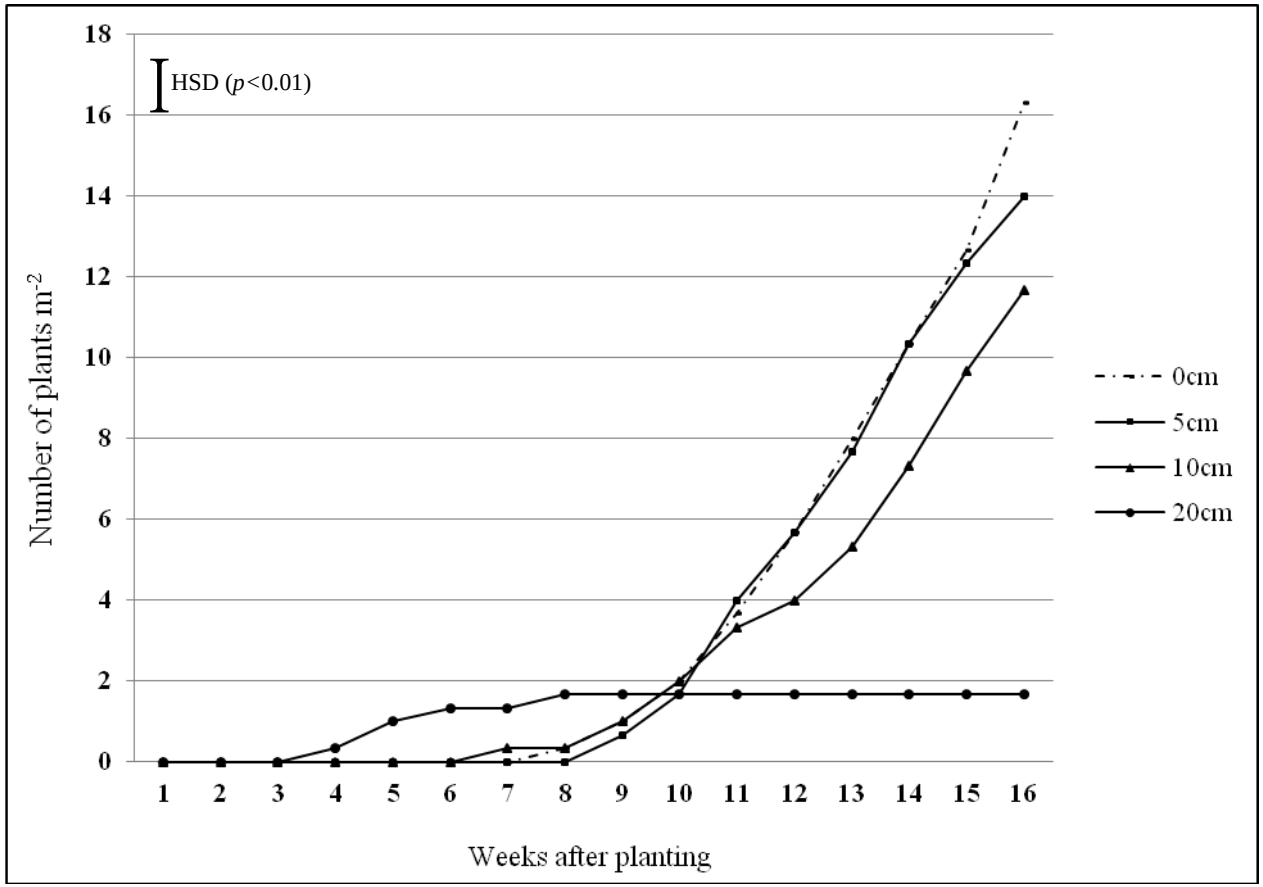

Fig. 2.14e Mortality number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 125 g/ 1250 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

2.3.2.2 Plant height of *Scirpus grossus* in grown at different water depths and fertilizer regimes in paddy soil.

In relation to plant height, recorded results showed that plant height was highest in the 10 cm water depth treatment followed by 20 cm, 5 cm and 0 cm water depth treatments, respectively. The results are shown in Table 2.7 and Fig. 2.15a. Plant height at the different water depths were as follows; (0 cm = 154.33, 5 cm = 150.00, 10 cm = 162.33, 20 cm = 175.33) respectively. All the results were not significantly different at $p<0.01$ (HSD tests).

As shown in Table 2.7 and Figs. 2.15a, 2.15b, 2.15c, 2.15d and 2.15e the results showed that between the different NPK concentrations used, the highest plant was after 16 weeks in all the F0, F2, F3, F5, F4 treatments. The men plant height up to 4 months, were as follows: F0 (154.33, 150.00, 162.33, 175.33 cm), F2 (148.67, 155.00, 182.67, 95.33 cm), F3 (152.67, 173.67, 147.00, 84.33 cm), F4 (133.00, 148.00, 155.67, 58.33 cm), F5 (142.67, 155.33, 164.00, 53.00 cm). The results were significantly different at $p<0.01$ (HSD tests). The ANOVA are summarised for all results in Appendix 6 (pp. xlvix).

There were obvious disparities in the growth of *S. grossus* subjected to different fertilizer and inundation regimes. Devoid of fertilizer application, the sedge displayed time-mediated increase in plant height from 154.33cm, one month after transplanting to 175.33 cm three months later. These trends were not registered with higher fertilizer applications and increasing depths of inundation. The two-way interactions between fertilizer and depths of inundation factors were very obvious among plants in the F5 x D4, as measured by plant height. The effects of inundation depths on n the plant height of the sedge were very obvious.

What could be the reasons for this poor show of growth by plants of *S. grossus*, despite high rates of fertilizer application? If we could draw parallelism from the studies by van Veen *et al.* (2013) on the response by two *Rumex* spp. when subjected to flooding to help explain the growth disparities displayed by *S. grossus* plants in this study. While flooded environment is lethal for most plant species, flooding-induced metabolic reprogramming specific to *R. acetosa* prevailed, illustrating a survival strategies in anticipation of restriction in gas exchange and mediate an energy and carbon crisis (van Veen *et al*. 2013). *Rumex palustris* uses the early flooding signal ethylene to increase survival by regulating shade avoidance and photomorphogenesis genes to outgrow submergence and by priming submerged plants for future low oxygen stress. It is only possible, but yet to be proven, that *S. grossus* may have employed the escape or quiescence strategy as illustrated by both *Rumex* spp. above either flooding-induced metabolic reprogramming with anticipated restriction in gas exchange in order to mediate an energy and carbon crisis, or making use of early signal ethylene for ensuing low oxygen stress. It would be interesting to pursue further studies on the above lines in order to mechanism(s) of survival fitness strategy of *S. grossus* when subjected to intermittent or prolonged inundation.

The escape growth is beneficial only if the flooding event is not too deep to outgrow and if the growth investment is rewarded by restored gas exchange and aerial photosynthesis as the leaves emerge above the water surface (Pierik *et al.*, 2009). Deep or transient flood conditions favour species with growth-suppressing behavior upon submergence by limiting carbohydrate consumption and elongation growth, the so-called quiescent strategy (Fukao *et al.*, 2006; Akman *et al.*, 2012). Indeed, studies show that species with an escape strategy are prevalent on natural sites with frequent shallow and long-term flooding events, whereas those with a quiescent strategy are restricted to

sites with deep or short-lasting floods (Voesenek *et al.*, 2004). In the case of *S. grossus*, there is strong evidences from this study that the depth of inundation in excess of 15 cm is deleterious to the growth of the sedge with shorter stature.

Table 2.7 Mean plant height (ramet) of *Scirpus grossus* plants grown under different NPK concentrations and water depths in paddy soil in Universiti Putra Malaysia, Serdang, Selangor, Malaysia[# *]

F0 (Control)				
Weeks after Planting	Water depths (cm)			
	D1	D2	D3	D4
1	4.00 j	0.00 j	3.00 i	4.83 i
2	17.00 i	27.00 i	19.17 hi	38.83 hi
3	32.17 h	44.33 hi	38.17 gh	57.50 gh
4	47.50 g	56.17 gh	57.17 fg	63.67 fgh
5	62.00 f	74.00 fg	83.33 ef	82.33 efg
6	76.33 e	85.33 ef	91.00 ef	98.67 def
7	79.67 e	88.67 ef	79.67 de	103.67 de
8	82.67 e	94.67 e	111.33 cde	106.33 de
9	85.33 e	100.67 de	122.67 bcd	111.67 cde
10	100.67 d	115.67 cd	131.33 abc	130.00 bcd
11	116.67 c	129.00 bc	138.67 abc	144.67 abc
12	133.33 b	136.67 ab	143.33 abc	151.67 ab
13	136.33 b	138.00 ab	147.33 ab	157.67 ab
14	143.33 ab	144.00 ab	155.33 a	160.33 ab
15	150.67 a	147.67 ab	159.00 a	166.67 a
16	154.33 a	150.00 a	162.33 a	175.33 a
F2				
Weeks after Planting	Water depths (cm)			
	D1	D2	D3	D4
1	3.33 j	7.50 h	4.17 i	0.00 d
2	27.33 i	14.83 h	19.67 hi	24.67 d
3	39.67 i	29.33 gh	30.50 hi	31.17 cd
4	49.17 hi	46.00 fgh	39.50 hi	33.33 bcd
5	62.67 gh	63.33 efg	59.67 gh	73.33 abc
6	67.33 gh	63.33 efg	86.33 fg	73.67 abc
7	74.33 fg	66.67 defg	96.67 efg	76.00 abc
8	75.33 fg	68.00 defg	108.33 ef	77.67 abc
9	78.00 fg	73.00 def	119.67 cef	79.33 abc
10	94.67 ef	92.33 cde	128.33 bcef	79.67 abc

Table 2.7(*continued*)

11	104.00 de	108.00 bcd	141.33 abce	80.67 ab
12	115.00 cde	118.67 abc	148.67 abc	82.67 a
13	125.00 bcd	123.33 abc	161.33 abc	85.67 a
14	137.67 abc	131.67 abc	167.67 ab	88.00 a
15	145.67 ab	144.67 ab	176.00 a	90.67 a
16	148.67 a	155.00 a	182.67 a	95.33 a

F3

Weeks after Planting	Water depths (cm)			
	D1	D2	D3	D4
1	0.00 h	7.33 j	2.17 j	0.00 d
2	22.50 gh	20.67 ij	19.33 ij	0.00 d
3	36.67 fg	35.00 hi	30.50 i	0.00 d
4	44.67 efg	49.67 gh	34.33 i	9.33 cd
5	61.00 def	71.67 fg	64.00 h	10.67 cd
6	66.33 def	83.00 ef	67.33 h	35.00 bcd
7	69.67 de	87.33 ef	75.00 gh	39.67 bc
8	71.67 de	90.00 ef	81.33 fgh	47.00 abc
9	73.33 de	92.67 ef	87.33 efgh	53.00 ab
10	89.67 cd	109.00 de	95.33 efg	54.33 ab
11	109.33 bc	121.00 cd	103.67 def	62.00 ab
12	125.33 ab	142.67 bc	111.67 cde	67.00 ab
13	128.33 ab	146.00 bc	120.67 bcd	67.33 ab
14	146.67 a	160.67 ab	131.00 abc	69.33 ab
15	151.00 a	168.67 ab	139.67 ab	78.00 a
16	152.67 a	173.67 a	147.00 a	84.33 a

F4

Weeks after Planting	Water depths (cm)			
	D1	D2	D3	D4
1	0.00 j	4.50 i	5.83 i	7.83 b
2	22.33 i	17.50 hi	22.33 hi	27.33 ab
3	43.67 h	34.67 gh	35.33 h	30.50 ab
4	47.00 h	41.83 fgh	39.50 h	33.33 ab
5	75.67 g	52.67 efg	85.67 g	45.67 ab
6	78.33 g	65.33 def	88.00 g	54.00 a
7	81.67 fg	70.67 de	91.00 g	55.00 a
8	85.67 fg	74.00 de	96.33 fg	55.67 a
9	88.00 efg	78.67 de	104.00 efg	51.33 a
10	97.67 def	89.67 cd	112.67 def	50.33 a
11	105.33 cde	107.00 bc	119.67 cde	52.33 a

Table 2.7(*continued*)

12	113.00 bcd	124.67 ab	128.67 bcd	53.00 a
13	116.00 abcd	127.67 ab	137.00 abc	54.00 a
14	123.67 abc	130.33 ab	145.67 ab	56.33 a
15	128.67 ab	141.33 a	150.67 a	56.67 a
16	133.00 a	148.00 a	155.67 a	58.33 a

F5

Weeks after Planting	Water depths (cm)			
	D1	D2	D3	D4
1	4.33 k	3.50 k	0.00 j	4.33 b
2	30.17 j	20.00 jk	11.17 ij	27.67 ab
3	44.17 ij	34.00 ij	15.67 i	33.00 ab
4	52.33 hi	41.17 hij	22.33 i	45.00 a
5	56.67 hi	52.67 ghi	47.33 h	56.33 a
6	62.00 ghi	60.00 fgh	52.33 h	59.67 a
7	64.00 fgh	63.33 fgh	59.33 gh	60.33 a
8	66.33 fgh	71.33 efg	68.00 fg	61.00 a
9	67.67 fgh	78.33 def	75.67 f	62.00 a
10	76.67 efg	90.67 de	91.33 e	58.00 a
11	83.33 ef	101.67 cd	112.33 d	56.33 a
12	94.00 de	124.00 bc	123.67 d	55.67 a
13	104.00 cd	132.33 ab	140.00 c	54.00 a
14	117.00 bc	144.33 ab	151.00 bc	54.00 a
15	130.00 ab	149.33 a	157.33 ab	53.67 a
16	143.67 a	155.33 a	164.00 a	53.67 a

[#]Figures in a column with same lowercase letters for each fertilizer concentration and each water depth are not significantly different at $p<0.01$ (HSD tests).
*F0 (control)(without fertilizer); F2 (50g/500 ml); F3 (75g/750 ml); F4 (100g/1000 ml); F5 (125g/1250 ml).

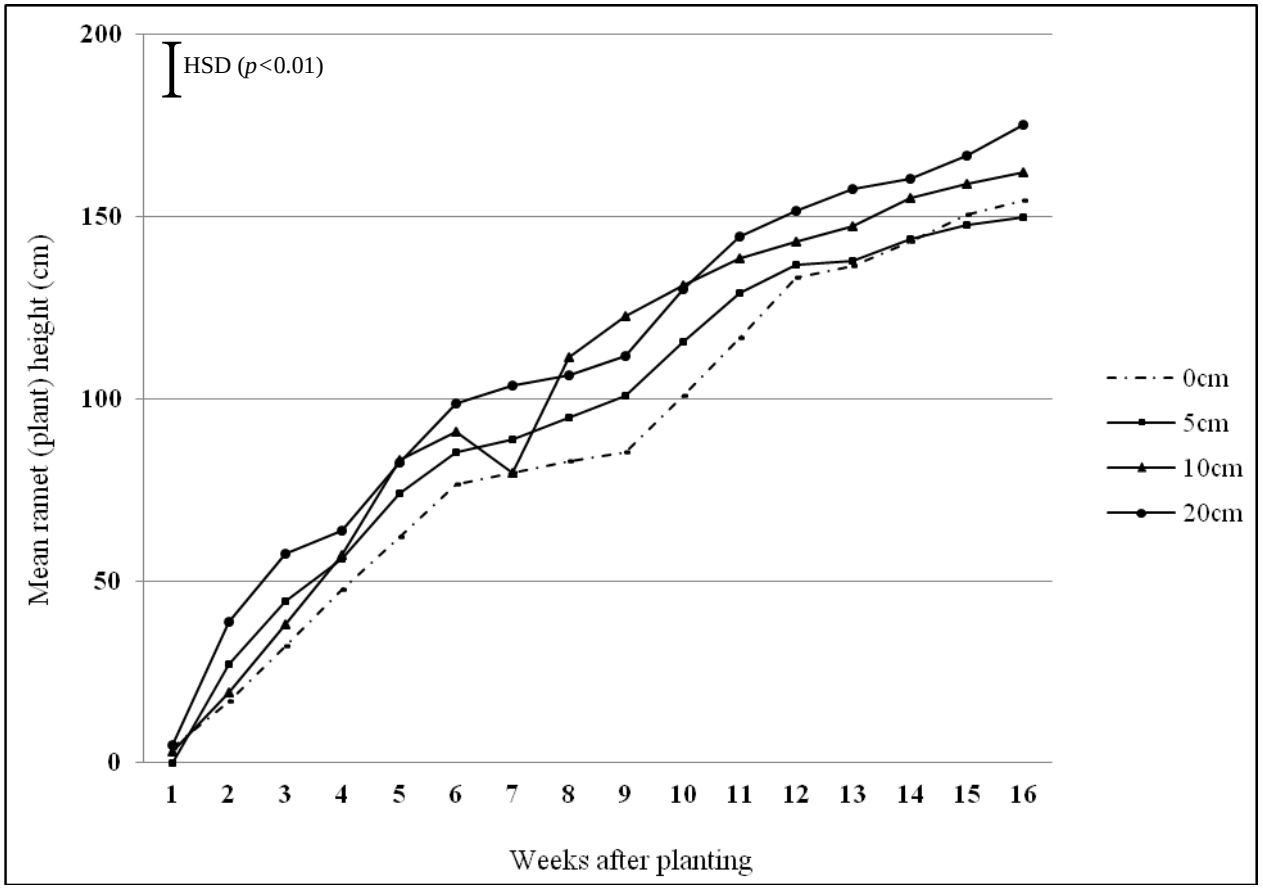

Fig. 2.15a Mean ramet (plant) height of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), without NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

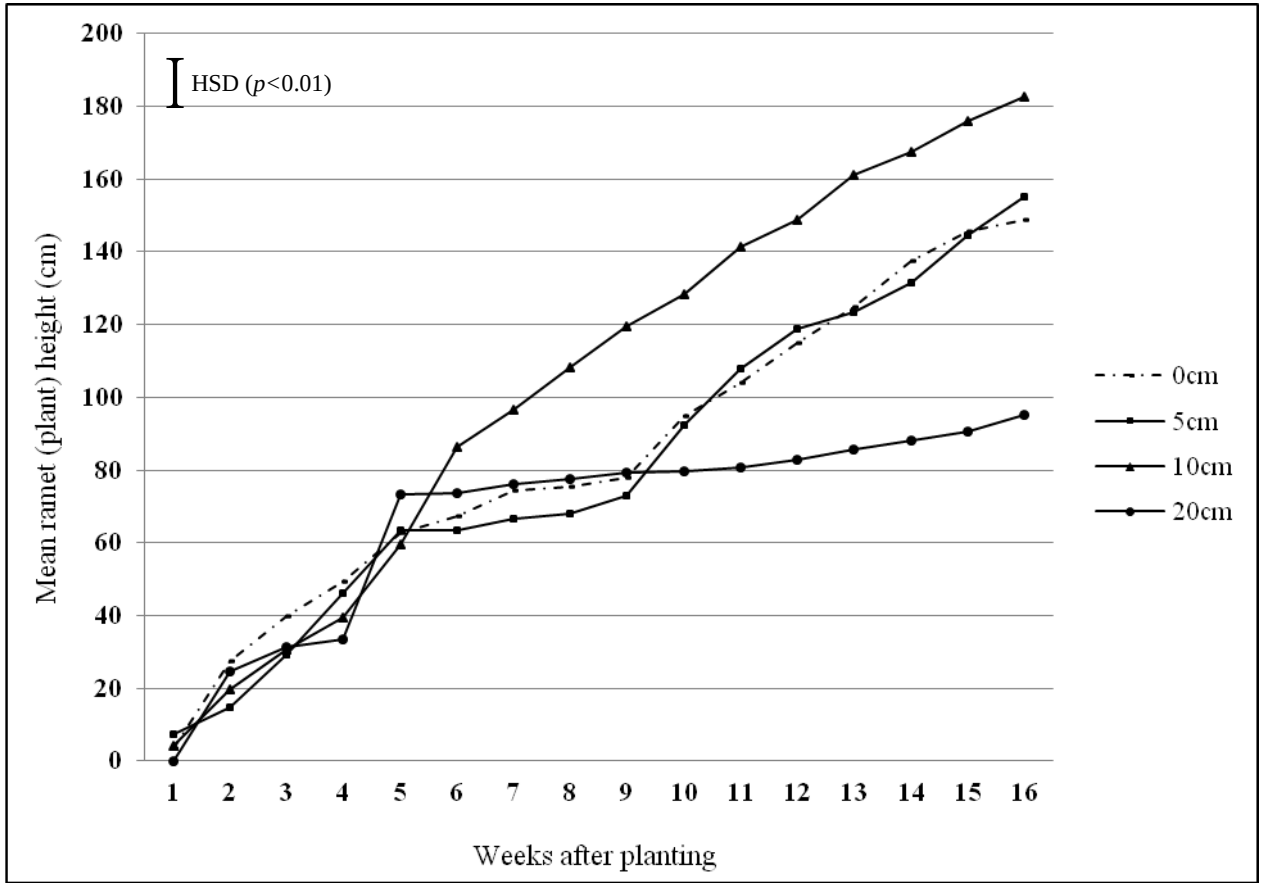

Fig. 2.15b Mean ramet (plant) height of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 50 g/ 500 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

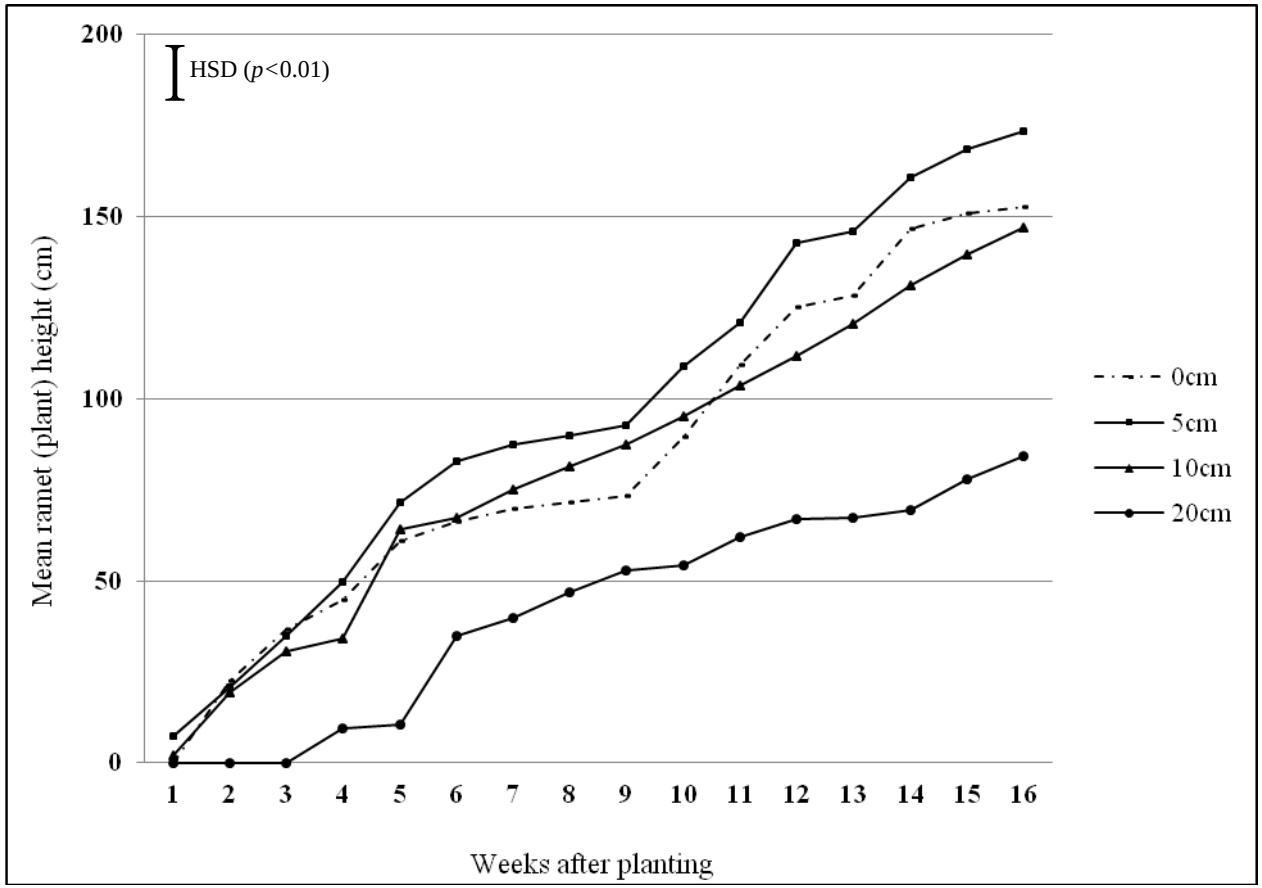

Fig. 2.15c Mean ramet (plant) height of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 75 g/ 750 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

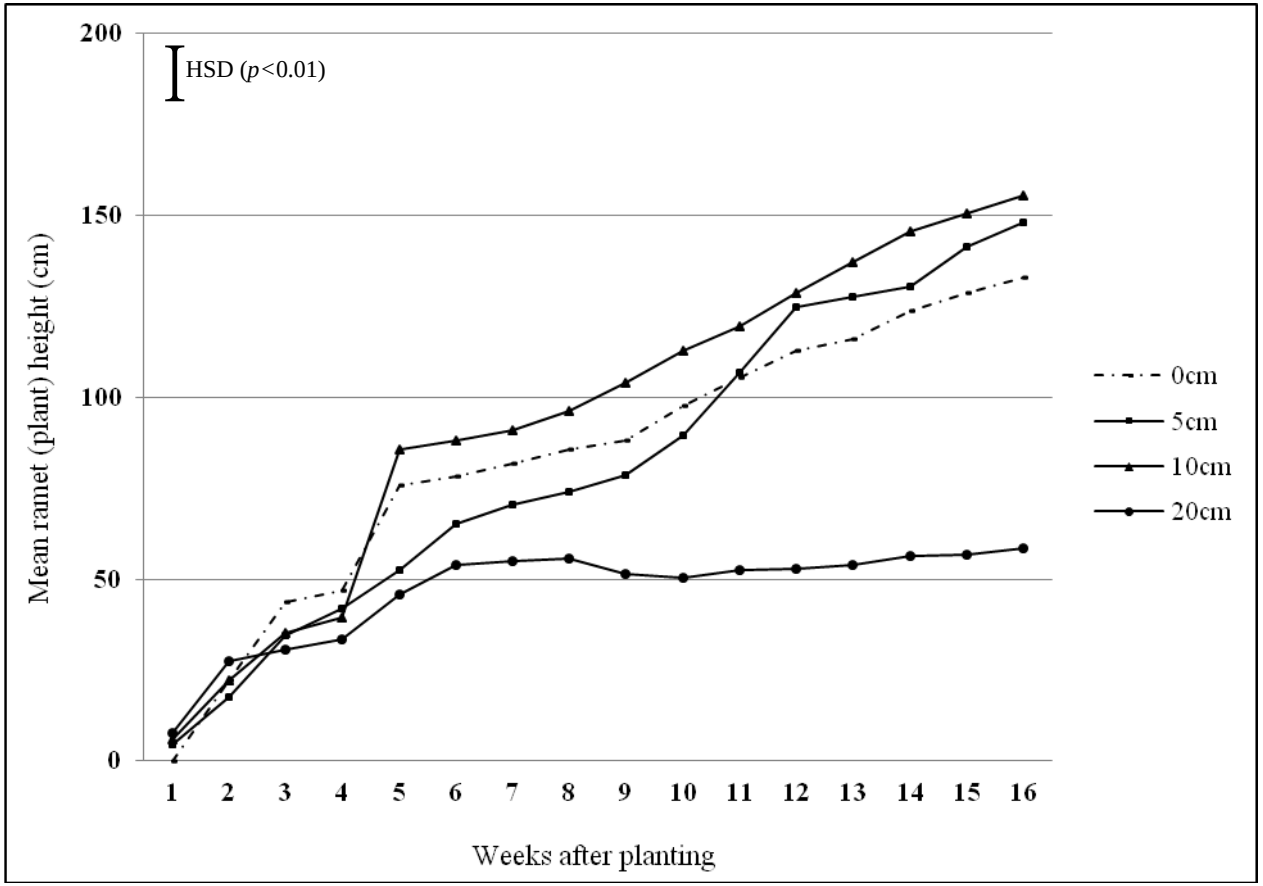

Fig. 2.15d Mean ramet (plant) height of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 100 g/ 1000 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

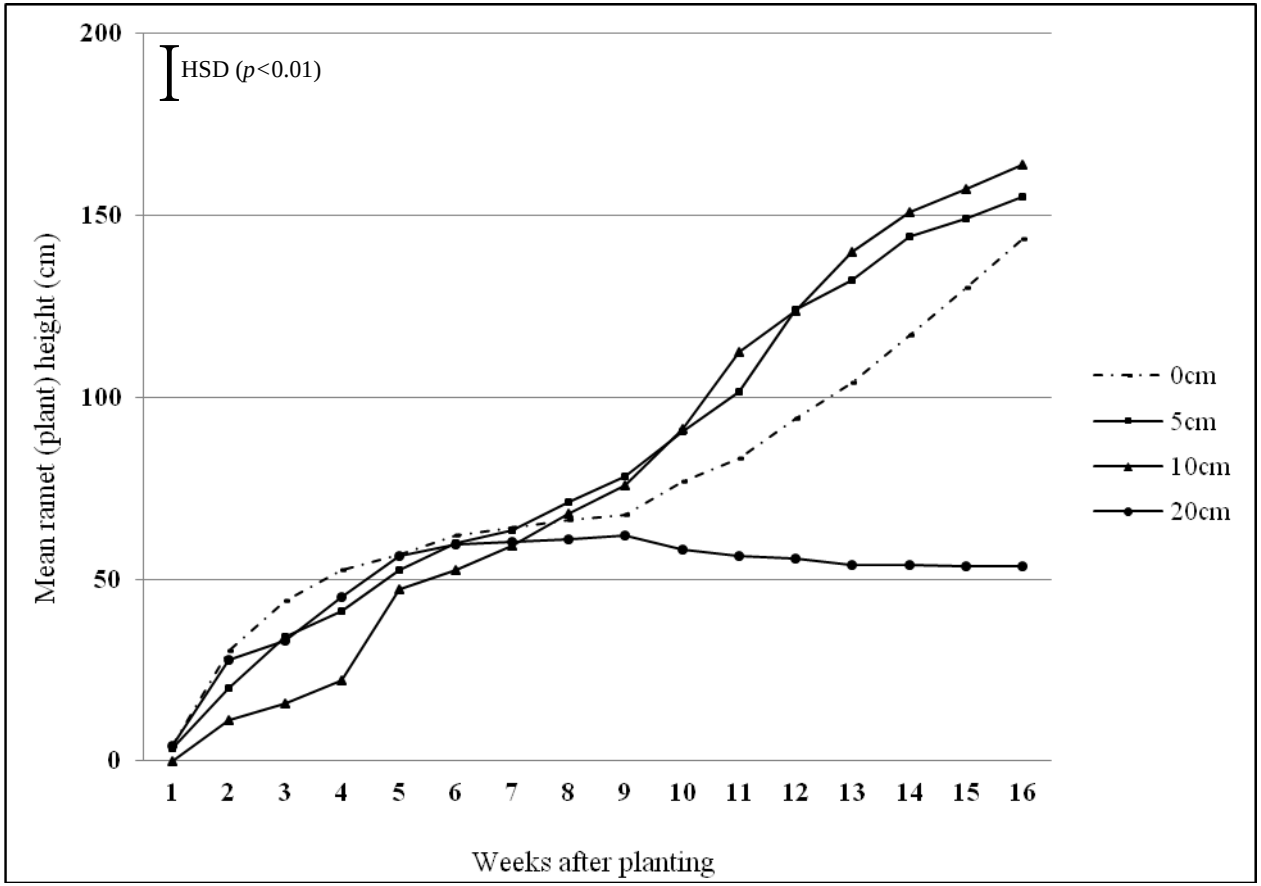

Fig. 2.15e Mean ramet (plant) height of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 125 g/ 1250 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

2.3.2.3 Phenology of *Scirpus grossus* in grown at different water depths and fertilizer regimes in paddy soils

The inflorescences in plants kept in water depths of 10 cm and 20 cm appeared on the 6th week of experimentation. *S. grossus* started to flower at weeks 8 under 5 cm, and 9th week under 0 cm . The results after 16 weeks of study are shown in Table 2.8 and Fig. 2.16a. The highest numbers for inflorescence production were recorded at 5 cm, 10 cm, 20 cm, and 0 cm water depths respectively, where the number of inflorescence observed were as follows; (0 cm = 15.00 m^{-2}, 5 cm = 25.67 m^{-2}, 10 cm = 25.00 m^{-2}, 20 cm = 22.33 m^{-2}) respectively. All the results were significantly different at p<0.01 (HSD tests).

Plants started to produce inflorescence in the F2, F3, F4, F5 treatments on the 9th and 10th week, while inflorescence appeared earlier in the F0 treatment on the 6th week (Table 2.8 and Figs. 2.16b, 2.16c, 2.16d and 2.16e). After 16 weeks of study the highest inflorescence number were recorded as follows: F0, F2, F3, F4, F5 respectively. The average inflorescence number for each NPK treatment were as follows; F0 (15.00, 25.67, 25.00, 22.33 m^{-2}), followed by F2 (15.33, 14.67, 31.33, 4.33 m^{-2}), F3 (14.00, 10.00, 7.00, 1.67 m^{-2}), F4 (4.67, 13.00, 12.67, 0.33 m^{-2}) and F5 (3.67, 8.33, 9.33, 0.00 m^{-2}) respectively. The results were significantly different at p<0.01 (HSD tests). The ANOVA are summarised for all results in Appendix 6 (pp. xlvix). Fertilizer applications did not appear to enhance inflorescence production in *S. grossus* compared with the control. The pattern of reduced flowering were observed in *Typha latifolia* and *T. domingensis* by Grace (1989), who cited carbon budgetary allocation, inducing more clonal growth for continued survivorship rather than allocating more energy for flower production under continued inundation.

Since plant response to prolonged sub-mergence includes alterations in architecture, metabolism, and elongation growth associated with a low O_2 escape strategy and an antithetical quiescence scheme that allows endurance of continued flooding (Serres and Voesenek 2008), it would not be insensible to argue that *S. grossus* would response likewise perhaps accompanied with a reduction of cellular O_2 content, mediated through multifaceted alterations in cellular and organ structure that promote access to and diffusion of O_2 . These processes are driven by phytohormones, including ethylene, gibberellin, and abscisic acid. Interestingly, flooding appeared to have enhanced flowering in the sedge. It would be interesting to explore how flooding would change the hormonal budgets in *S. grossus* favouring more clonal growth against the production of inflorescence as shown in this experiment.

Table 2.8 Mean inflorescence number of ramets (m^{-2}) of *Scirpus grossus* plants grown under different NPK concentrations and water depths in paddy soil in Universiti Putra Malaysia, Serdang, Selangor, Malaysia[#*]

F0 (Control)				
Weeks after Planting	Water depths (cm)			
	D1	D2	D3	D4
1	0.00 e	0.00 f	0.00 f	0.00 e
2	0.00 e	0.00 f	0.00 f	0.00 e
3	0.00 e	0.00 f	0.00 f	0.00 e
4	0.00 e	0.00 f	0.00 f	0.00 e
5	0.00 e	0.00 f	0.00 f	0.00 e
6	0.00 e	0.00 f	1.00 ef	0.67 e
7	0.00 e	0.00 f	2.33 ef	2.33 de
8	0.00 e	0.33 f	4.00 def	4.00 cde
9	0.33 de	0.67 ef	6.33 cdef	4.67 cde
10	1.67 de	2.67 de	8.00 bcde	8.33 bcd
11	3.00 cde	5.00 d	12.33 abcd	11.00 abc
12	4.67 bcde	11.00 c	15.00 abc	14.33 ab
13	5.67 bcd	13.67 c	17.00 ab	16.00 ab
14	9.33 abc	16.00 bc	20.33 ab	19.33 a
15	11.67 ab	21.33 ab	23.67 a	21.00 a
16	15.00 a	25.67 a	25.00 a	22.33 a
F2				
Weeks after Planting	Water depths (cm)			
	D1	D2	D3	D4
1	0.00 d	0.00 d	0.00 f	0.00 a
2	0.00 d	0.00 d	0.00 f	0.00 a
3	0.00 d	0.00 d	0.00 f	0.00 a
4	0.00 d	0.00 d	0.00 f	0.00 a
5	0.00 d	0.00 d	0.00 f	0.00 a
6	0.00 d	0.00 d	0.00 f	0.00 a
7	0.00 d	0.00 d	0.00 f	0.00 a
8	0.00 d	0.00 d	0.00 f	0.00 a
9	0.00 d	0.00 d	0.67 f	0.33 a
10	0.33 d	0.00 d	2.67 ef	0.67 a
11	1.00 cd	0.33 cd	6.33 de	1.67 a
12	2.67 cd	1.33 cd	11.67 cd	2.33 a
13	4.00 cd	2.00 c	17.00 bc	3.33 a
14	5.67 bc	5.00 b	22.67 ab	3.67 a
15	10.33 ab	12.00 a	29.00 a	4.33 a

Table 2.8(*continued*)

16	15.33 a	14.67 a	31.33 a	4.33 a
		F3		
Weeks after Planting		Water depths (cm)		
	D1	D2	D3	D4
1	0.00 c	0.00 d	0.00 d	0.00 b
2	0.00 c	0.00 d	0.00 d	0.00 b
3	0.00 c	0.00 d	0.00 d	0.00 b
4	0.00 c	0.00 d	0.00 d	0.00 b
5	0.00 c	0.00 d	0.00 d	0.00 b
6	0.00 c	0.00 d	0.00 d	0.00 b
7	0.00 c	0.00 d	0.00 d	0.00 b
8	0.00 c	0.00 d	0.00 d	0.00 b
9	0.00 c	0.00 d	0.00 d	0.00 b
10	0.33 c	0.00 d	0.00 d	0.00 b
11	1.33 c	1.00 cd	1.00 cd	0.00 b
12	2.00 c	3.00 bc	1.67 cd	0.00 b
13	3.67 bc	3.33 bc	2.67 bcd	0.00 b
14	6.33 abc	6.00 ab	4.00 abc	0.00 b
15	12.33 ab	8.33 a	5.67 ab	0.33 ab
16	14.00 a	10.00 a	7.00 a	1.67 a
		F4		
Weeks after Planting		Water depths (cm)		
	D1	D2	D3	D4
1	0.00 b	0.00 d	0.00 e	0.00 a
2	0.00 b	0.00 d	0.00 e	0.00 a
3	0.00 b	0.00 d	0.00 e	0.00 a
4	0.00 b	0.00 d	0.00 e	0.00 a
5	0.00 b	0.00 d	0.00 e	0.00 a
6	0.00 b	0.00 d	0.00 e	0.00 a
7	0.00 b	0.00 d	0.00 e	0.00 a
8	0.00 b	0.00 d	0.00 e	0.00 a
9	0.00 b	0.00 d	0.00 e	0.00 a
10	0.00 b	0.00 d	0.33 de	0.00 a
11	0.33 b	0.67 d	1.67 cde	0.00 a
12	0.67 b	2.00 cd	3.00 cd	0.00 a
13	1.00 ab	2.33 cd	5.00 bc	0.00 a
14	2.00 ab	6.00 bc	8.00 ab	0.00 a
15	3.67 ab	9.33 ab	10.00 ab	0.00 a
16	4.67 a	13.00 a	12.67 a	0.33 a

Table 2.8(*continued*)

	F5			
Weeks after Planting	Water depths (cm)			
	D1	D2	D3	D4
1	0.00 c	0.00 d	0.00 d	0.00 a
2	0.00 c	0.00 d	0.00 d	0.00 a
3	0.00 c	0.00 d	0.00 d	0.00 a
4	0.00 c	0.00 d	0.00 d	0.00 a
5	0.00 c	0.00 d	0.00 d	0.00 a
6	0.00 c	0.00 d	0.00 d	0.00 a
7	0.00 c	0.00 d	0.00 d	0.00 a
8	0.00 c	0.00 d	0.00 d	0.00 a
9	0.00 c	0.00 d	0.00 d	0.00 a
10	0.00 c	0.33 cd	0.00 d	0.00 a
11	0.00 c	1.00 cd	0.33 d	0.00 a
12	0.00 c	2.33 bcd	2.00 cd	0.00 a
13	0.00 c	3.00 bc	2.67 cd	0.00 a
14	0.33 c	5.00 ab	4.33 bc	0.00 a
15	2.33 b	6.33 ab	7.00 ab	0.00 a
16	3.67 a	8.33 a	9.33 a	0.00 a

[#]Figures in a column with same lowercase letters for each fertilizer concentration and each water depth are not significantly different at $p<0.01$ (HSD tests).
*F0 (control)(without fertilizer); F2 (50g/500 ml); F3 (75g/750 ml); F4 (100g/1000 ml); F5 (125g/1250 ml).

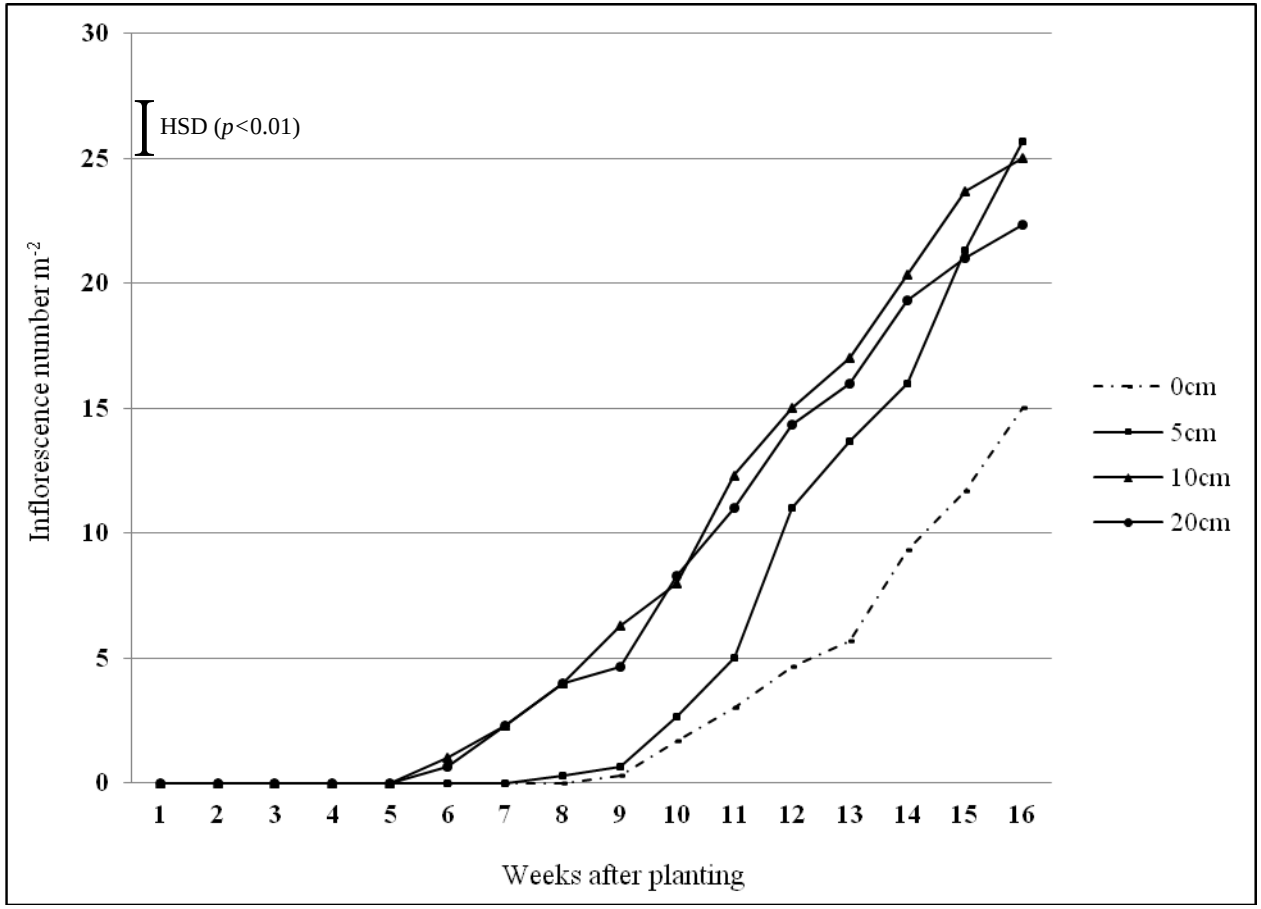

Fig. 2.16a Mean inflorescence number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), without addition of NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

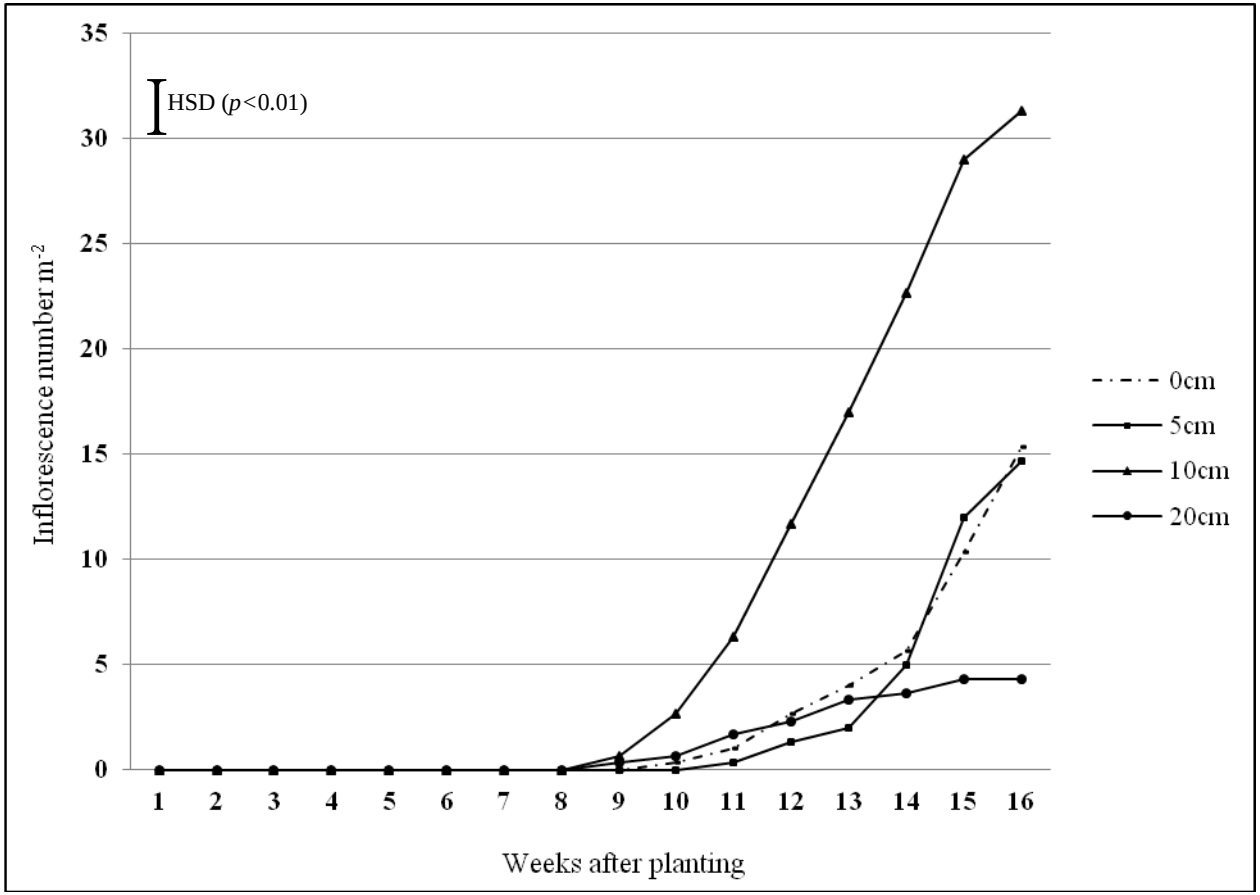

Fig. 2.16b Mean inflorescence number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 50 g/ 500 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

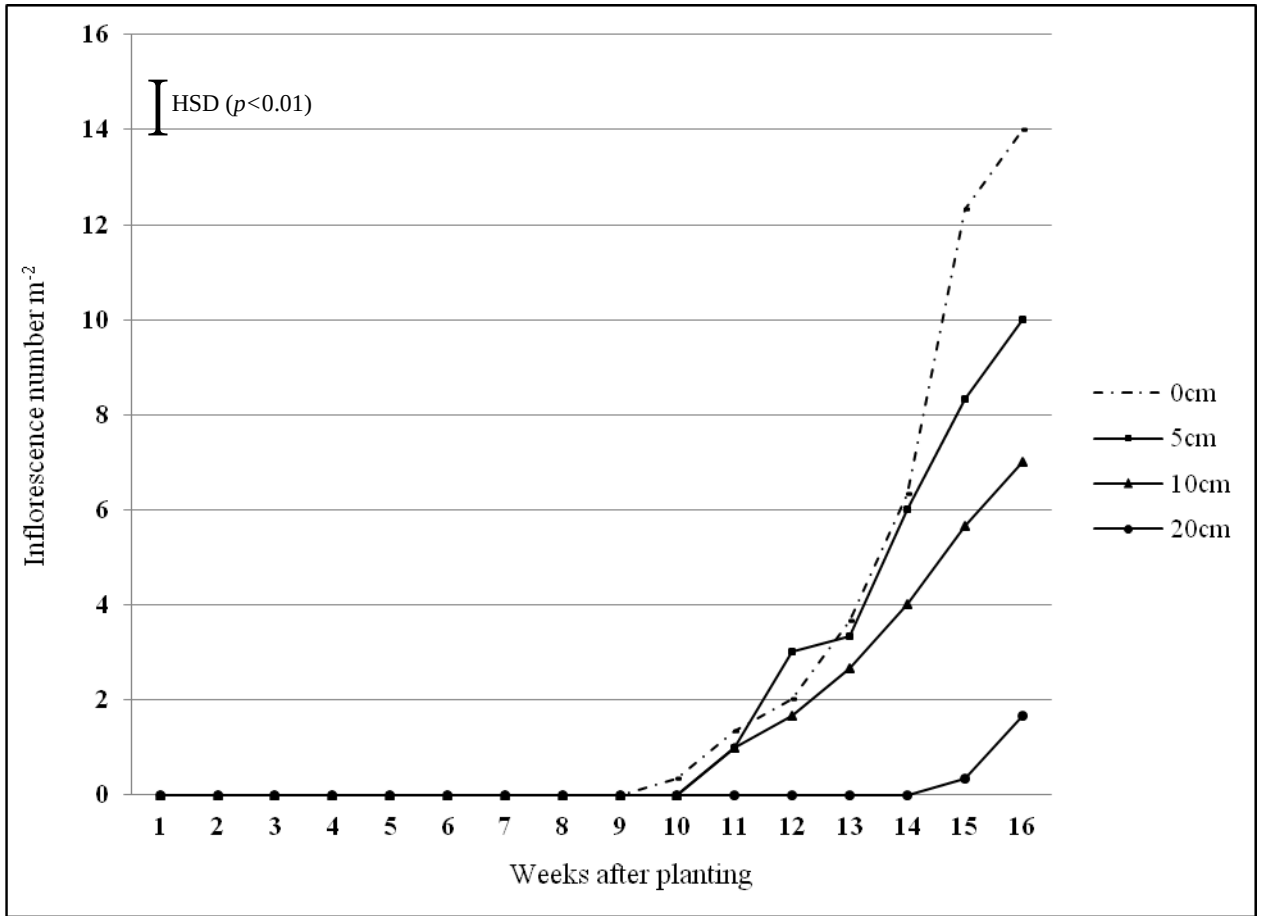

Fig. 2.16c Mean inflorescence number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 75 g/ 750 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

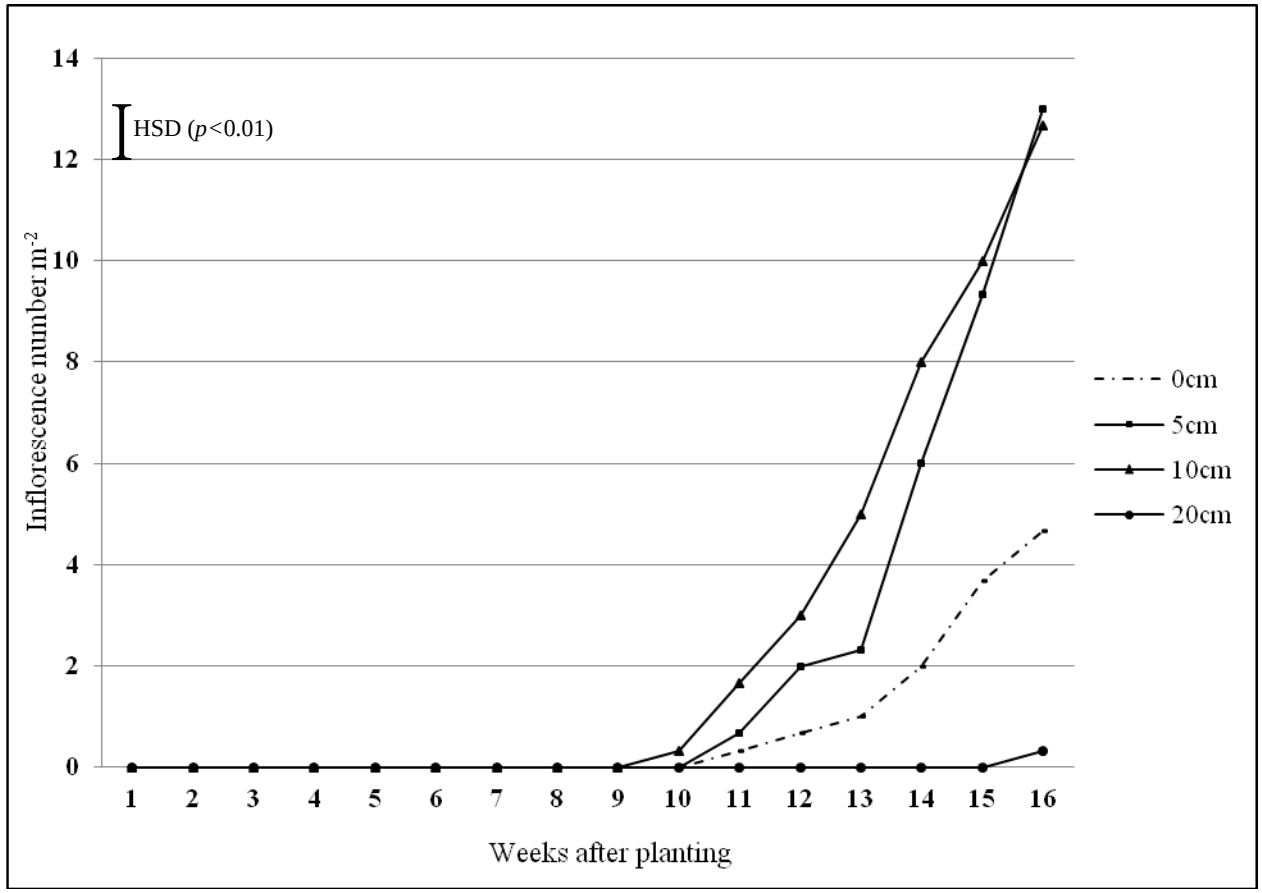

Fig. 2.16d Mean inflorescence number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 100 g/ 1000 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

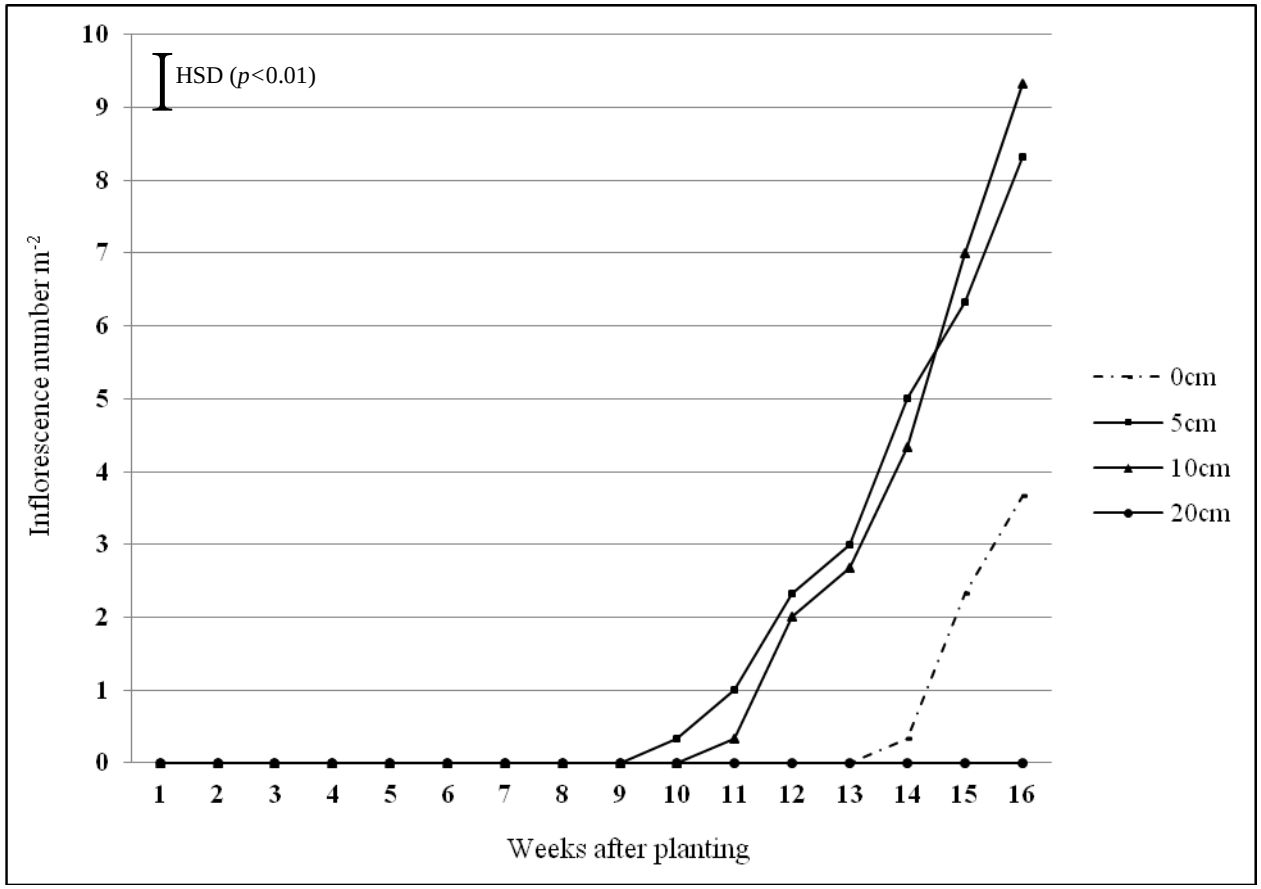

Fig. 2.16e Mean inflorescence number of *Scirpus grossus* under different water depths (0 cm, 5 cm, 10 cm and 20 cm), with 125 g/ 1250 ml NPK application in paddy soil in Unversiti Putra Malaysia, Serdang, Selangor, Malaysia.

2.3.3 Physico-chemical characteristics of fertilized and unfertilized peat and paddy soils

The physico-chemical traits of fertilized and unfertilized peat and paddy soils are shown in Tables 2.9 Interestingly, paddy soils were more fertile compared with peat soil, and should support a better and more robust growth of *S. grossus* populations during experimentation.

The nutrient contents of *S. grossus* plants 24 weeks after transplanting in peat and paddy soils are shown in Tables 3.4 (p. 180) (Chapter 3).

Table 2.9 Nutrient status of peat and paddy soils used at MARDI Research Station, Jalan Kebun and Tanjung Karang, Selangor, Malaysia, 24 weeks after experimentation*

Elements, moisture content, pH	Treatments			
	Unfertilized soil (F_0)		Fertilized soil (F_1)	
	Peat	Paddy	Peat	Paddy
Al	7600.0	36600.0	9900.0	34000.0
B	22.5	0.0	34.2	0.0
Ca	24000.0	3100.0	24200.0	5200.0
Cu	112.6	10.6	125.8	8.6
Fe	7743.7	32633.2	10883.7	27848.7
K	300.0	3500.0	300.0	3700.0
Mg	5100.0	7300.0	6100.0	9100.0
Mn	153.4	382.3	206.9	557.0
Na	298.8	602.3	281.8	1186.0
P	1000.0	700.0	1400.0	900.0
S	3100.0	2000.0	3200.0	3900.0
Zn	110.1	139.8	131.8	108.3
Total Nitrogen	11300.0	2900.0	10200.0	2400.0
Moisture content	8.3%	5.7 %	7.7 %	5.8 %
pH	5.9	4.3	6.4	4.6

*****All values are in ppm, except for moisture content and pH