CHAPTER 5

ARCHITECTURAL MODELS OF SUBTERRANEAN RHIZOMES OF *SCIRPUS GROSSUS* L.

INTRODUCTION

5.1.1 Subterranean rhizomes: Growth patterns and architecture

Rhizomatous plants principally among grasses and sedges grow through reiteration of subterranean modules (Baki 1986, 1988). In others, the ensuing clonal growth are reflected in the fluxes of modular units which can be either above ground or below the soil surface. It is through these modular units that above-ground tillers in grasses or sedges, or ramets in broadleaves emerged either still attached to the whole plant *en – masse* or detached eventually as single plant entities. Invariably both above- and below-ground growths of plants are governed by the immediate microclimatic conditions in which those plants reside coupled with exogenous and endogenous factors governing those growth and their ensuing sustenance.

There are a lot of evidences that indicated measurable absorption rhizosphere for large N, P, and K (Hinsinger 1998, 2001; Jungk and Claassen 1986, 1997; Jungk 2002). The first evidence of this phenomenon was obtained by using radioactive isotope-labelled soils and autoradiography techniques (Bhat and Nye, 1974). Moreover, reports referred to more complex patterns of nutritive distribution in the rhizosphere, combining depletion at the very root surface with alimental accumulation occurring farther away from the root. (Calvaruso *et al.* 2011; Hinsinger, 1998, 2001; Hinsinger *et al.* 2009).

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depletion at the very root surface with alimental accumulation occurring farther away from the root. (Calvaruso *et al.* 2011; Hinsinger, 1998, 2001; Hinsinger *et al.* 2009).

In a study on the role of nitrogen concentration in the tissues of the root, it was evident that N fertilization enhanced both root respiration and tissue N concentration. For example, the increases in average root respiration for N fertilization treatment were 13.30% in larch and 18.25% in ash at 6 °C indicating that this effect may cause a change in plant mass and plant growth patterns (Shuxia *et al.* 2011). The nitrogen (N) and phosphate (P) were among the most nutrients affected ecosystem services. This is the consequence of the considerable increase in agricultural inputs and the steady decrease of N and P fertilizer efficiency (Hinsinger *et al.* 2011; Tilman *et al.* 2002).

Diffusion-limited elements, such as P, move slowly through soil (Schenk and Barber, 1979), so soil volumes in the immediate vicinity of roots are often depleted of P, while bulk soil 1-2 cm away have P concentrations that remain largely unchanged. The soil that has had P concentration decreased by root uptake is referred to as the depletion volume, the size of which is proportional to the rate of diffusion of P through the soil. Some soil is depleted of P by more than one root from a single plant. The volume of soil explored by multiple roots is defined as competition volume. Since competition volume increases as the root system grows, it is often useful to calculate proportional competition, which in this report is competition volume divided by depletion volume. Using these concepts of depletion and competition, P efficiency can be defined as minimization of proportional competition. This definition has been used in geometric modeling to evaluate the P efficiency of contrasting root architectures (Ge *et al.* 2000; Rubio *et al.* 2001).

The architecture of plants affected by endogenous factors such as hormone signals and trophic competition between organs, but by exogenous factors such as light distribution, temperature, soil water and nutrient regimes. Plant morphology can as well be artificially modified. Many efforts have been made in the last decade to model the structural development of plants taking into account their plasticity, i.e. their ability to adapt their shape and to regulate their functions in a changing environment (Yan *et al.* 2011). This is illustrated by the work of Pallas *et al.* (2011) who investigated the architectural growth of grapevine (*Vitis vinifera*). Cieslak *et al.* (2011) developed an L-system based model of the kiwifruit vine that integrates structural development, carbon dynamics, and environmental and management effects on vegetative and generative components. Jullien *et al.* (2011) evaluated the costs of ramification through quantifying the interaction between architecture and source-sink dynamics in crop winter oilseed rape (*Brassica napus*). This work provides promising clues for the construction of functional–structural (FS) models for plants with complex architectural plasticity and oleaginous components. It is important to quantify the growth and development of plants and their interaction with fragile ecosystems. The morphology of rice (*Oryza sativa*) has been substantially modified by breeding in recent decades in order to enhance its yield potential. In this context, genetic analyses of morphological traits have been investigated in detail (Yang and Hwa, 2008; Qian *et al.* 2011).

In life sciences, the term “model” has various connotations depending on the target organism, and their temporal and spatial scales. Le *et al.* (1998) reviewed the history of plant nutrition modelling, and their application to strategic and tactical crop management, and used as a practical tool for crop management, e.g. fertilizer recommendation. Knowledge of the model used for the absorption of nutrients in a part of the root, helps us to understand the intricacy the full root system and the forms of the root growth. (Willigen *et al.* 2002). So far, most models rely on a very poor description of root growth, and do not explicitly account for root architecture, in spite of its importance in resource exploitation efficiency (Fitter and Stickland 1992). In particular, the contribution of very deep roots on water and nutrient uptake in natural and processes established on highly weathered tropical soils is still poorly known (Battie-Laclau and Laclau, 2009; Christina *et al.* 2011; Silva *et al.* 2011). These lack of understanding on root system growth is all the more prevalent in rhizomatous plants. Nevertheless, root architecture models have proven useful for predicting water uptake (Doussan *et al.* 2003, 2006; Pierret *et al.* 2007). Thus, linkage appears feasible in architecture models where topological relationships among different root types makes it possible (Collet *et al.* 2006; Vercambre *et al.* 2003). Accounting for architecture is especially needed for the most mobile nutrients such as nitrate, as root competition and consequent overlapping of nutrient depletion zones is increasing with increasing diffusion coefficient (Ge *et al.* 2000; Hinsinger *et al.* 2005). Dunbabin *et al.* (2006) in study showed that in order for the upscaling from the root segment of the achieved root system scale led to a more realistic description of the achieved plant functioning, enabling feedback effects of rhizosphere processes on root growth to be accounted for because crop improvement by phosphate. It also found models of nutrient acquisition have been improved decades ago to account for root hairs growth (Bhat and Nye 1974; Itoh and Barber, 1983a, b; Leitner *et al.* 2010b), and these root hairs play a prominent role in extending the volume of the depletion zone in the rhizosphere.

Rhizomatous root growth is effected through the acquisition, distribution, and consumption of water and nutrients of plants. If we want to understand root branching complexity, mathematical models using fractals and computers can be applied to accurately understand the growth and model the complexity of plant root systems, such as using the Fractal Dimensions (FD) software's box-counting method of fractal analyses. The data generated from fractal counting can be tabulated and plotted on a log-log plot graph (Klarizze, 2005).

5.1.2 Fractals and fractal dimensions

Rhizome growth is effected to the acquisition, distribution, and consumption of water and nutrients of plants. If we want to understand rhizome branching complexity, mathematical models using fractals and computers can be applied to accurately understand the growth and complexity of plant rhizome systems, such as using the Fractal Dimensions FD software's box-counting method of fractal analyses. The data from the fractal counting can be tabulated and plotted on a log-log plot graph (Klarizze 2005).

Fractals are unusual geometric structures that can be used to analyze many biologic structures not amenable to conventional analysis (Richardson and Gillepsy 2000). It was suggested that when rhizomes develop under favorable conditions, FD is a good indicator for estimating the system's size and rhizome branching (Klarizze 2005).

A number of researchers have demonstrated that fractal analysis may be biologically relevant. Many aspects of morphological and physiological variation have been associated with variation in FD. As rhizomes grow, the FD increases (Fitter and Stickland 1992; Lynch and van Beem 1994; Nielsen *et al.* 1998). The FD has been correlated with rhizome topology (Fitter and Stickland 1992) and rhizome architecture (Nielsen *et al.* 1997). Differences in FD have been noted among four species of monocots (Fitter and Stickland 1992), as well as among genotypes of sorghum, rice and common bean (Izumi *et al.* 1995; Masi and Maranville 1998; Nielsen *et al.* 1998).

Genotypic variation of rhizome mass and rhizome: shoot ratio was correlated with variation in FD of rhizomes (Masi and Maranville 1998).

In 1997, Nielsen *et al.* (1997) successfully applied fractal analysis to a computer model of bean rhizomes. They also demonstrated that the true three dimensional fractal dimension (D3) is tightly correlated with planar (D2) and linear (D1) fractal dimensions. This attribute may prove to be a cardinal factor for the application of fractal analysis to soil-grown rhizome systems because D2 can be determined from data collected by trenching. Many studies have used this technique for different targets. The architecture of the rhizome system is also well known to be a major determinant of rhizome functions in the acquisition of soil resources such as nutrients and water (Lynch 1995; Yamauchi *et al.* 1996; Fitter 2002; Wang *et al.* 2006). Fractal geometry is widely applied to assess the rhizome system architecture and the distribution of rhizome systems in soils (Fitter and Stickland 1992; Berntson *et al.* 1997; Lynch and van Beem 1993; Tatsumi *et al.* 1989; Tatsumi 1995,2001; Masi and Maranville 1998; Walk *et al.* 2004; Dannowski and Block 2005). Fractal geometry is a system of geometry that is more suitable to the description of complex natural objects than standard euclidian geometry (Mandelbrot 1983). A fractal is an object having a non-integer dimension. Rhizome systems also have self-similarity and are considered as the approximate fractal objects over a finite range of scales (Tatsumi *et al.* 1989). Fractal analysis in rhizome biology often typically utilizes the box-counting method and the equation: $N(r) = Kr - D$ is obtained (Tatsumi *et al.* 1989; Tatsumi 2001; Walk *et al.* 2004), where r is the length on the box side, and N(r) is the number of boxes of size r needed to cover the object. In terms of fractal analysis, the equation: $N(r) = Kr - D$ is transformed to the regression of log of N(r) intersected by rhizomes vs. r levels. The slope (D) and intercept to log K are computed. D is the fractal dimension (FD), and log K is associated with fractal abundance (FA). The FD is closely related with the branching pattern of rhizomes, while the FA with the volume of space explored by rhizomes (Tatsumi *et al.* 1989; Tatsumi 2001; Walk *et al.* 2004).

Diffusion-limited elements, such as P, move slowly through soil (Schenk and Barber 1979), so soil volumes in the immediate vicinity of rhizomes are often depleted of P, while bulk soil 1-2 cm away have P concentrations that remain largely unchanged. The soil that has had P concentration decreased by rhizome uptake is referred to as the depletion volume, the size of which is proportional to the rate of diffusion of P through the soil. Some soil is depleted of P by more than one rhizome from a single plant. The volume of soil explored by multiple rhizomes is defined as competition volume. Since competition volume increases as the rhizome system grows, it is often useful to calculate proportional competition, which in this report is competition volume divided by depletion volume. Using these concepts of depletion and competition, P efficiency can be defined as minimization of proportional competition. This definition has been used in geometric modeling to evaluate the P efficiency of contrasting rhizome architectures (Ge *et al.* 2000; Rubio *et al.* 2001).

5.1.3 Objectives of study

In this study assessment on the growth patterns of subterranean rhizomes of *S. grossus* grown under different soil and fertilizer conditions were made. From the collated data on time-mediated growth of the subterranean rhizomes, architectural model prototypes were developed.

MATERIALS AND METHODS

5.2.1 Growth patterns and population models of rhizomes of *Scirpus grossus* in peat soil

Synthetic populations of *S. grossus* were established on peat soils in 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. Young ramets at 2-3-leaf stage of *S. grossus*, were obtained from rice fields of Tanjung Karang, Selangor. Each ramet was planted at the centre of a plot measuring 2 m x 2 m, previously demarcated and lined with 5 cm x 5 cm grids and sub-plots (Fig. 2.2). Fertilizer applications with nitrophoska blue special NPK fertilizers 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 with while another three sets devoid of fertilizer application served as control. Watering of the plots were made twice daily, one in the morning and the other in the late afternoon using a fine rose fitted to a water hose. No weeds were allowed to grow in the plots during experimentation. The rainfall and temperature data is shown in Fig 2.4 The rainfall ranged from 3.9 - 10.8 mm, and the temperature ranged from 26.5 - 28.6 ^{0}C, while the physico-chemical characteristics of peat soils are depicted in Table 2.1 (in fertilized soils: N: 1.13%, P:0.14%, K: 0.03%, and unfertilized soils: N: 1.02%, P: 0.10%, K: 0.03%).

5.2.2 Growth patterns and population models of rhizomes of *Scirpus grossus* in paddy soil

Plant establishment and care: Synthetic populations of *S. grossus* were established on peat soils in the Malaysian Agriculture Research Development Institute (MARDI)

Research Station, Tanjung Karang, Selangor (N 3.28^o / E 101.08^o), Malaysia for 24 weeks commencing on 26 October 2010. Young ramets at 2-3-leaf stage of *S. grossus*, were obtained from rice fields of Tanjung Karang, Selangor. Each ramet was planted and located after as described in 5.2.1. above.

The rainfall in Tanjung Karang between 3.4-7.2 mm per month, and the temperature ranged between 26-28.3 ^{o}C (Fig. 2.5). The physio-chemical characteristics of peat soils are depicted in Table 2.2 (in fertilized soils: N: 0.29%, P: 0.09%, K: 0.37%, and unfertilized soils: N: 0.24%, P: 0.07%, K: 0.35%).

5.2.3 Patterns of ramets emergence of *Scirpus grossus* in peat and paddy soils

Ramets number was determined by counting the number of ramet/plant on a weekly basis. For each plot all ramet growth were selected for measurement for each treatment and recorded on the map.

5.2.4 Ramet/rhizome dynamics of *Scirpus grossus* in peat and paddy soils

Ramets and mortality number was determined by counting the number of ramet/plant on a weekly basis. For each plot all ramet were selected for measurement for each treatment and recorded on the map. The mortality number equals to the number of dead plants.

5.2.5 Total length rhizomes of *Scirpus grossus* in peat and paddy soils

The exposed rhizomes were mapped by measuring inter-nodal lengths of each rhizome, and noting the precise positions of the harvested plants. These data were transferred into the data logger, and together with the weekly data on the precise spatio-temporal positions of emerged plants of *S. grossus*. Computer generated subterranean rhizome architectures were produced. The computer program used was AutoCAD 10 (model from Autodesk C. From USA).

5.2.6 Fractal dimension of *Scirpus grossus* in peat and paddy soils

The fractal dimension boxing analyses of rhizomes in both fertilized and unfertilized paddy soils were done. Rhizome system structures of heterogeneous plant communities were recorded as integral systems by using the trench profile method. Fractal dimensions of the rhizome images were calculated from image files by the box-counting method (2, 4, 8, 16, 32, 64, 80, 128, 200, 256). This method allows the structural complexity of such associations to be compared plant communities, with regard to their potentials for soil resource acquisition and utilization. The digitized rhizome images were used for fractal analysis following the box-counting method described by (Tatsumi *et al.* 1989) and (Ketipearachchi and Tatsumi 2000; Klarizze 2005; Margitta and Arthur 2005).

The rhizome patterns of the rhizome system associations of different plant communities were analysed and quantified as integral basic functional units. The box-counting method (Block *et al.* 1990; Diebel and Feret 1993; Ketipearachchi and Tatsumi 2000) was applied to determine the fractal dimension. The scanned images of rhizome system associations were first covered by a frame. The frame was divided into a grid, each box having a side length ‘a’. The box size changed within a range of 5 – 20 mm (corresponding to a range of 50 – 200 mm for the original profile) in three steps. The number of intersected box's N(a), found in the rhizome images at each scale were counted. Plotting number of box's N(a) against side length a on a log–log scale gave a straight line. The slope as the line was used to calculate the fractal dimension (D) which results from the quotient of two logarithms following the power-law relationship:

$$N = a^{D} \rightarrow D = \log N / \log a.$$

In this study we used: $N \sim L^{-D}$, $\log N = \log c - D \log L$

L= Box size, N= # of Box count the intersected.

RESULTS AND DISCUSSION

5.3.1 Subterranean architectural models of *Scirpus grossus*

5.3.1.1 Length of rhizomes in both fertilized and unfertilized peat and paddy soils

The general clonal growth patterns of *S. grossus* plants reiterated by rhizomatous growth and branches in peat and paddy soils, as exemplified by gross number of ramets produced and subterranean rhizome lengths from a single-mother plant are shown in Tables 5.1and 5.2 and Figs. 5.1a, b, 5.2a, b). As in the aerial ramets described in Chapter 4 (pp.190 - 199), the growth of subterranean rhizomes displayed the initial lag-phase with very slow recruitments of new rhizomes for the first ten weeks after transplanting with or without fertilizer applications. Thereafter, albeit different quanta of increase, there were some manifestations in enhance growth with geometric increments in the length of rhizomes in unfertilized peat and paddy soils (Figs 5.1a, 5.2a) as well as unfertilized peat soils (Fig. 5.1b). Interestingly, the growth of rhizomes in fertilized paddy soils showed logistic increments up to 24 weeks of experimentation. In peat soils, fertilizer application did appear to increase the rhizome lengths with readings slightly higher compared with those counterparts in unfertilized plots. For example in the first 12 weeks after experimentation, the total mean length of rhizomes in the 1 mx 1 m quadrant was only 6.5 cm in unfertilized peat soils, while in the fertilized peat soils this was 9.0 cm. By the end of the experiment at 24 weeks, the parallel figures were 60.0 cm and 65.0 cm, respectively. In paddy soils, rhizome growth was substantially more robust with readings at the end of 24 weeks of experimentation at 82.50 cm in unfertilized soils and 87.50 cm, albeit insignificantly different from each other at $p>0.05$(HSD tests) in the 1 m x 1m quadrant. It was intriguing that the ensuing growth of rhizomes in the fertilized paddy soils between 18 and 24 weeks were asymptotic, with possibly due to very tight phalanxes of aerial ramets, thereby displaying very parallels in the slow growth in subterranean rhizomes, with marginal increase of only 7.5 cm per 1m x 1m quadrant for that period.

The length of rhizomes recorded was 82.50 cm m^2 in unfertilized soils and 87.50 cm m^2 in fertilized soils (Table 5.1 and Fig. 5.1). it was not significantly differently different at 0.05%.

The general clonal growth patterns of *S. grossus* plant is shown by rhizomatous growth and branches from a single-mother plant. As shown in (Table 5.2 and Fig. 5.2), the best period of Subterranean rhizome's growth in general was between 12-16 weeks. The best period of Subterranean rhizome's growth in fertilized soils was at week 24th and similarly in unfertilized soils, it was also at week 24th. The Length of rhizomes recorded was 60.00 cm m^2 in unfertilized soils and 65.00 cm m^2 in fertilized soils, (Table 5.2 and Fig. 5.2) not significantly different at 0.05%.

Table 5.1 Mean gross number of aerial ramets and total length of rhizomes (m^{-2}) of *Scirpus grossus* grown in fertilized and unfertilized peat soil used at MARDI Research Station, Jalan Kebun, Selangor, Malaysia[#]

Weeks after transplanting	Gross number of ramets m^{-2}		Mean total length rhizomes (cm) (1 m x 1 m quadrant)	
	F0	F1	F0	F1
2	0.92 g	0.75 ij	0.25 i	0.25 i
4	1.67 fg	1.67 ghi	0.75 i	0.50 i
6	4.92 efg	4.42 ghi	1.25 hi	1.75 hi
8	10.50 defg	11.17 efgh	2.00 hi	3.50 hi
10	26.17 bcdef	26.75 cdefg	3.50 ghi	5.25 ghi
12	50.92 abcd	53.92 abcde	6.25 efg	9.00 efg
14	74.17 abc	81.42 abc	10.75 cde	13.00 cde
16	95.50 ab	101.67ab	15.75 abcd	19.50 abcd
18	105.25 a	105.67 ab	22.00 abc	27.50 abc
20	109.83 a	120.17 ab	32.50 ab	35.00 ab
22	116.83 a	125.17 a	42.50 ab	47.50 ab
24	117.83 a	126.75 a	60.00 a	65.00 a

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

Table 5.2 Mean gross number of aerial ramets and total length of rhizomes (m^{-2}) of *Scirpus grossus* grown in fertilized and unfertilized peat soil used at MARDI Research Station, Tanjung Karang, Selangor, Malaysia[#]

Weeks after transplanting	Gross number of ramets m^{-2}		Mean total length rhizomes (cm) (1 m x 1 m quadrant)	
	F0	F1	F0	F1
2	0.00 j	0.75 l	0.25 i	0.50 i
4	0.00 j	2.00 jk	0.50 i	1.25 i
6	1.00 hij	3.92 hij	1.00 hi	2.50 hi
8	2.33 fgh	6.75 fgh	1.75 hi	4.75 hi
10	4.92 f	10.58 f	7.50 ghi	11.75 ghi
12	15.83 e	25.83 e	17.5 efg	23.00 efg
14	34.42 cd	43.83 cd	30.00 cde	37.50 cde
16	48.00 abc	64.92 abc	50.00 abcd	60.00 abcd
18	54.67 abc	72.33 abc	72.50 abc	80.00 abc
20	63.92 ab	80.83 ab	82.50 ab	85.00 ab
22	74.67 ab	88.08 ab	82.50 ab	87.50 ab
24	83.67 ab	97.08 a	82.50 a	87.50 a

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

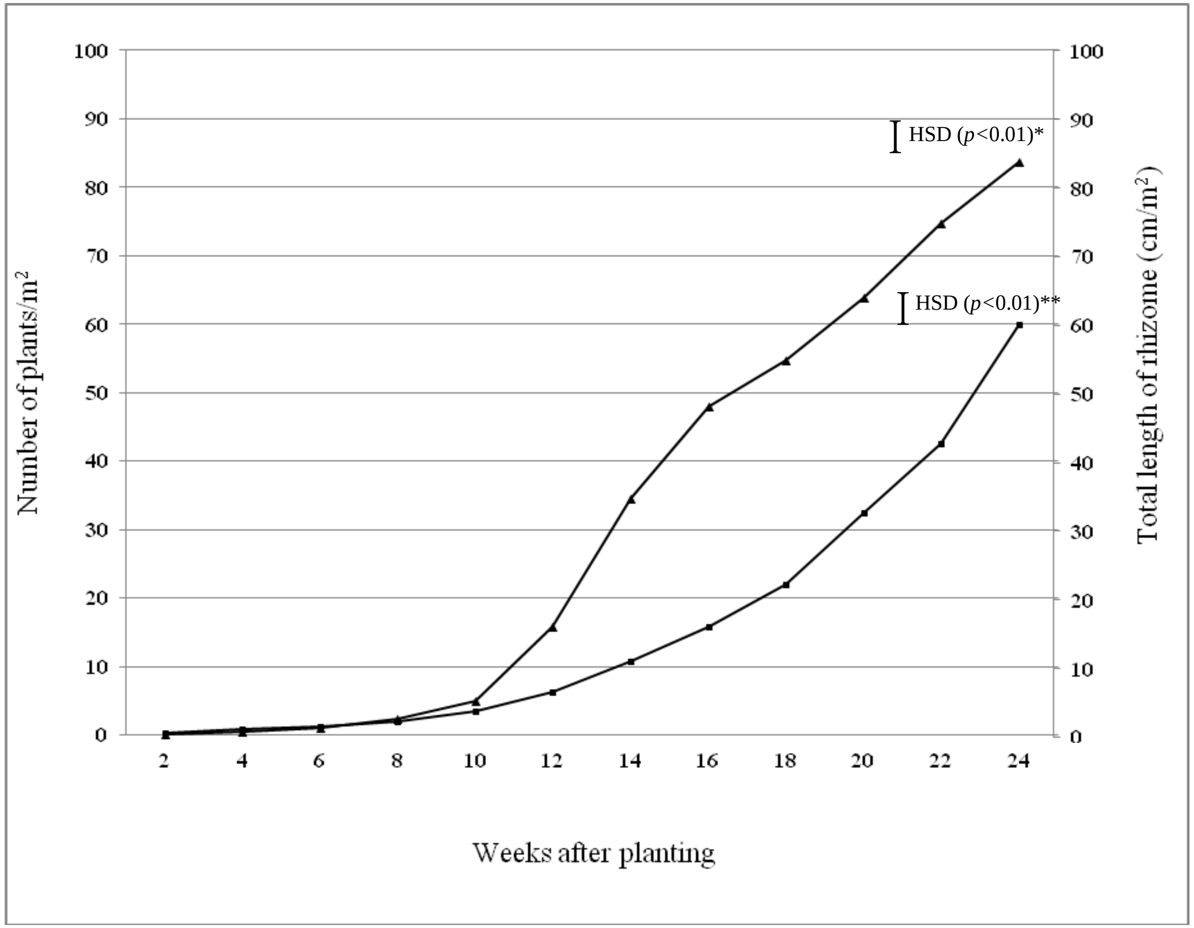


Fig. 5.1a Population increase of aerial ramets and total length rhizomes of *Scirpus grossus* grown on unfertilized (F0) peat soil. Plant number (▲), Total length (■).*Plant number, ** Total length rhizomes.

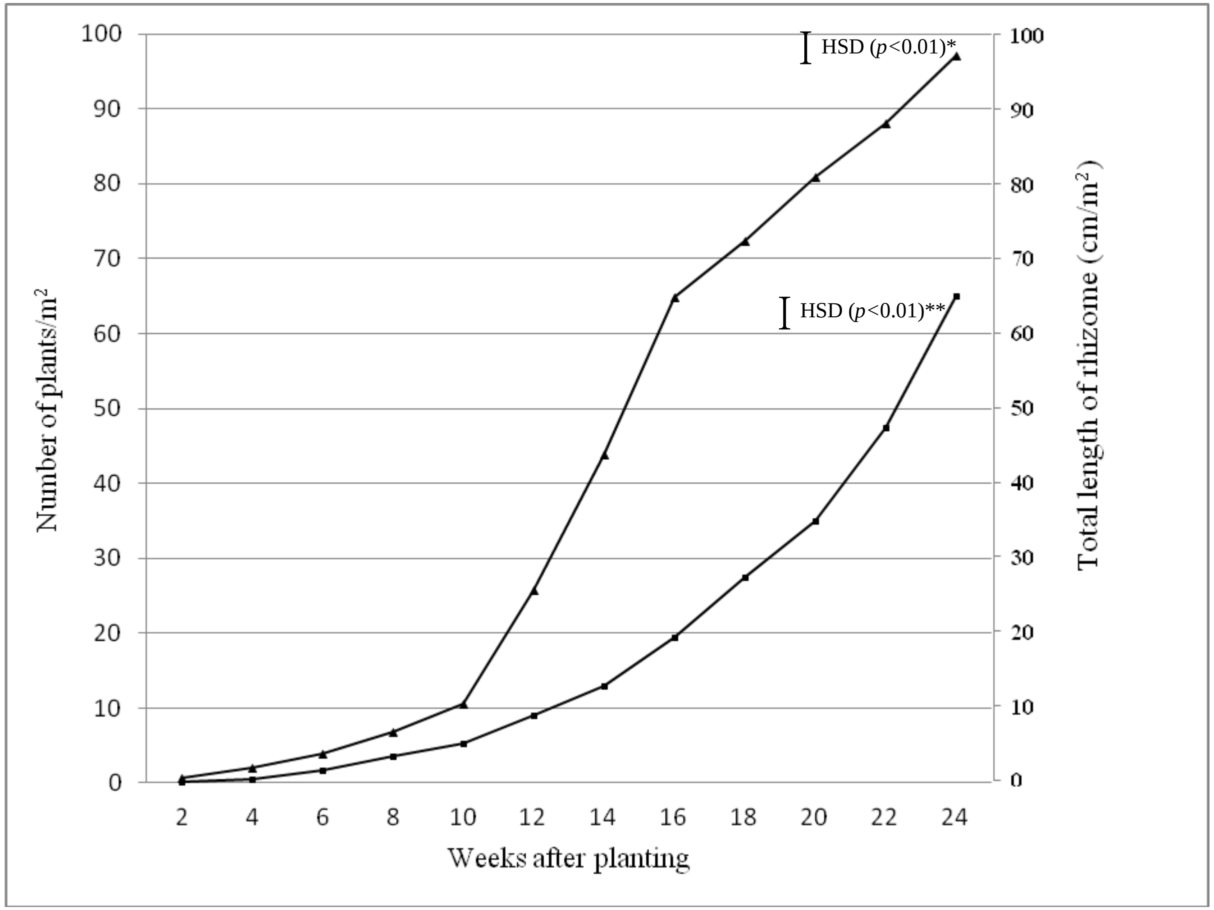


Fig. 5.1b Population increase of aerial ramets and total length rhizomes of *Scirpus grossus* grown on fertilized (F1) peat soil. Plant number (▲), Total length (■).*Plant number, ** Total length rhizomes.

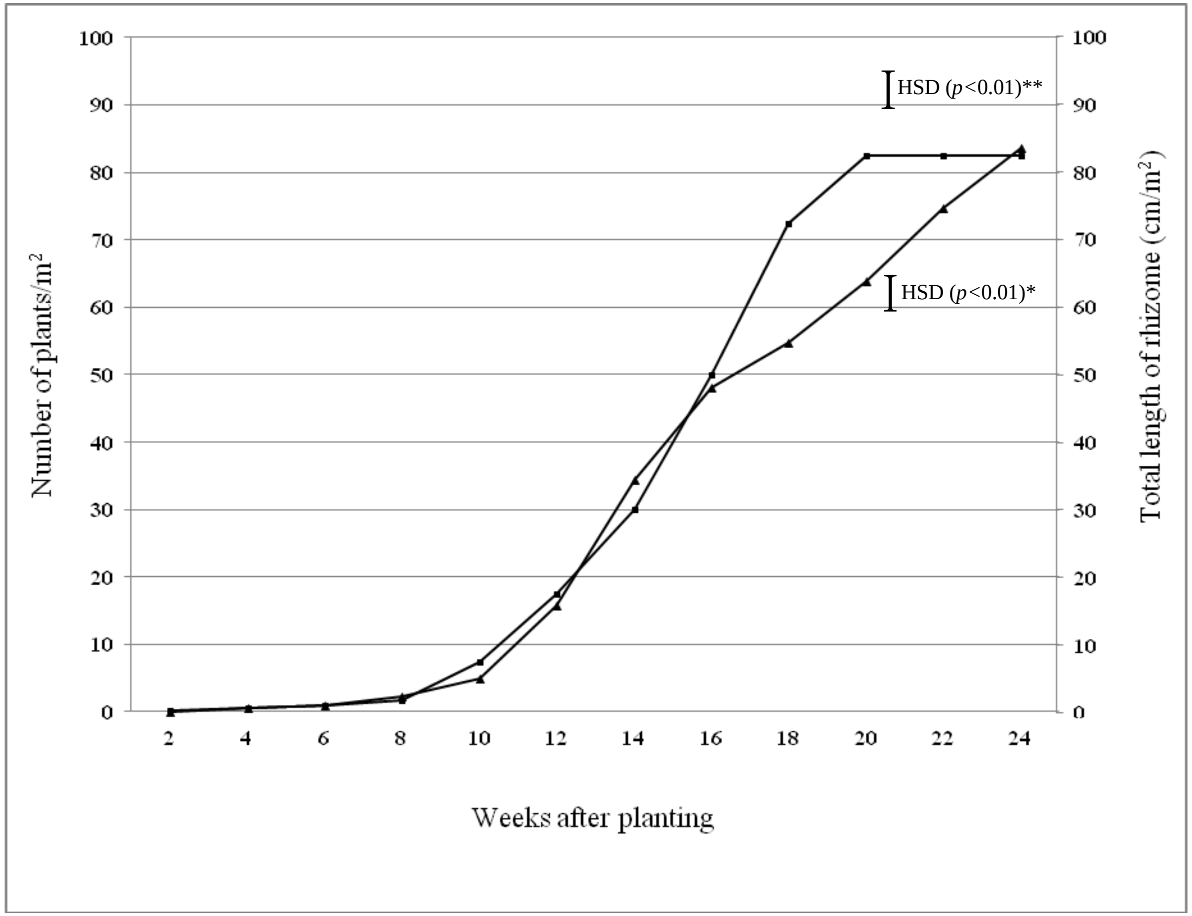


Fig. 5.2a Population increase of aerial ramets and total length rhizomes of *Scirpus grossus* grown on unfertilized paddy soil. Plant number (▲), Total length (■).*Plant number. ** Total length rhizomes.

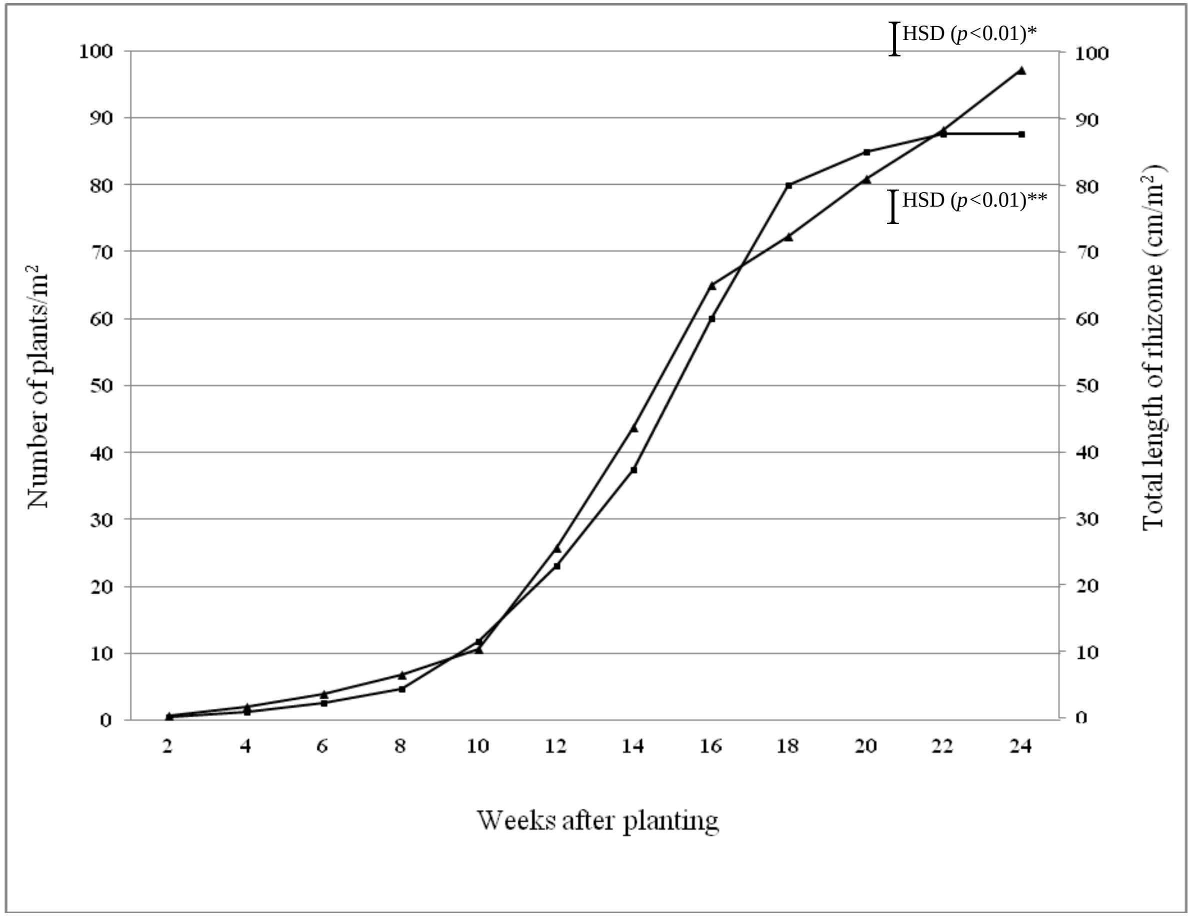


Fig. 5.2b Population increase of aerial ramets and total length rhizomes of *Scirpus grossus* grown on fertilized (F1) paddy soil. Plant number (▲), Total length (■).*Plant number, ** Total length rhizomes.

5.3.1.2 Subterranean modular growth of *Scirpus grossus* grown in peat and paddy soils

As shown in Figs. 5.3 - 5.14 time-mediated growth of subterranean rhizomes of *S. grossus.* in unfertilized soils, showed the best growth period at 3 month. While in fertilized soils the best growth period was at 4 month.

Figs. 5.15 - 5.26 show time-mediated growth of subterranean rhizomes of *Scirpus grossus.* in unfertilized soils, showing the best period of growth was at 6 month. Similarly in fertilized soils the best period of growth was also at 6 month.

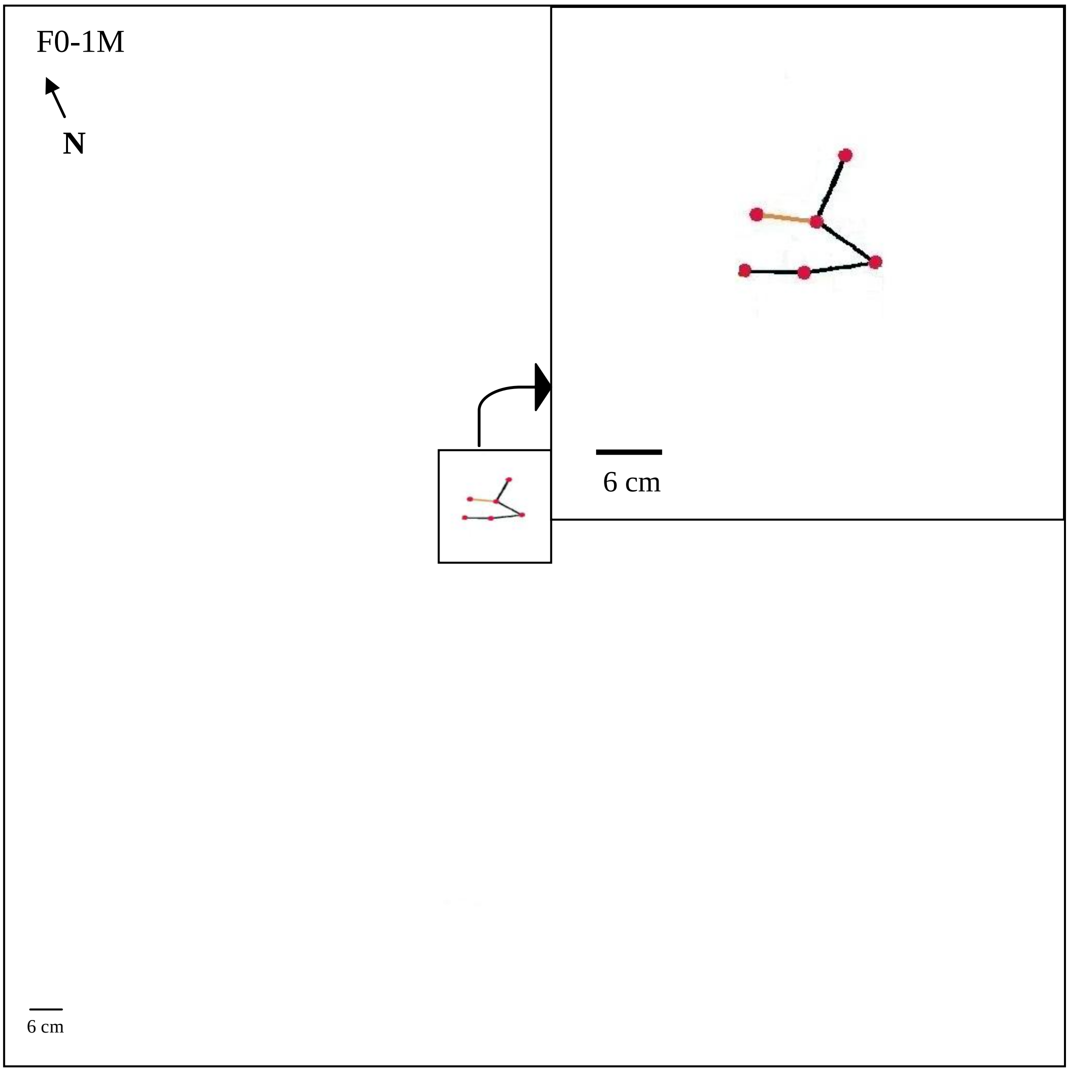


Fig. 5.3 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 1month after experimentation (F0- 1M). ↑N denotes geographical north.

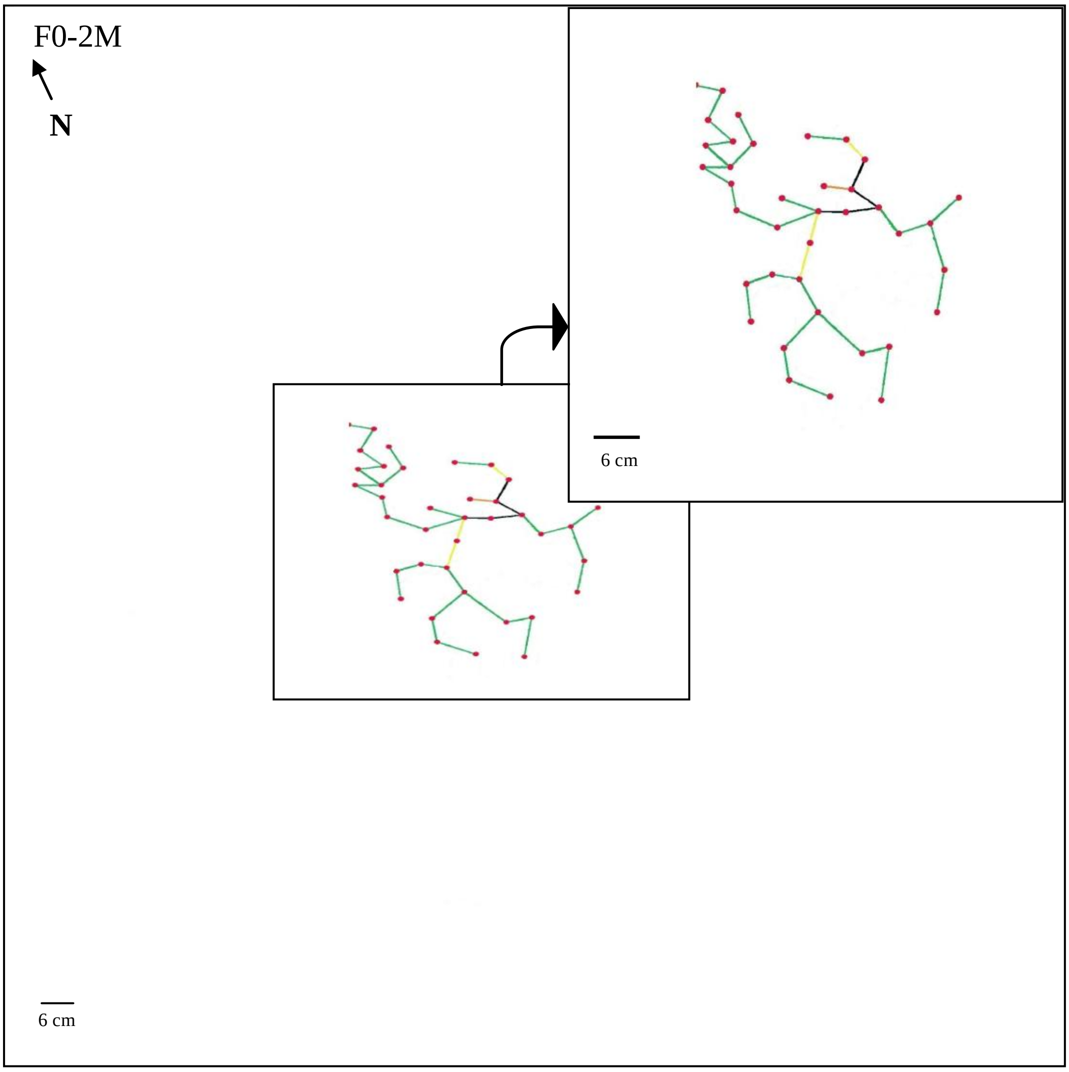


Fig. 5.4 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 2months after experimentation (F0 – 2M). ↑N denotes geographical north.

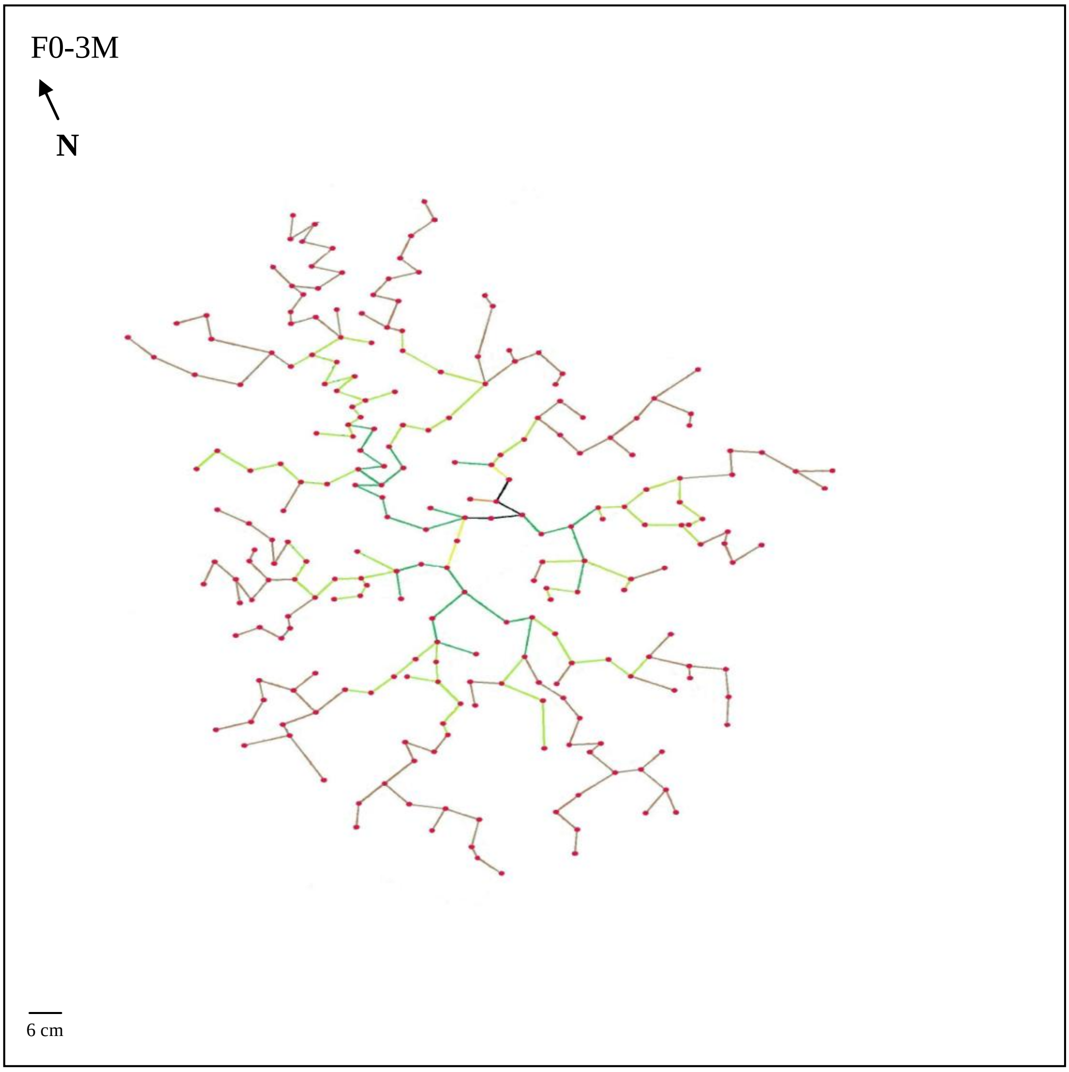


Fig. 5.5 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 3months after experimentation (F0 – 3M). ↑N denotes geographical north.

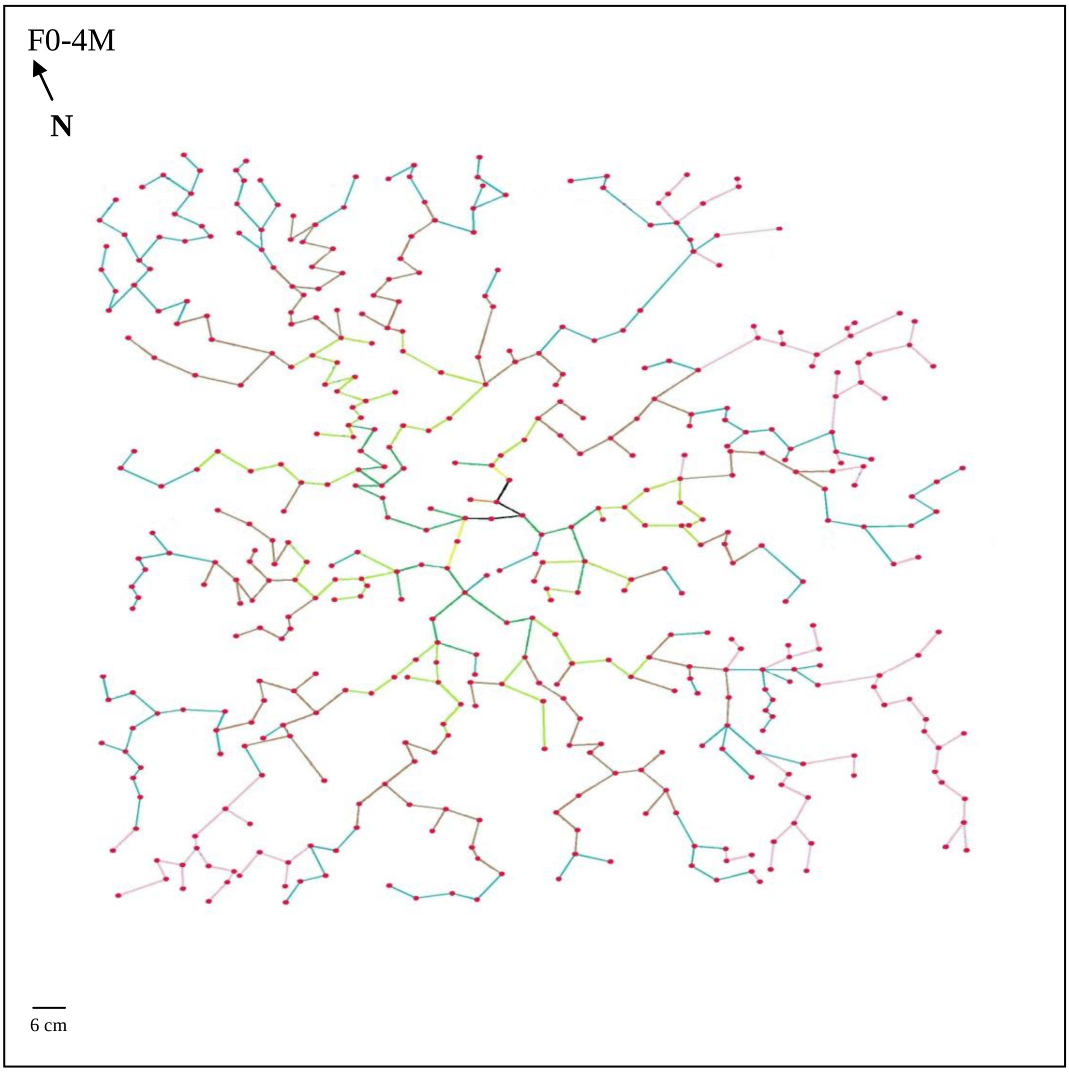


Fig. 5.6 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 4months after experimentation (F0 – 4M). ↑N denotes geographical north.

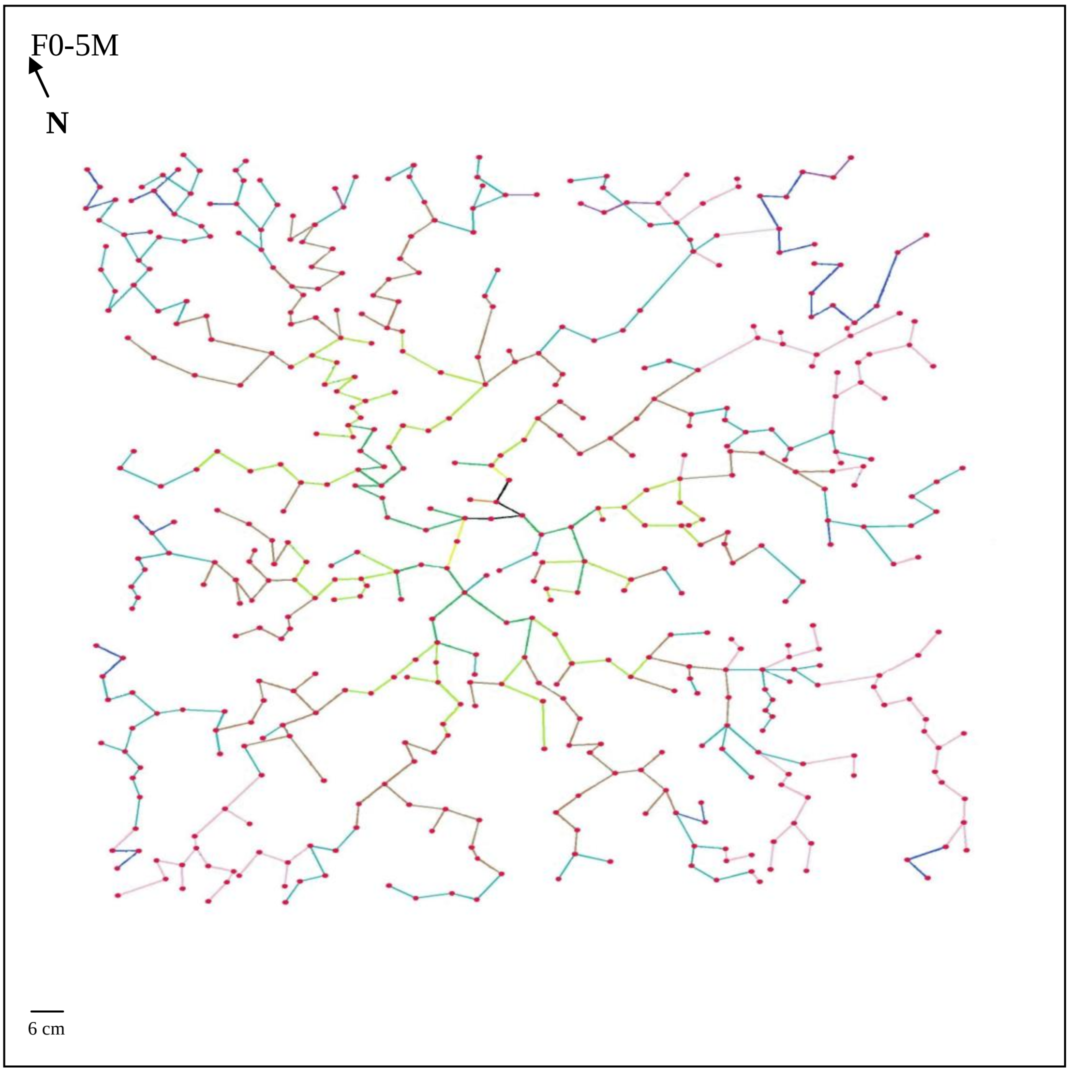


Fig. 5.7 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 5months after experimentation (F0 – 5M). ↑N denotes geographical north.

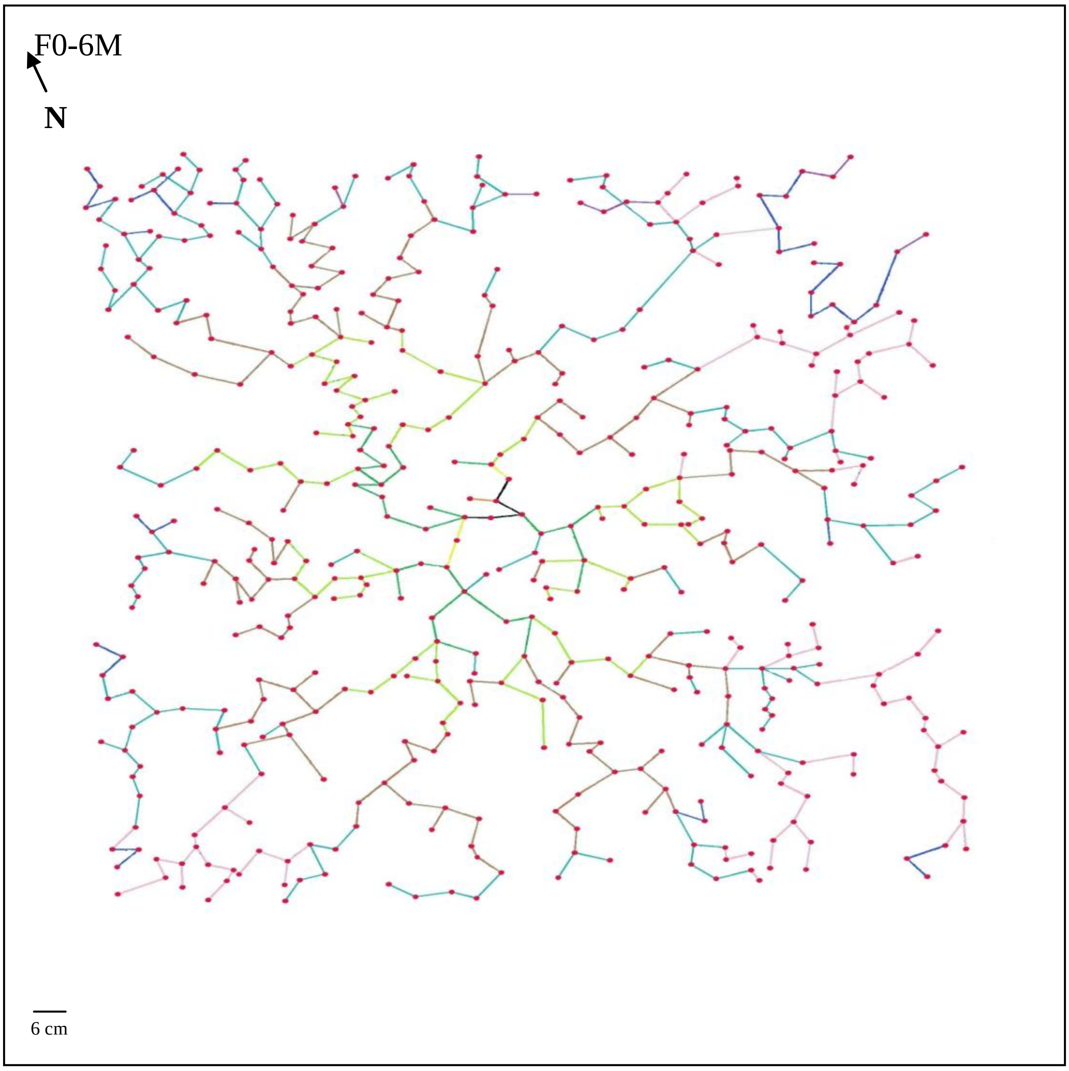


Fig. 5.8 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 6months after experimentation (F0 – 6M). ↑N denotes geographical north.

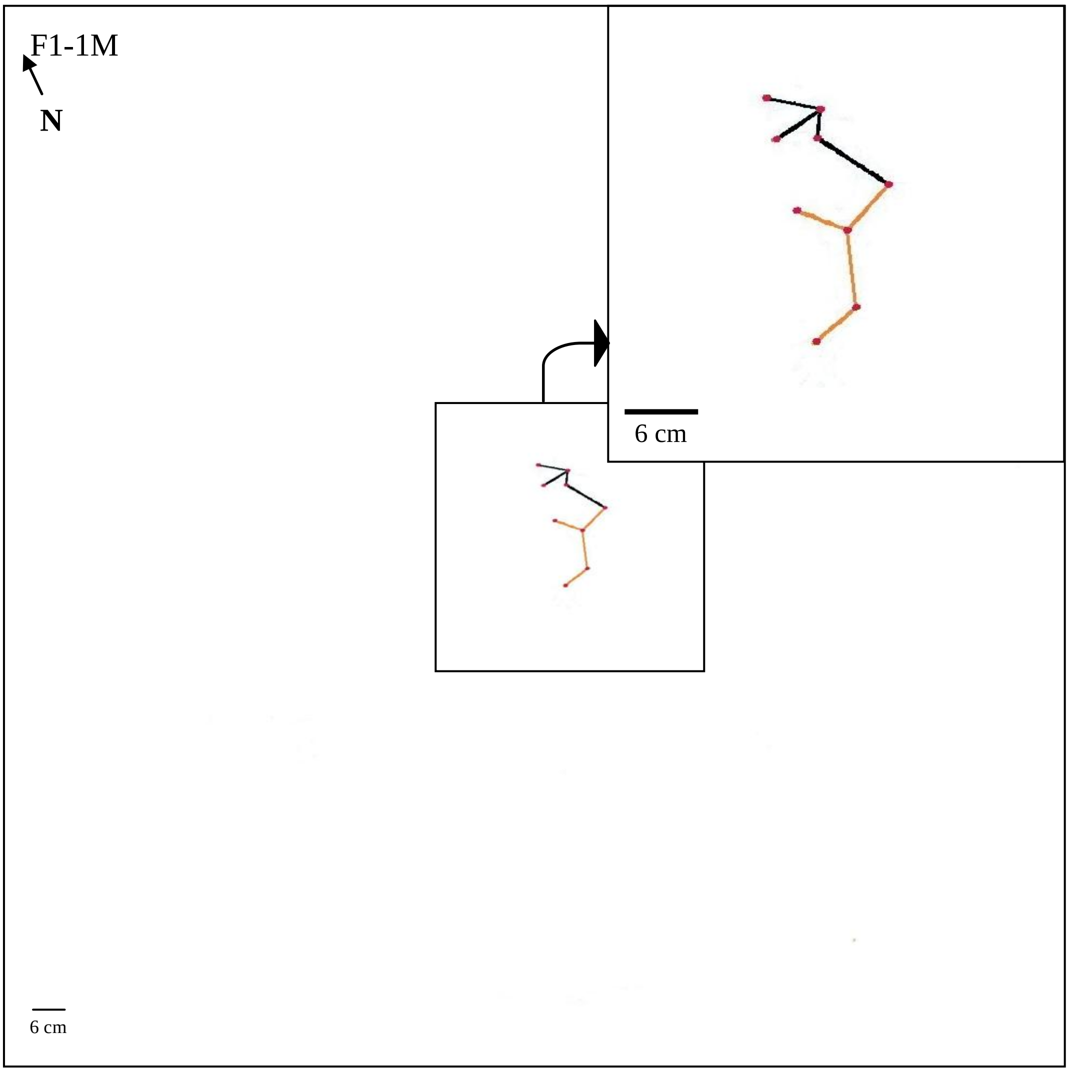


Fig. 5.9 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 1month after experimentation (F1 – 1M). ↑N denotes geographical north.

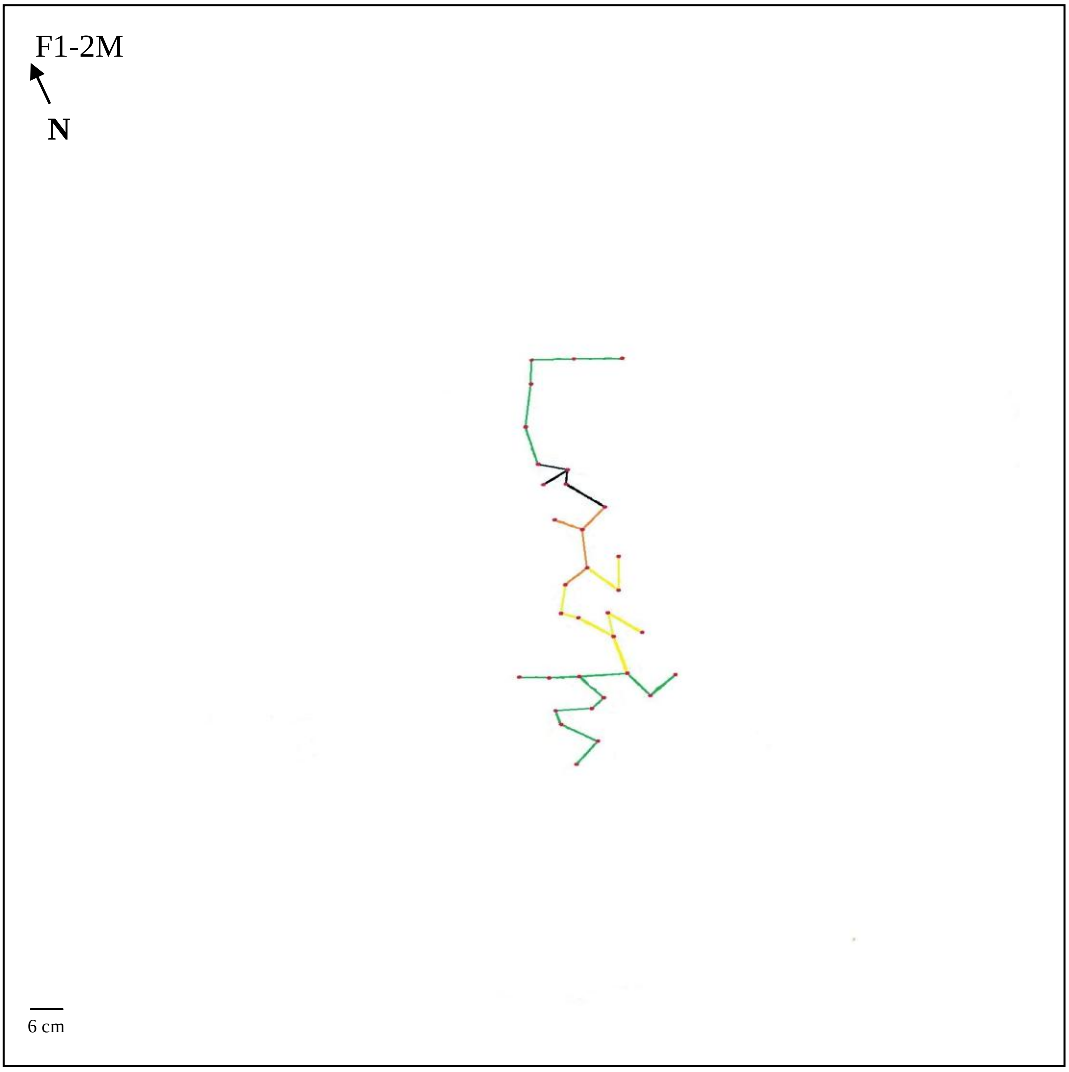


Fig. 5. Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 2months after experimentation (F1 – 2M). ↑N denotes geographical north.

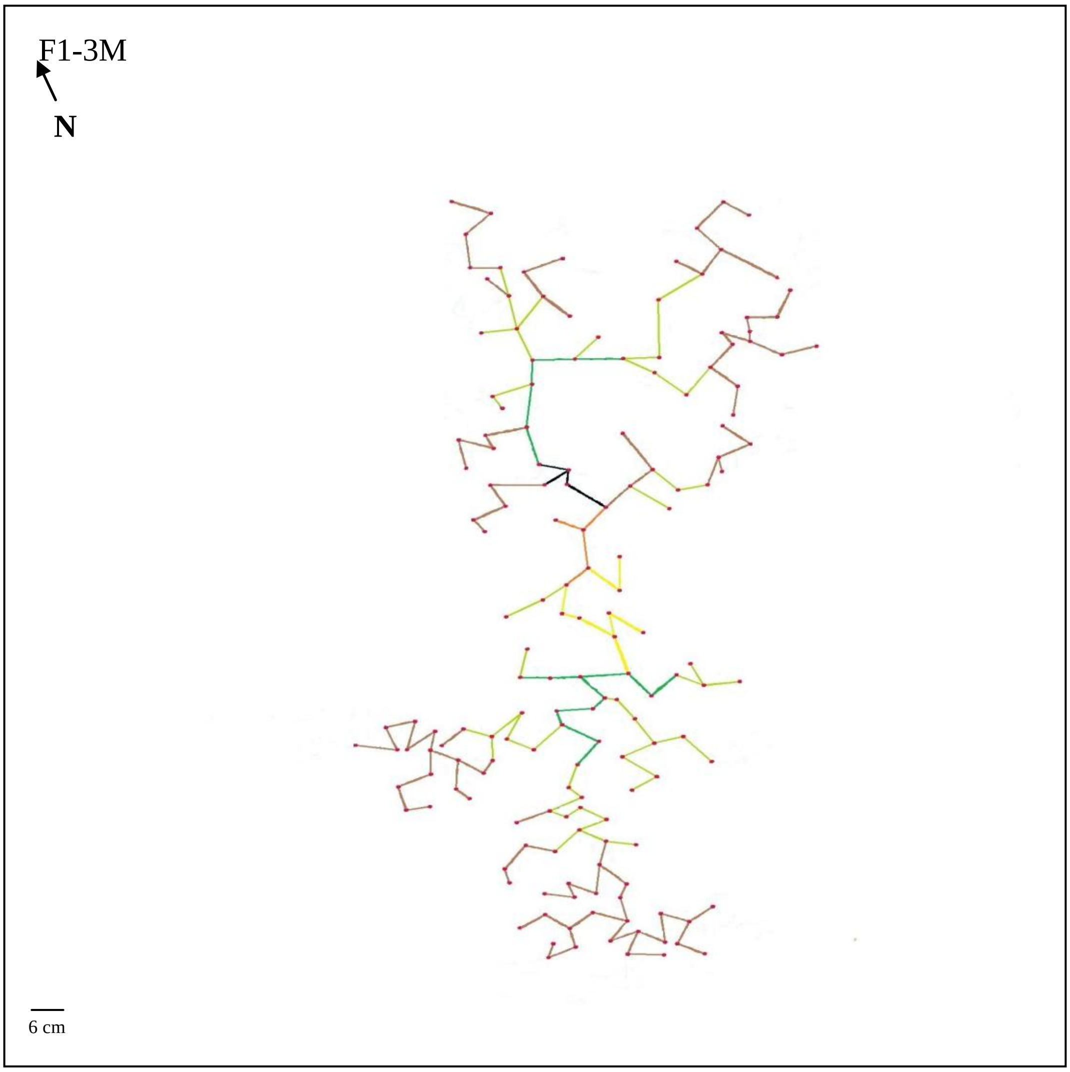


Fig. 5.11 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 3months after experimentation (F1 – 3M). ↑N denotes geographical north.

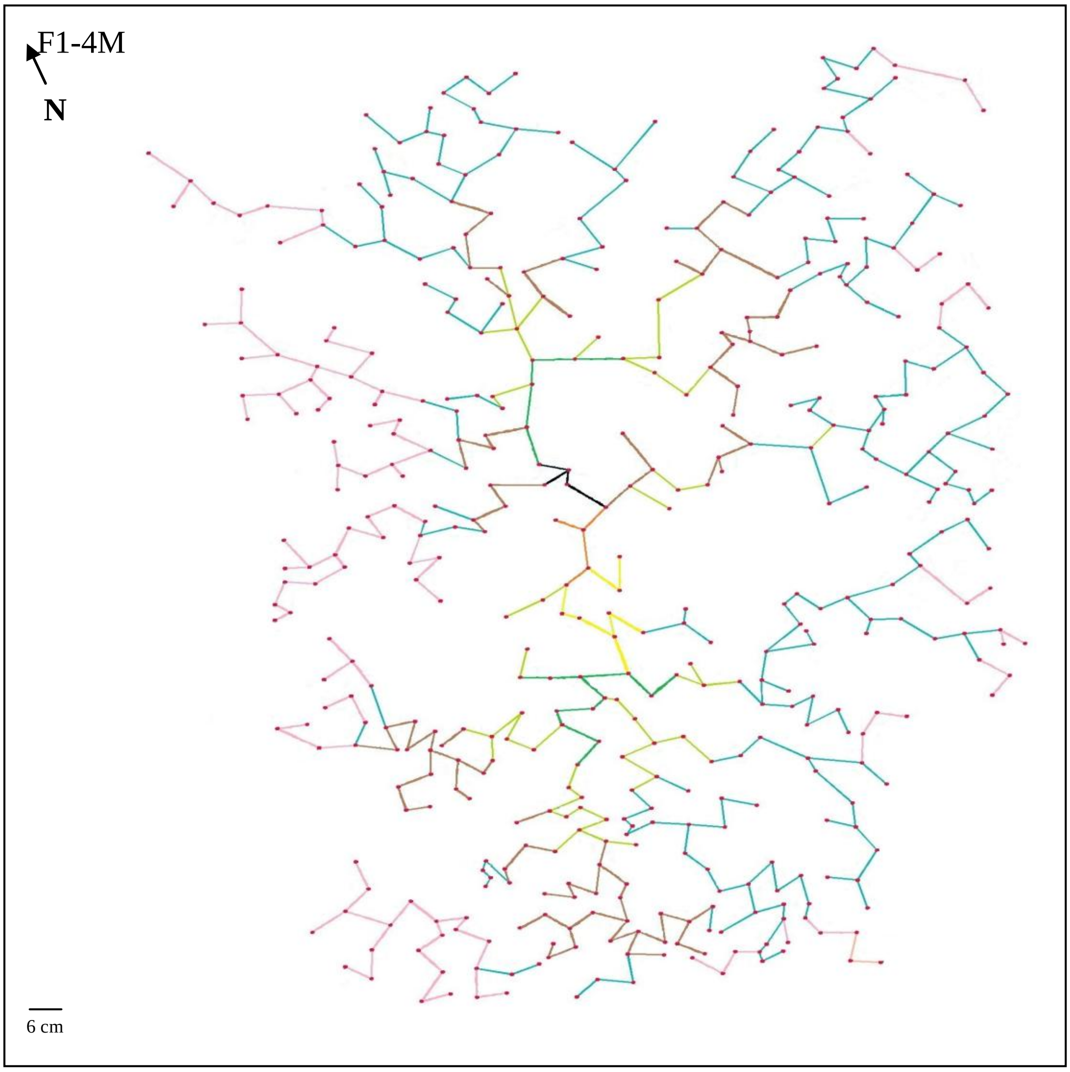


Fig. 5.12 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 4months after experimentation (F1 – 4M). ↑N denotes geographical north.

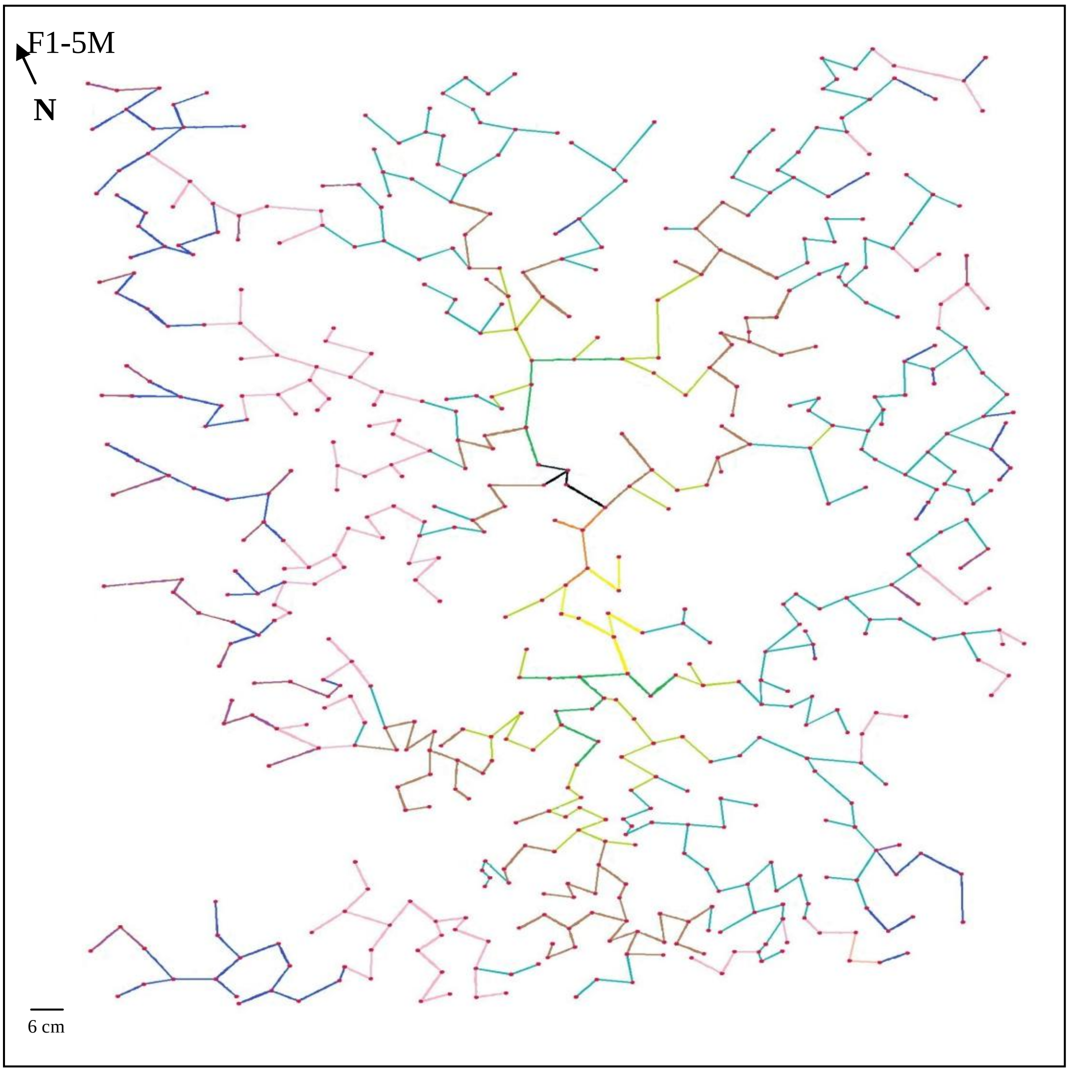


Fig. 5.13 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 5months after experimentation (F1 – 5M). ↑N denotes geographical north.

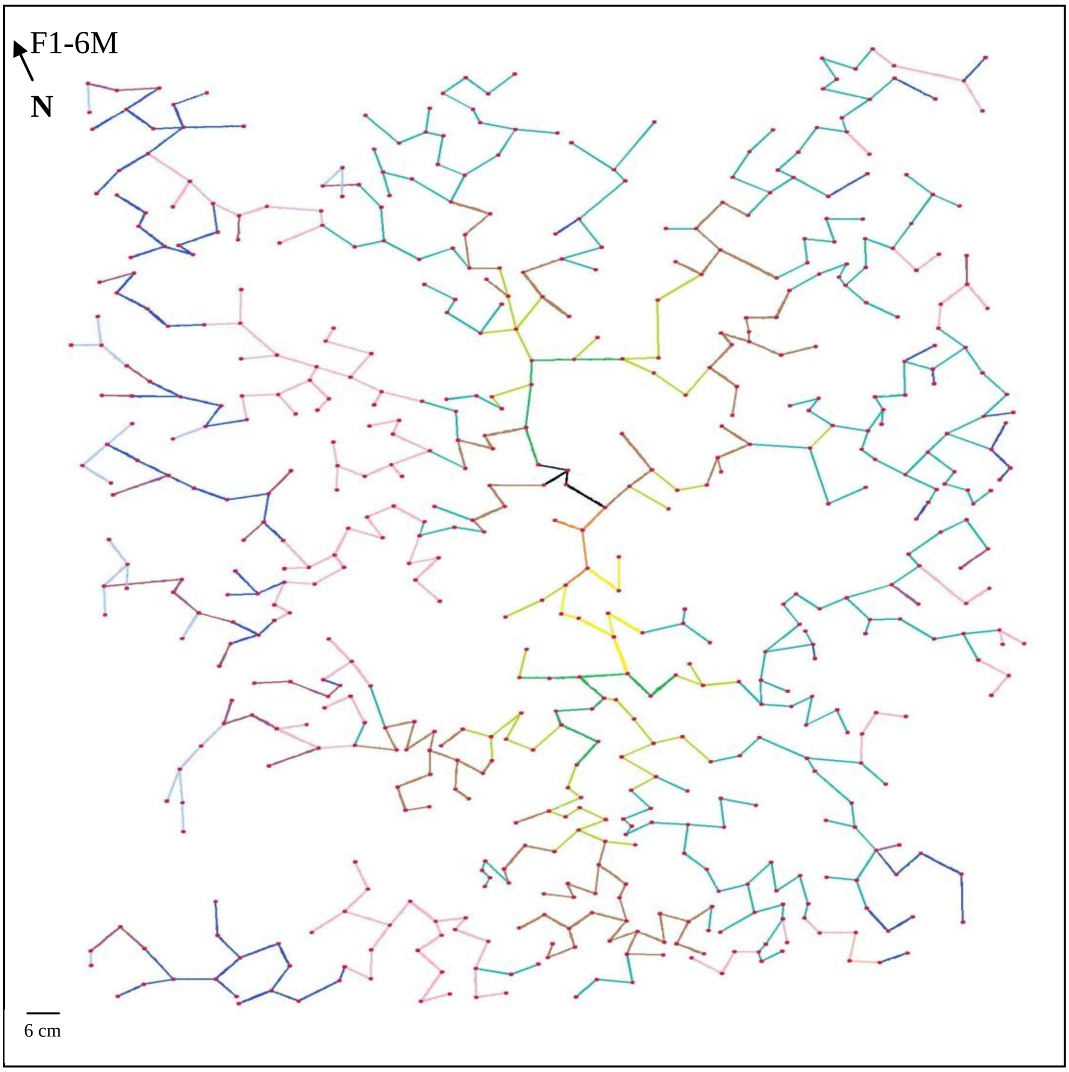


Fig. 5.14 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized peat soil after 6months after experimentation (F1 – 6M). ↑N denotes geographical north.

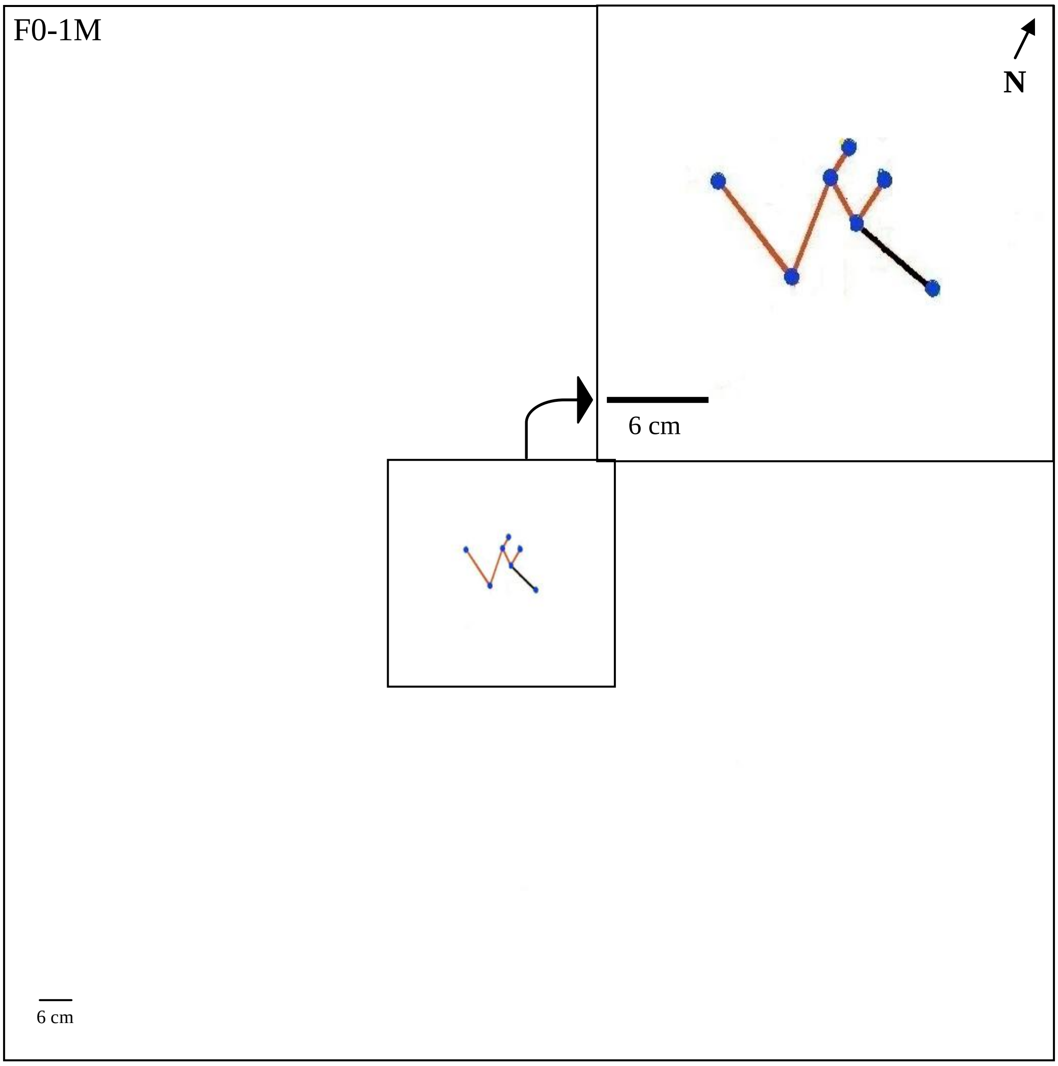


Fig. 5.15 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 1month after experimentation (F0 – 1M). ↑N denotes geographical north.

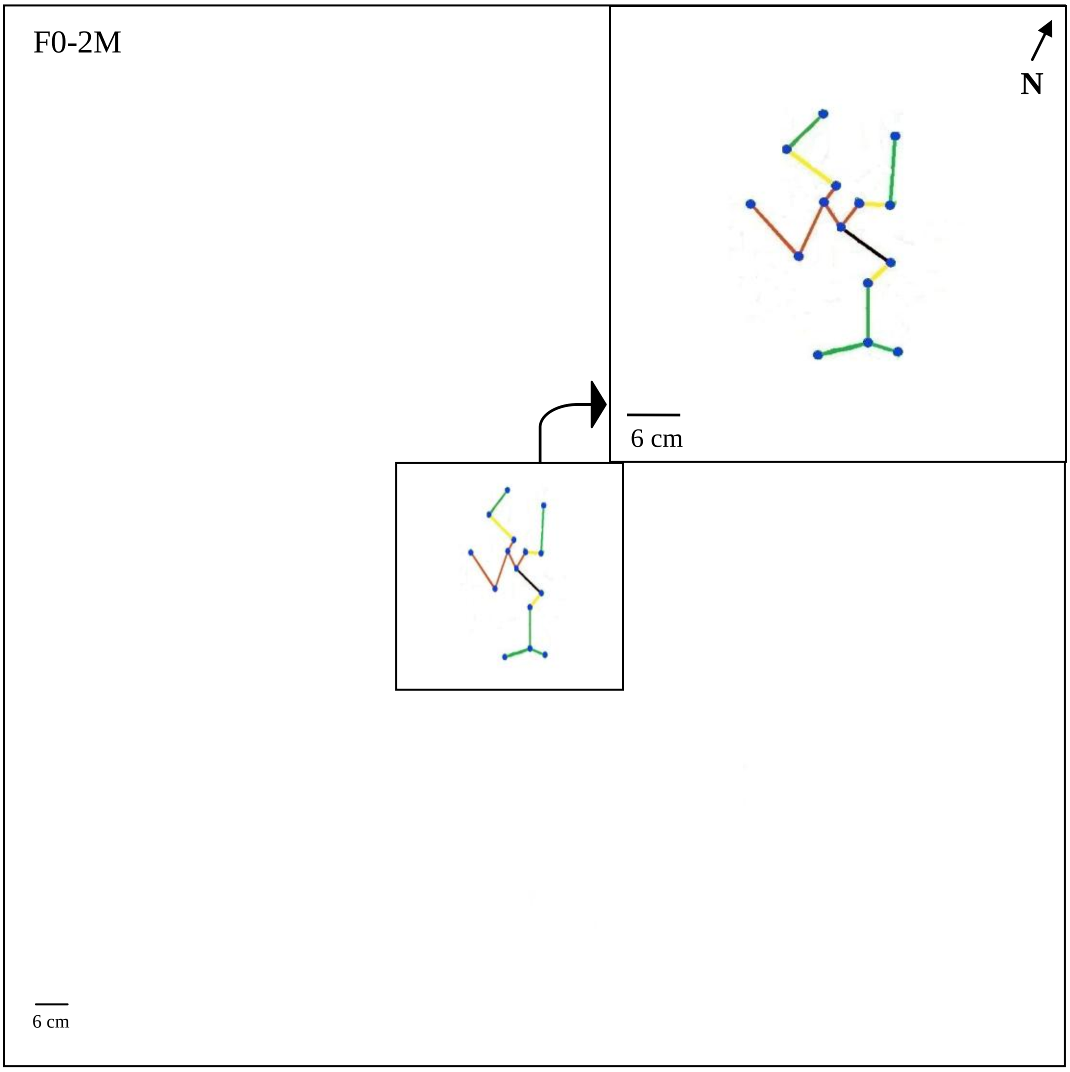


Fig. 5.16 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 2months after experimentation (F0 – 2M). ↑N denotes geographical north.

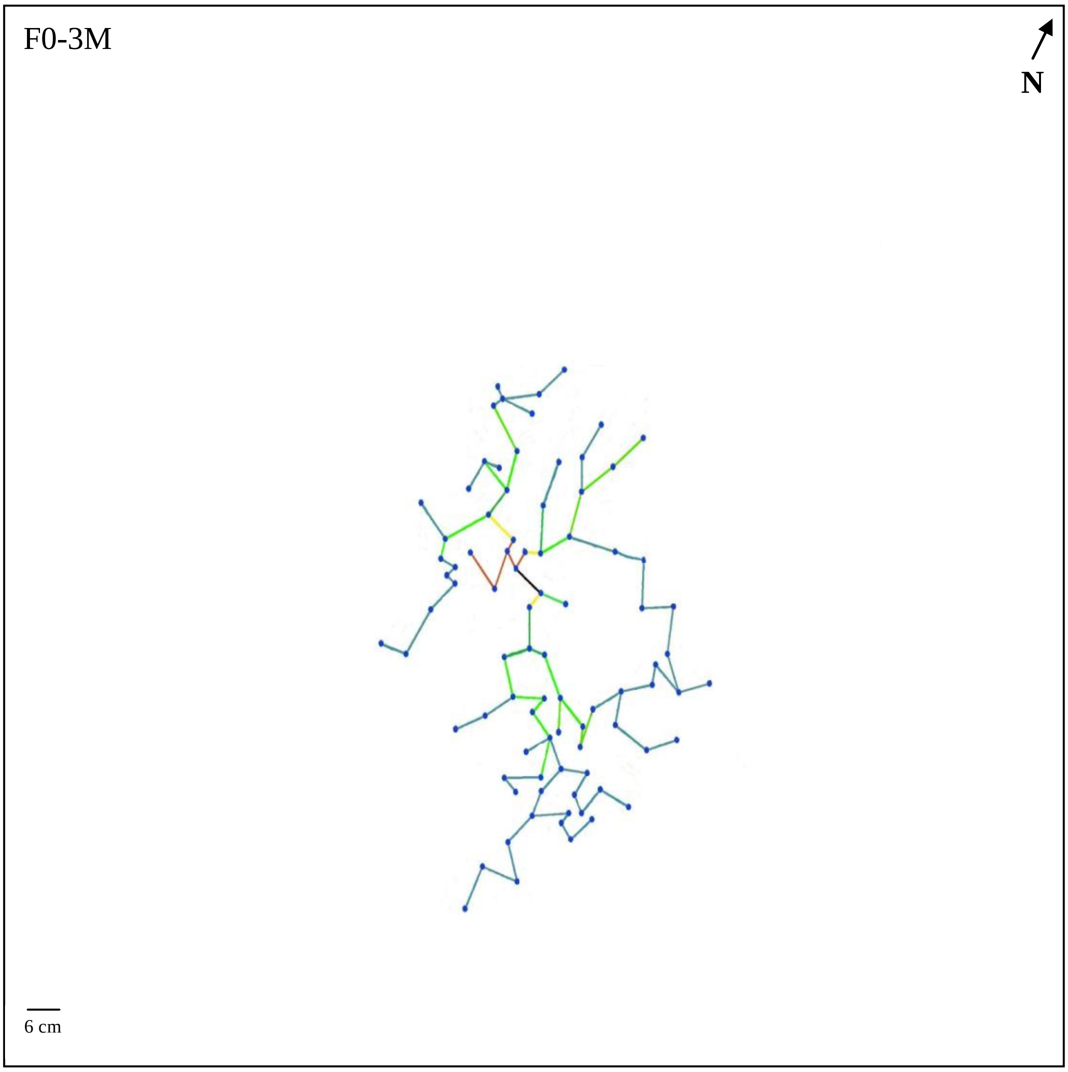


Fig. 5.17 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 3months after experimentation (F0 – 3M). ↑N denotes geographical north.

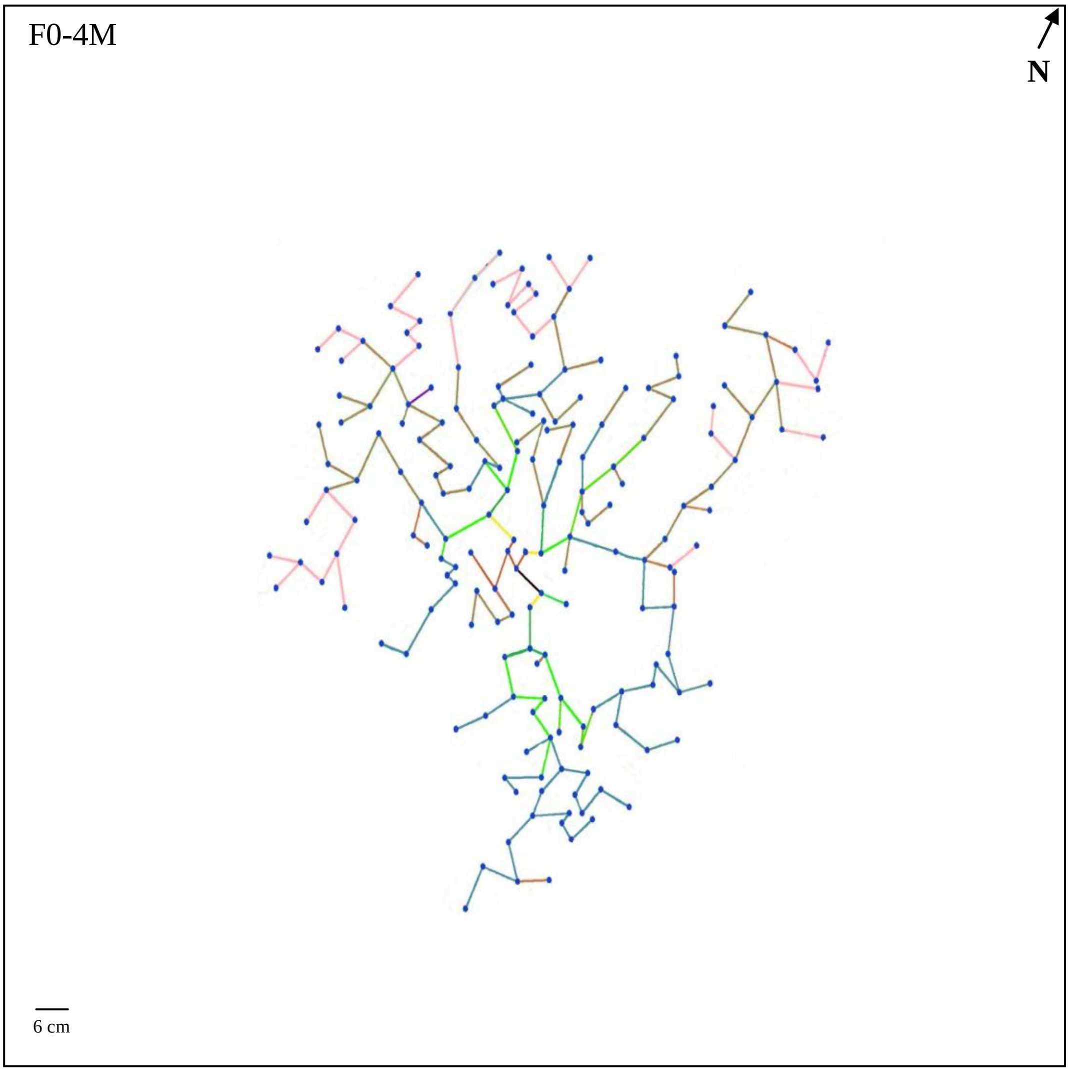


Fig. 5.18 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 4months after experimentation (F0 – 4M). ↑N denotes geographical north.

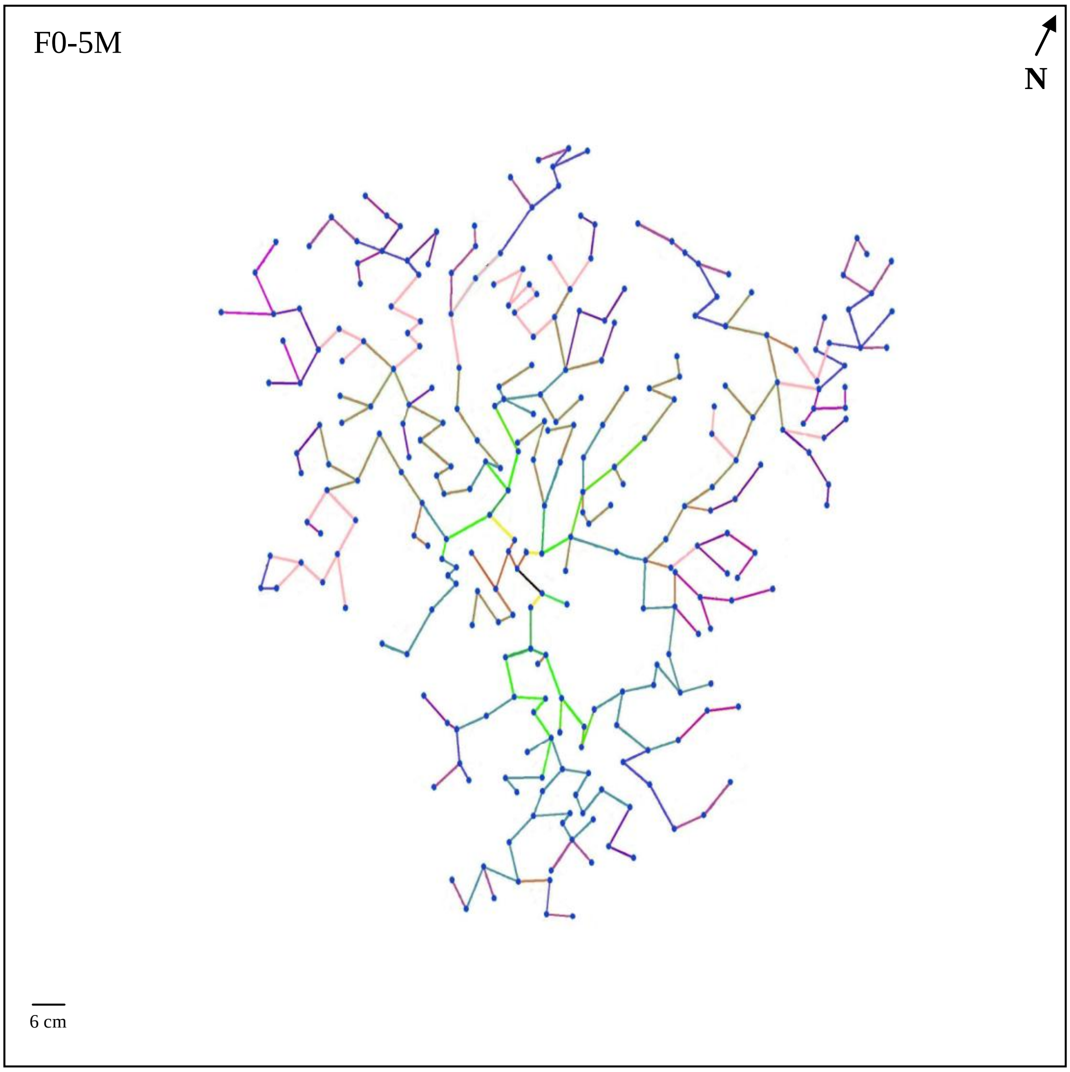


Fig. 5.19 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 5months after experimentation (F0 – 5M). ↑N denotes geographical north.

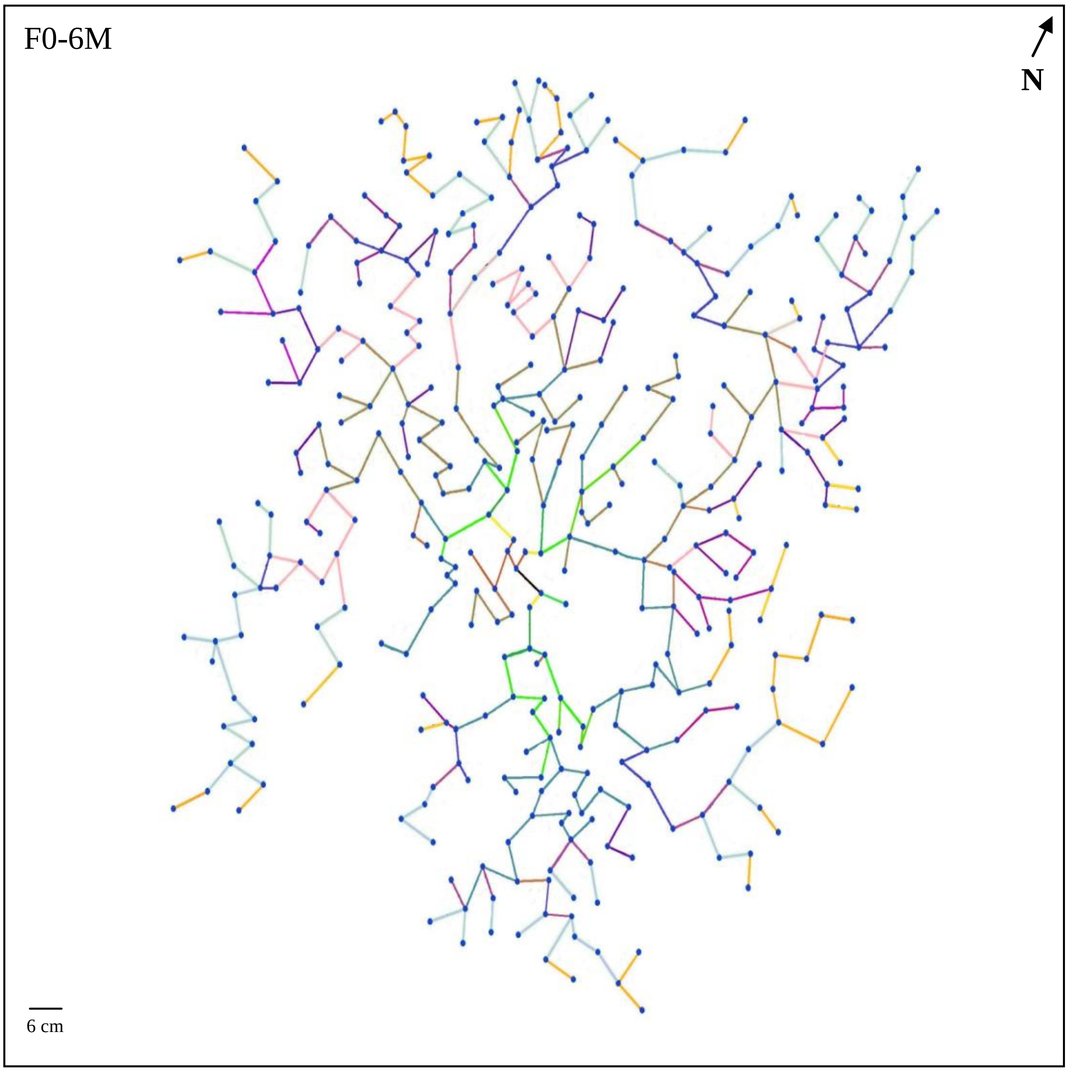


Fig. 5.20 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 6months after experimentation (F0 – 6M). ↑N denotes geographical north.

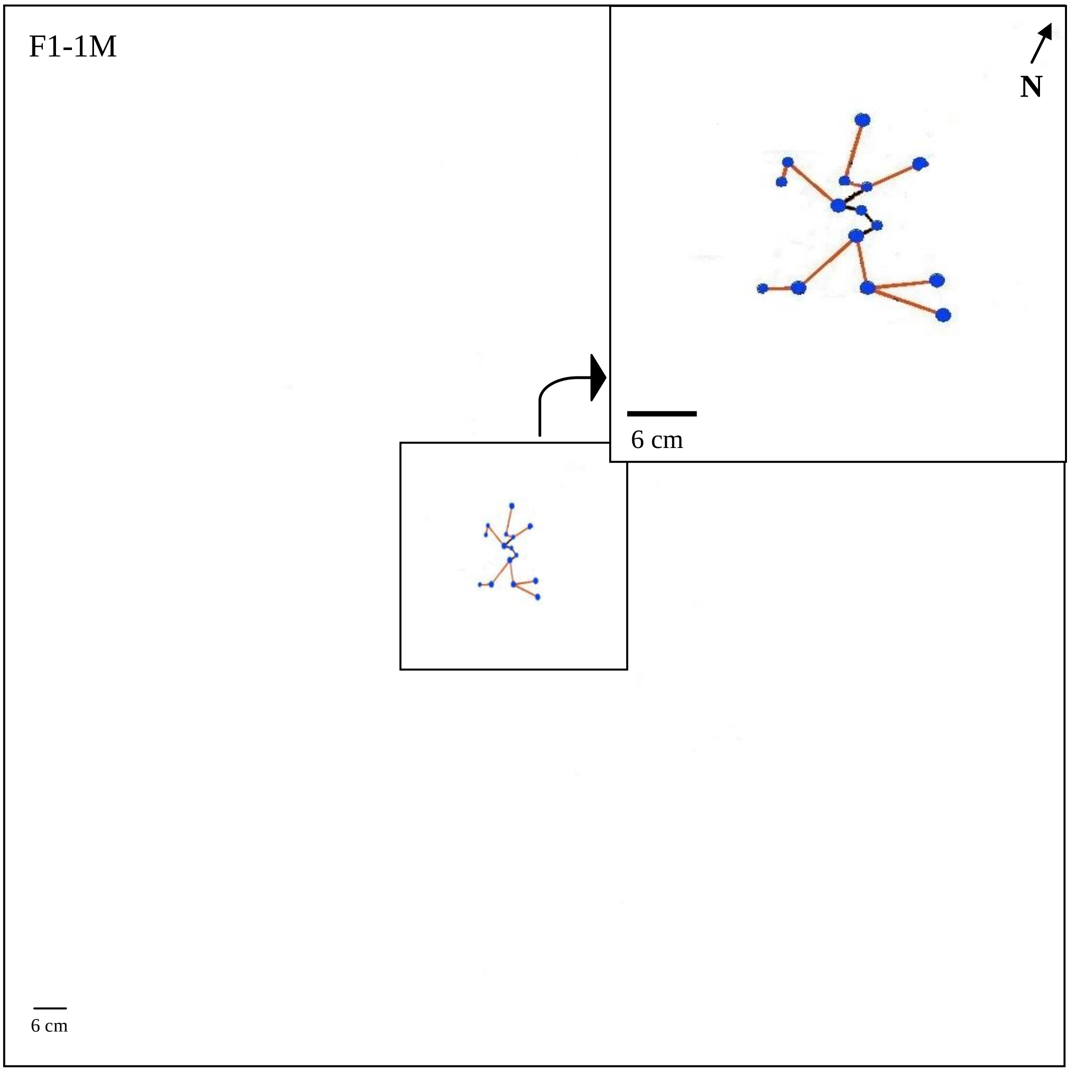


Fig. 5.21 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 1month after experimentation (F1 – 1M). ↑N denotes geographical north.

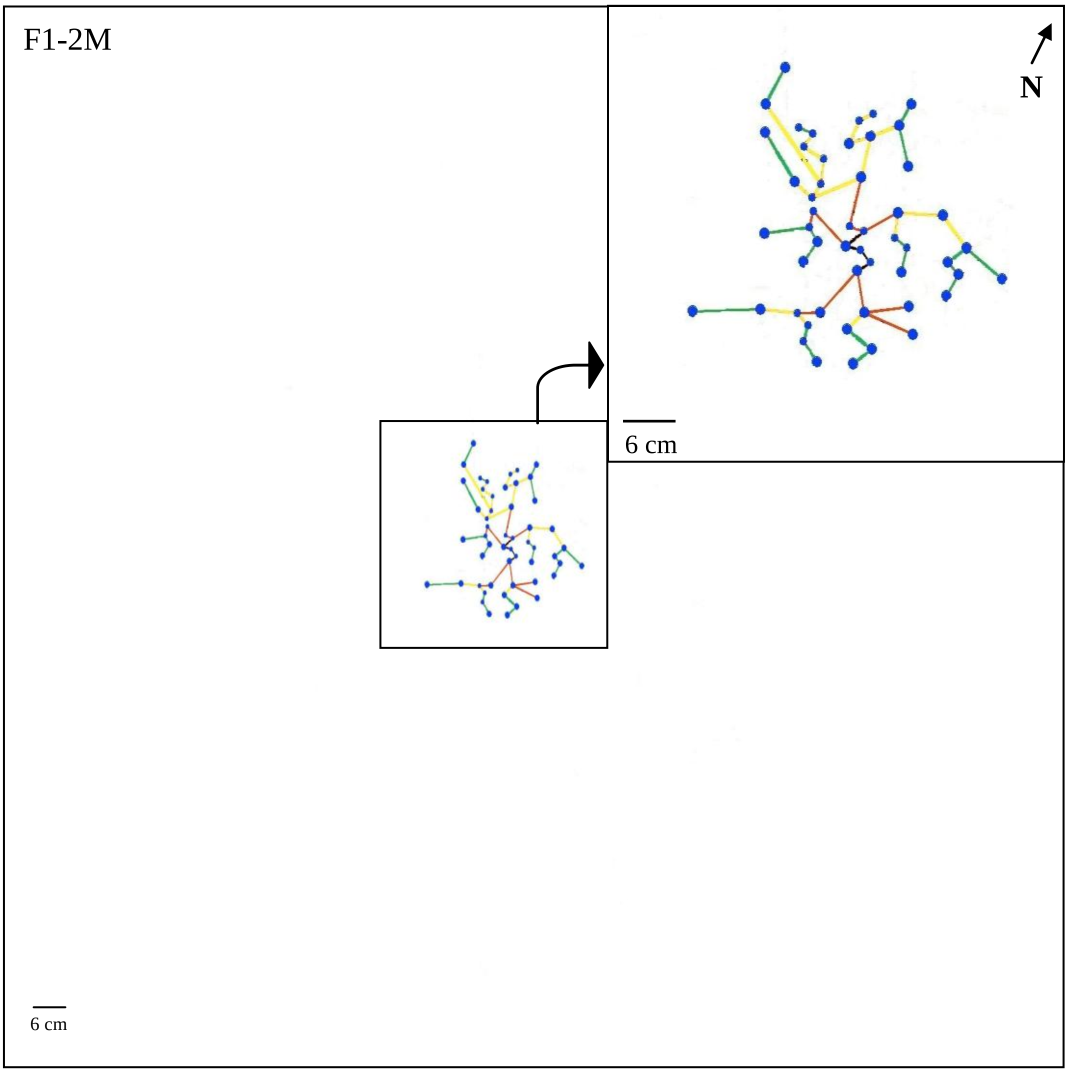


Fig. 5.22 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 2months after experimentation (F1 – 2M). ↑N denotes geographical north.

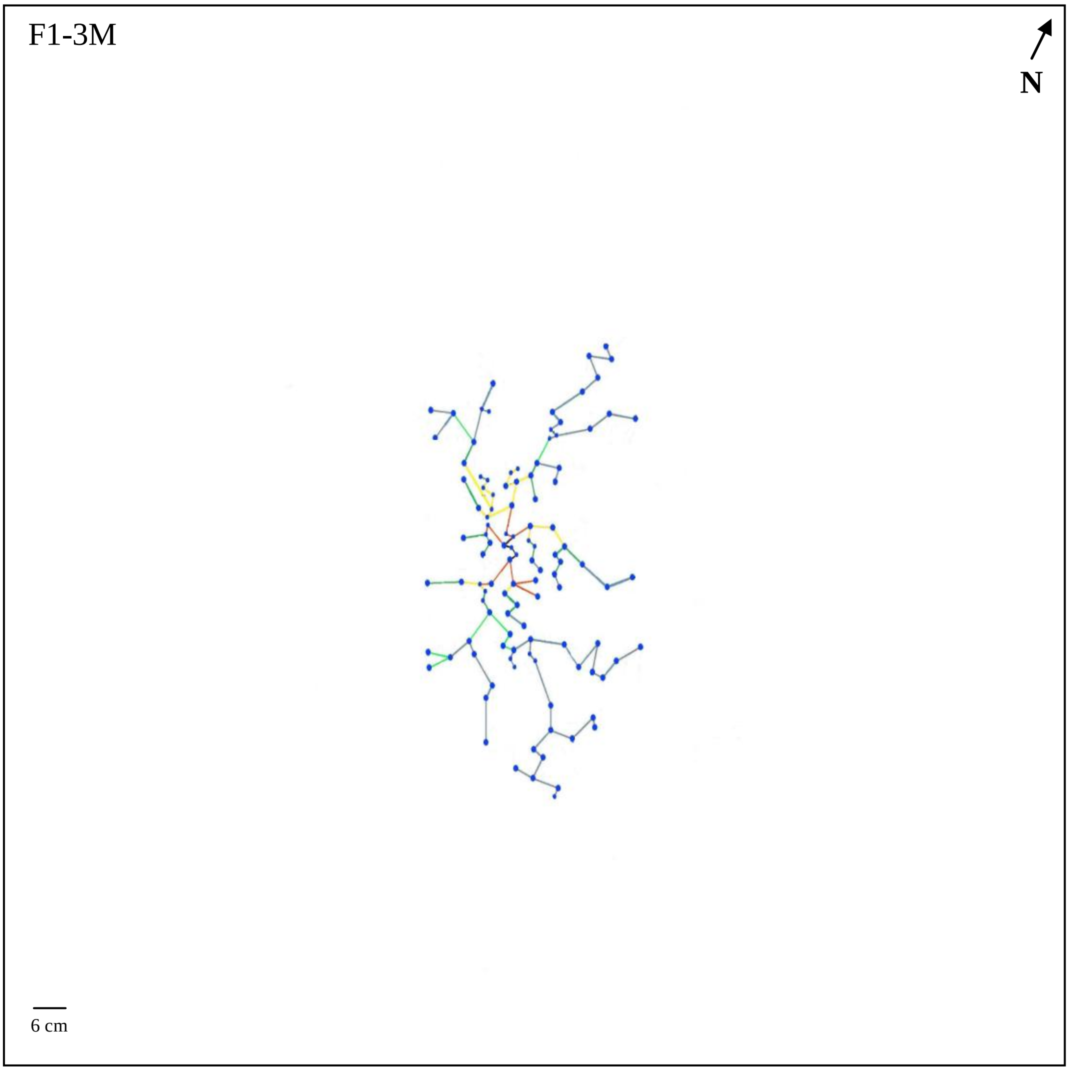


Fig. 5.23 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 3months after experimentation (F1 – 3M). ↑N denotes geographical north.

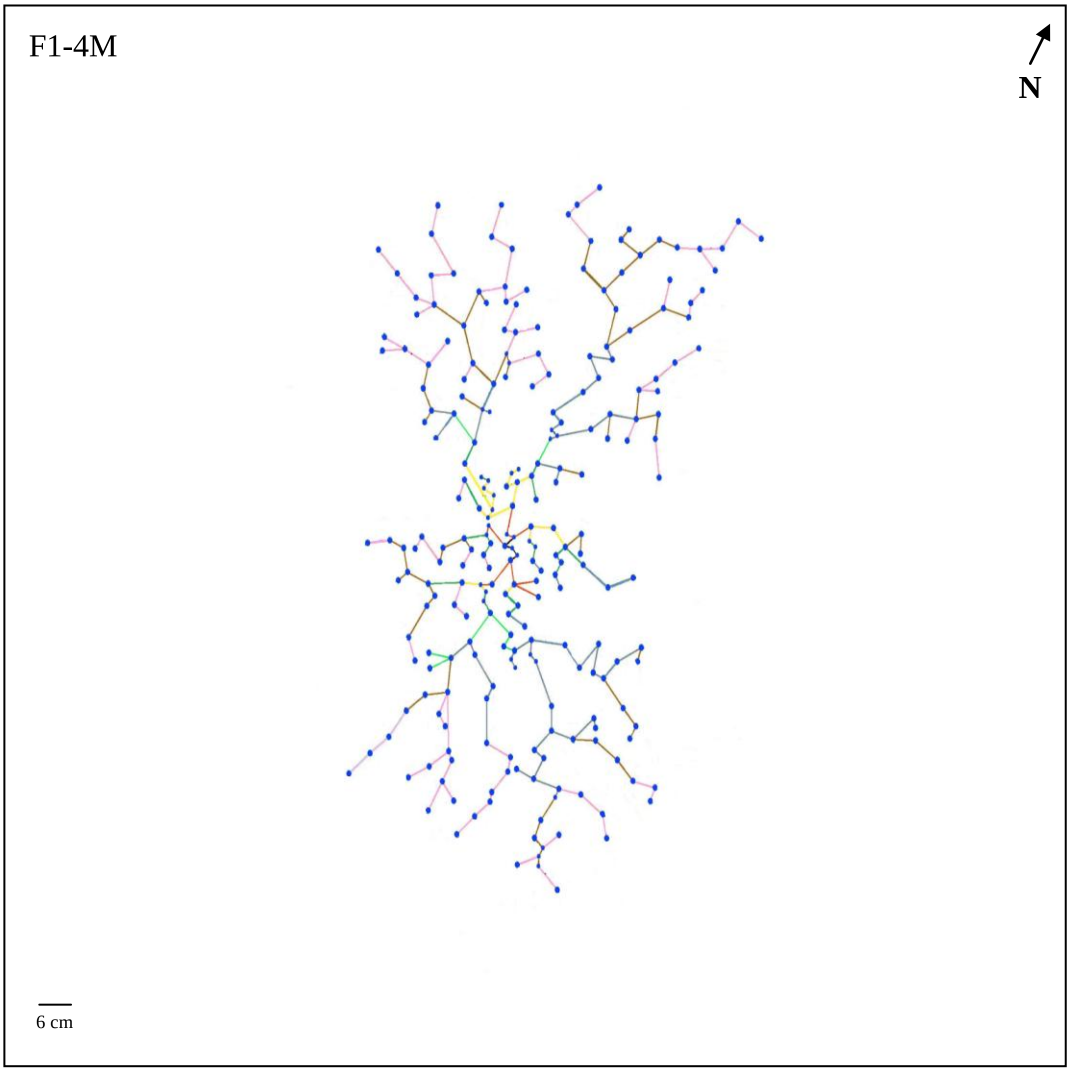


Fig. 5.24 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 4months after experimentation (F1 – 4M). ↑N denotes geographical north.

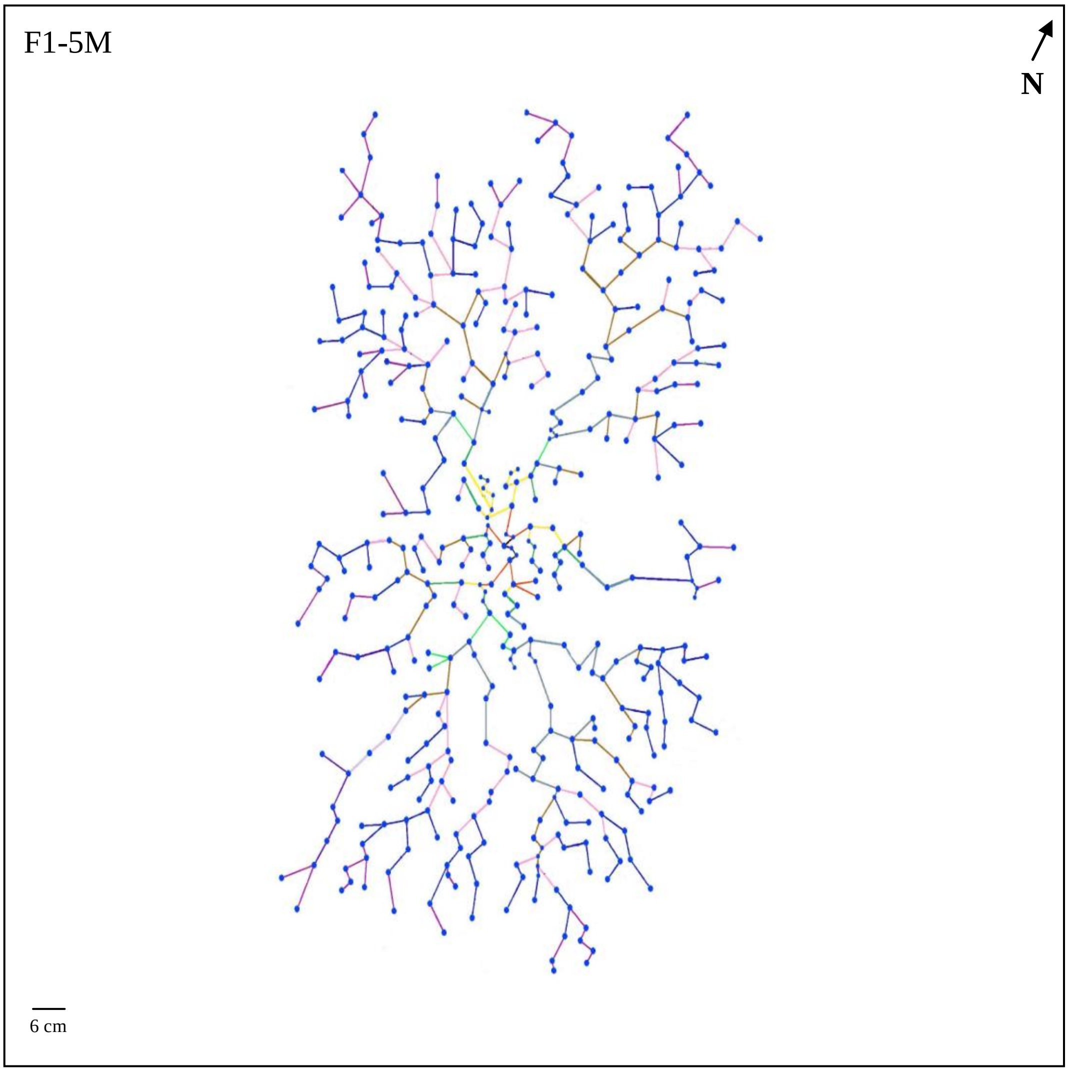


Fig. 5.25 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 5months after experimentation (F1 – 5M). ↑N denotes geographical north.

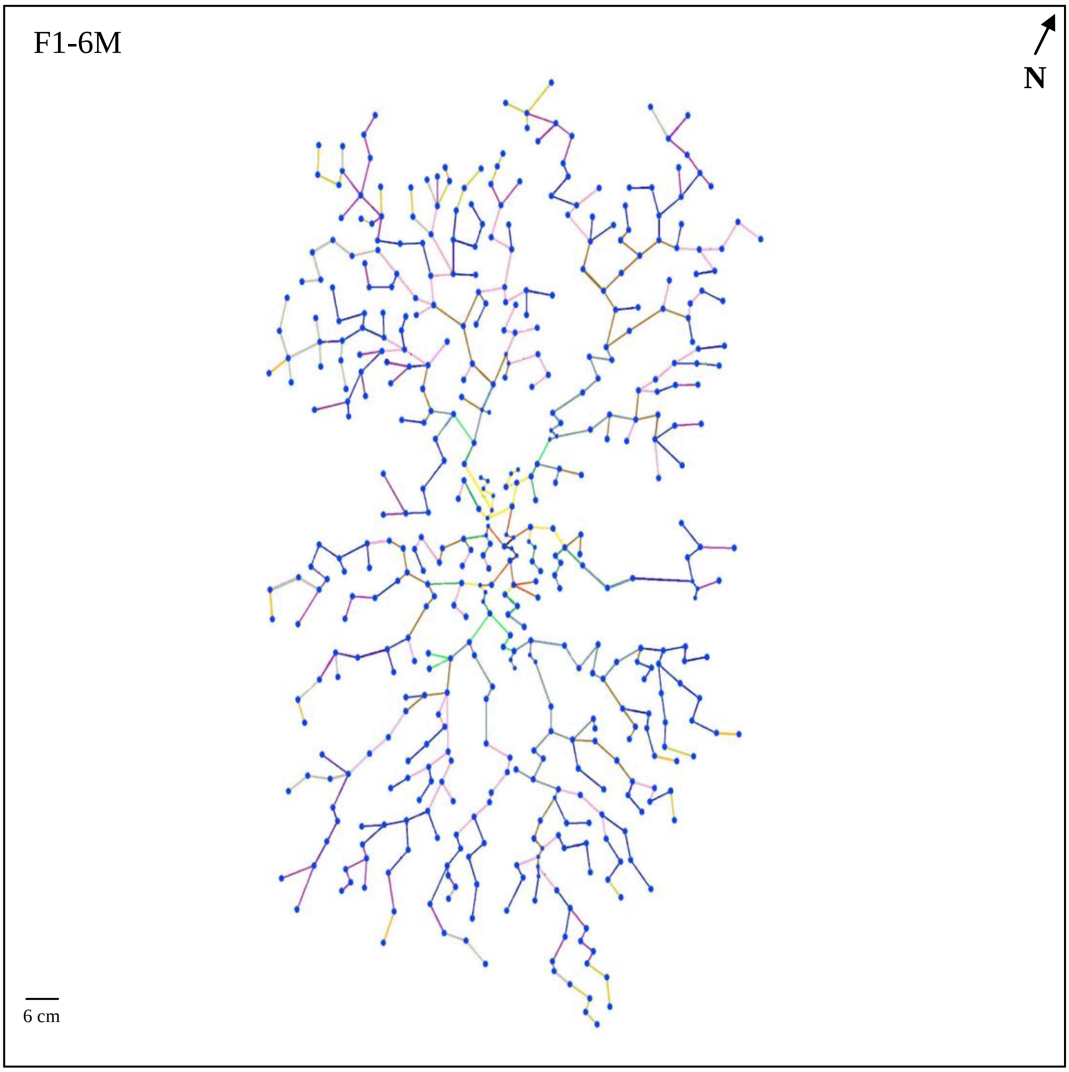


Fig. 5.26 Time-mediated growth and ramification of subterranean rhizomes of *Scirpus grossus* in unfertilized paddy soil after 6months after experimentation (F1 – 6M). ↑N denotes geographical north.

5.3.2 Fractal dimension boxing analyses of *Scirpus grossus*

5.3.2.1 Fractal dimension boxing analyses of rhizomes in both fertilized and unfertilized peat and paddy soils

Rhizome growth is affected by the acquisition, distribution, and consumption of water and nutrients. To understand of rhizome branching complexity, mathematical models using fractals and computers can be applied to accurately understand the growth and complexity of plant rhizome systems, using the Fractal Dimensions software's box-counting method of fractal analyses. The data from the fractal counting were tabulated and plotted on a log-log plot graph. Fractal dimension analysis of subterranean rhizomes by ImageJ program on *S. grossus* in peat and paddy soils showed no significant differences in peat soils (fractal dimension between 1.52 ± 0.53 and 1.50 ± 0.59) in unfertilized and fertilized plots. (Table 5.3 and Fig. 5.27). But it was observed there were significant differences in the direction of growth in peat until 12 weeks in fertilized plots, where we can see two different directions of growth (Table 5.3 and Fig. 5.27). Also, it was found that in peat soils there was more space between plants (Fig. 5.28), indicating the extra ability of rhizomes to penetrate further the peat soils lattices *vis-à-vis* the paddy soils.

Rhizome growth is effected to the acquisition, distribution, and consumption of water and nutrients of plants. If we want to understand of rhizome branching complexity, mathematical models using fractals and computers can be applied to accurately understand the growth and complexity of plant rhizome systems. Of the ways is to use the Fractal Dimensions software's box-counting method of fractal analyses. The data from the fractal counting were tabulated and plotted on a log-log plot graph. Fractal dimension analysis of subterranean rhizomes by Image J program on *S. grossus* in peat and paddy soils showed no significant differences in peat soils (fractal dimension between 1.53 ± 0.55 and 1.52 ± 0.49) in unfertilized and fertilized plots (Table 5.4 and Fig. 5.29). But we saw two direction in both plots unfertilized and fertilized. However, we found in fertilized heavier density of rhizomes (Table 5.4 and Fig. 5.29). Additionally, in peat soils there was more distance between emerged ramets. However, in paddy soils, there was a higher density of emerged ramets in a given unit area (Fig. 5.30). This method was used to examine the developmental responses of root systems in upland rice genotype (Hong *et al.* 2009). Also, In study, root system structures of heterogeneous plant communities were recorded as integral systems by using the trench profile method. Fractal dimensions of the root images were calculated from image files by the box-counting method. They founded similar results (Margitta D. & Arthur B. 2005).

Table 5.3 Fractal dimensions of *Scirpus grossus* in unfertilized and fertilized peat soils

	Week after planting					
Boxsize\Count	4	8	12	16	20	24
2	90	674	4292	8173	8909	8909
4	36	284	1811	3437	3700	3700
8	17	118	796	1512	1608	1608
16	7	54	331	632	691	691
32	3	24	122	236	251	251
64	1	9	41	71	72	72
80	1	6	29	49	52	52
128	1	4	13	20	20	20
200	1	1	7	9	9	9
256	1	1	4	6	6	6
D_{CA}	0.99	1.34	1.43	1.50	1.52	1.52
D_{FA}	0.94	1.18	1.35	1.46	1.49	1.50

*D_{CA}: Dimension control area A (peat soil).

*D_{FA} : Dimension fertilizer area A(peat soil).

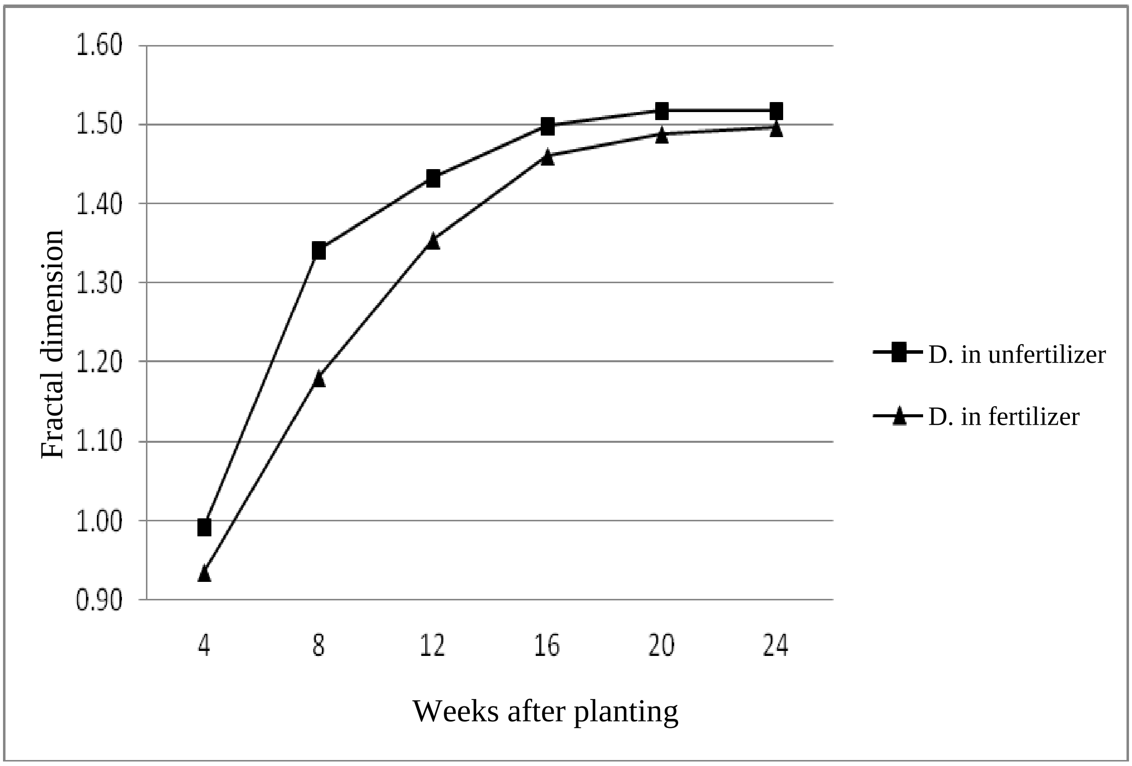
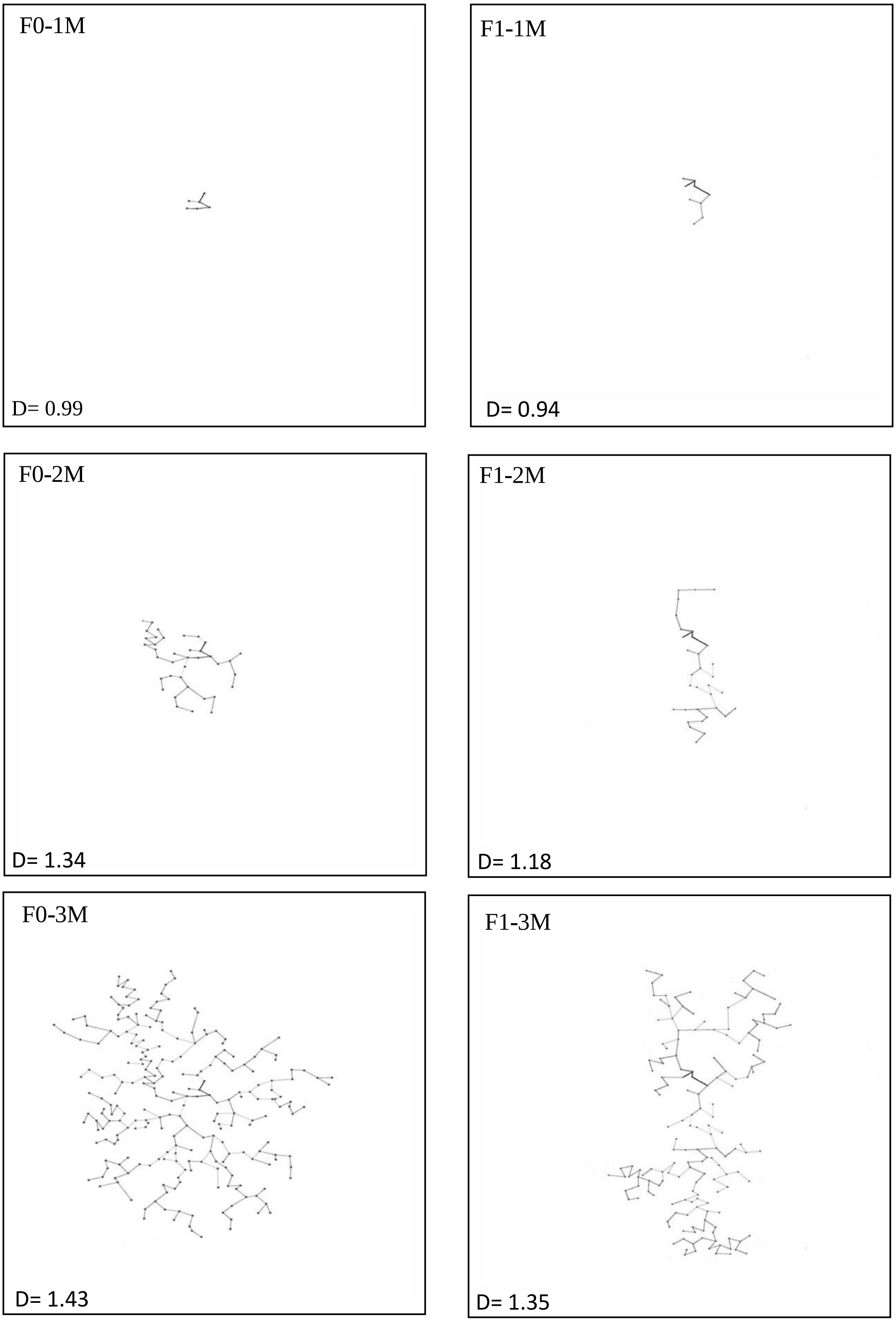


Fig 5.27 Fractal dimensions of *Scirpus grossus* grown in unfertilized and fertilized in peat soils.



Peat soil unfertilized (F0)

Peat soil fertilized (F1)

Fig. 5.28a Fractal dimensions with time-mediated growth of subterranean rhizomes of *Scirpus grossus* in unfertilized and fertilized peat soils.

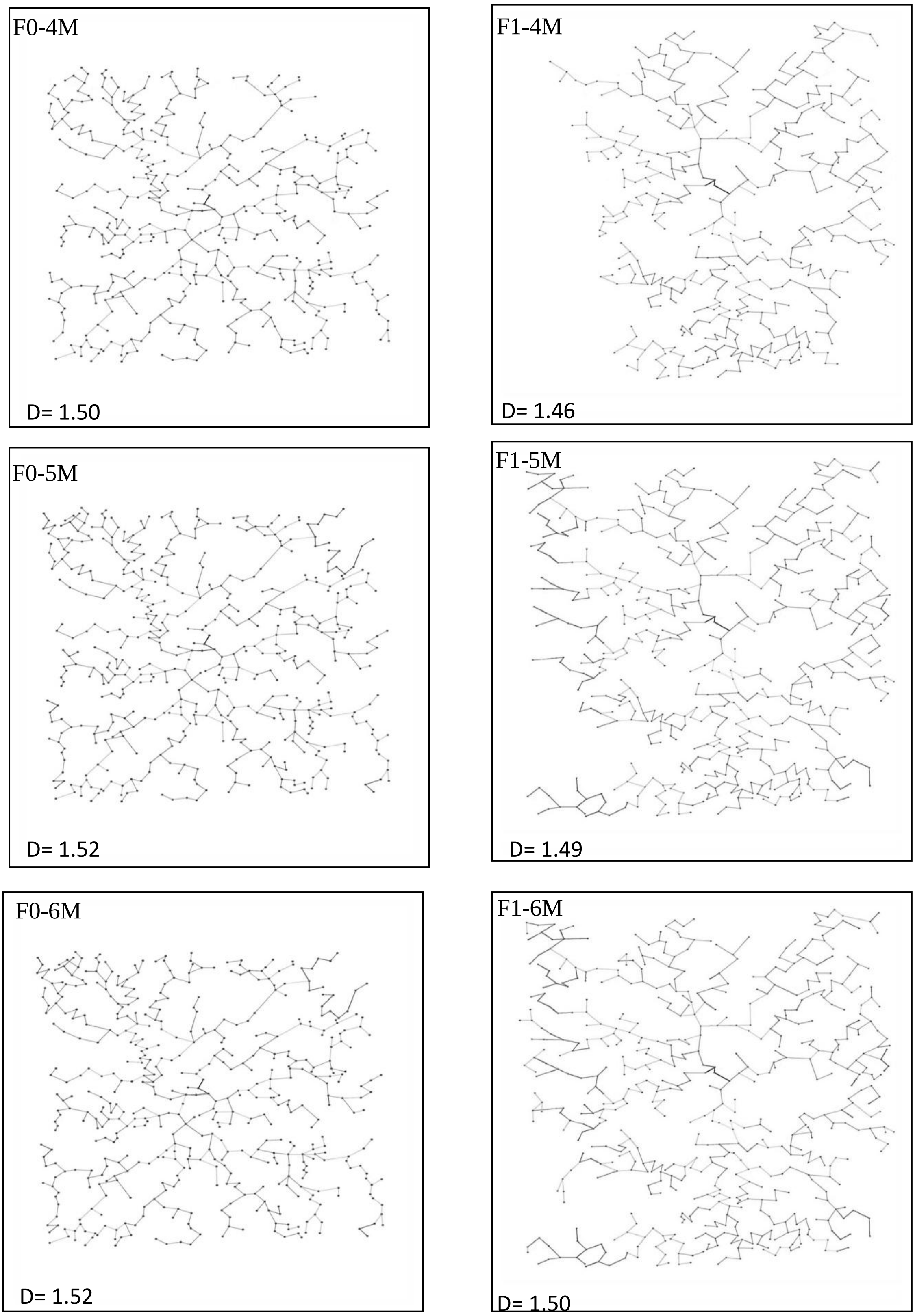


Fig. 5.28b Fractal dimensions with time-mediated growth of subterranean rhizomes of *Scirpus grossus* in unfertilized and fertilized peat soils.

Table 5.4 Fractal dimensions of *Scirpus grossus* grown in unfertilized and fertilized paddy soils

Box Size \ Count	Weeks after planting					
	4	8	12	16	20	24
2	86	189	4292	8173	8909	8909
4	33	284	1811	3437	3700	3700
8	17	118	796	1512	1608	1608
16	6	54	331	632	691	691
32	2	24	122	236	251	251
64	1	9	41	71	72	72
80	1	6	29	49	52	52
128	1	4	13	20	20	20
200	1	1	7	9	9	9
256	1	1	4	6	6	6
D_{CB}	0.98	1.34	1.43	1.50	1.52	1.52
D_{FB}	1.03	1.18	1.35	1.46	1.49	1.50

*D_{CB}: Dimension control area B(paddy soil).

*D_{FB} : Dimension fertilizer area B(paddy soil).

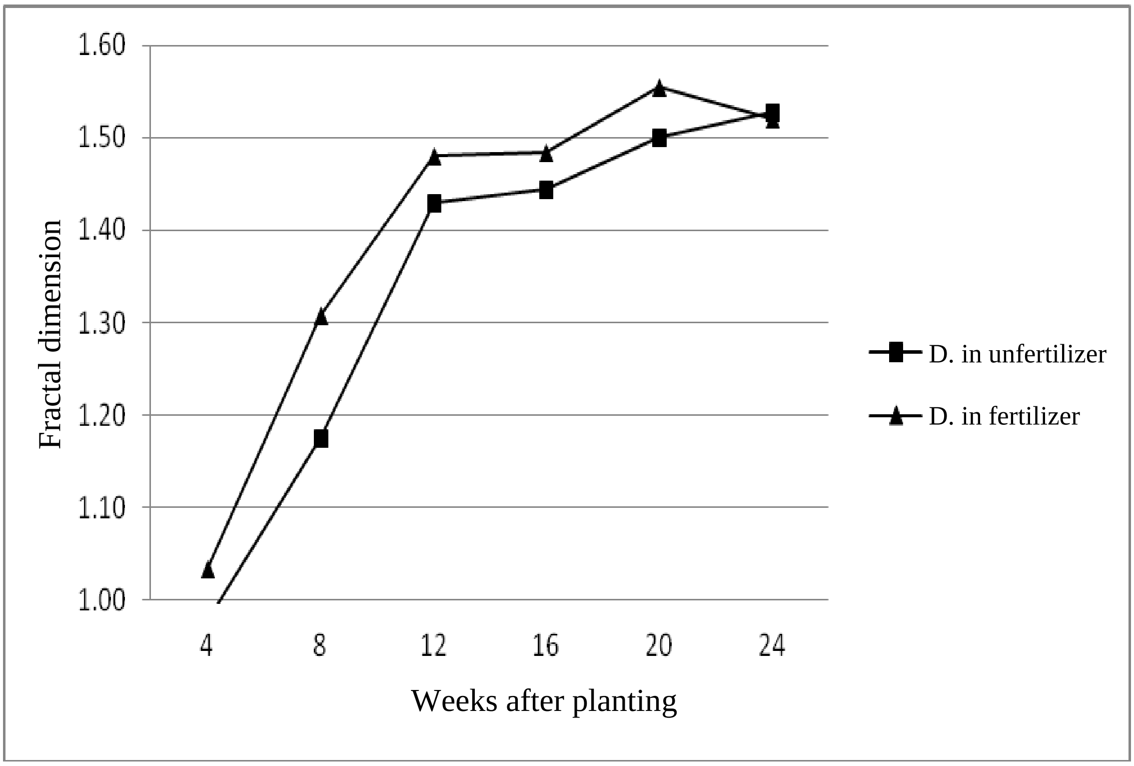
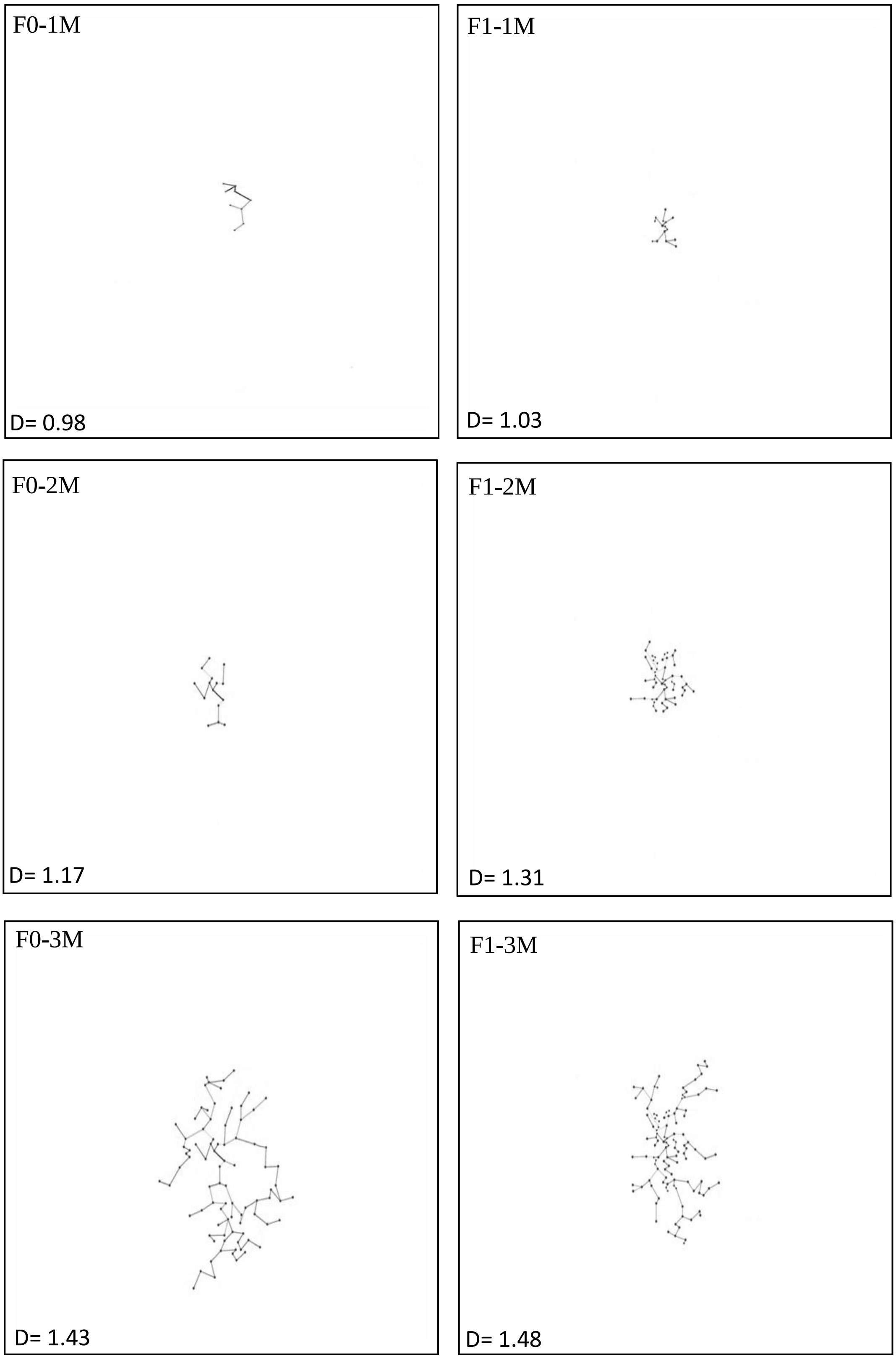
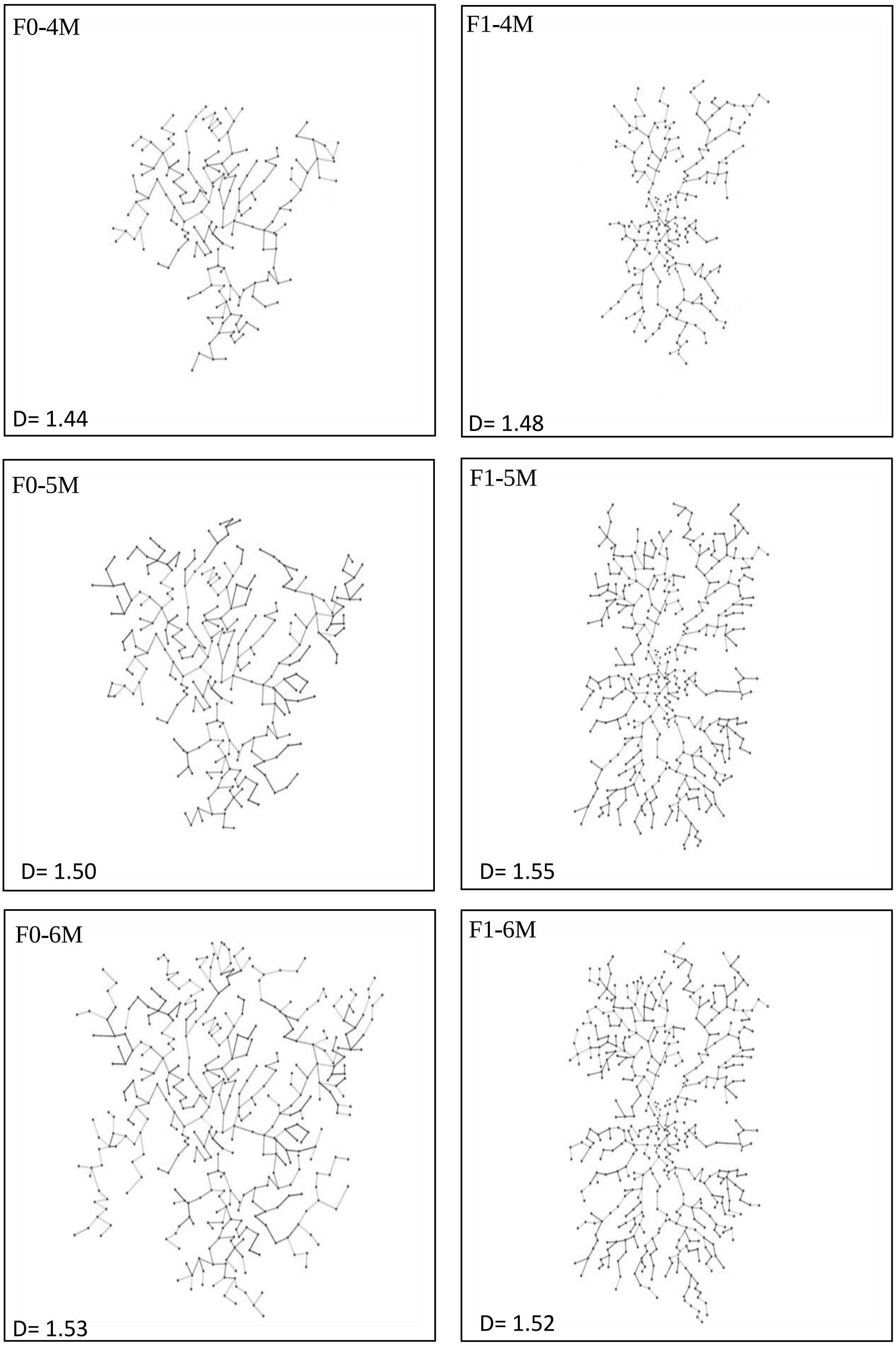


Fig 5.29 Fractal dimensions of *Scirpus grossus* grown in unfertilized and fertilized in paddy soils.



Paddy soil unfertilized (F0) Paddy soil fertilized (F1)

Fig 5,30a Fractal dimensions with time-mediated growth of subterranean rhizomes of *Scirpus grossus* in unfertilized and fertilized paddy soils.



Paddy soil unfertilized (F0)

Paddy soil fertilized (F1)

Fig 5.30b Fractal dimensions with time-mediated growth of subterranean rhizomes of *Scirpus grossus* in unfertilized and fertilized paddy soils.

In experiments 5.3.1.1 and 5.3.1.2, the subterranean rhizomes *S. grossus* was subjected to different soils, NPK fertilizer and difference time of 24 weeks. Baki (1988) who studied the structural demography and growth patterns of *S. grossus*. The NPK fertilizer, which contains 30% of phosphate, also increased the flowering rate of the weed. A similar observation was reported by Baki (1988). In addition, the NPK fertilizer helped to strengthen the plant, and this was observed in the significant increase in the weights of the various plant parts in fertilized soils. A lot of previous studies have shown that the application NPK fertilizer can affect clonal growth of crop plants, such as wheat (Ognjanovic *et al.* 1994; Jelic *et al.* 1995; Biberdzic *et al.* 2011).

In a study on the effects N and P dynamics of the growth of the rhizome, where the results showed a significant increase in rhizome growth and patterns (Juan *et al.* 2010). Allocation pattern, shoot N and K, and rhizome K were unaffected by both rate and timing of fall fertilization. However, shoot P concentration of fall fertilized plants was significantly increased, and rhizome P concentration was enhanced by applying fertilizer at either the highest rate or during early fall. This revealed a different nutrient dynamics during fall that was dependent on the specific nutrient and plant component. This result confirmed the rhizome growth potential was positively correlated to nursery rhizome P concentration. Six months after planting, fall fertilized plants showed taller shoot biomass, taller proportion of new leaves, and faster development, producing leaves earlier compared with unfertilized plants (Juan *et al.* 2010). Some of the mentioned studies were bare rhizome stock where no limits to rhizome expansion exist. However, found rhizome growth response to additional fertilizer supply during fall (Oliet *et al.* 2009b). In fall fertilized, Pinus taeda, N and K also experienced dilution during fall regardless of fertilization treatment (Sung *et al.* 1997). In contrast, N and K in rhizomes experienced dilution simply at no or at the lowest rates of fertilization, although differences were at most significant for rhizome N., This indicates that rhizome dilution of these nutrients could be prevented by increasing the amount of fertilizer applied during the hardening period (Boivin *et al.* 2004).

It is known that high potassium rates in the soil may affect seed germination due to salinity stress, resulting in non-uniform stands and decreasing the plant population. Rosolem *et al.* (2006) studying the available soil potassium fertilization as a result of millet straw, found that high potassium availability in the region impaired rhizome growth in plant populations of millet due to high salinity. In previous studies showed a significant effect of fertilization on the rhizome growth potential; although this effect could not be associated to any nutrient, in particular, mortality after planting showed a significant and negative relationship with rhizome P (Villar-Salvador *et al.* 2004; Molla *et al.* 2006), i.e., fewer seedlings died when rhizomes had more P. Our findings agree with those of Villar-Salvador *et al.* (2004). The response of rhizome growth and survival after planting to P concentration in rhizomes has been observed in earlier studies with other Mediterranean species, like *Acacia salicina* Lindl. and *Pinus halepensis* Mill. (Oliet *et al.* 2005,2009a) and also with Holm's oak (Sardans *et al.* 2006a). However, the mechanisms by which P could promote rhizome extension after planting are still debated (Folk and Grossnickle 2000; Landis and Steenis 2004).

Rhizome growth of plants played a vital role in absorbing nutrients and moisture from the soil. Thus, rhizome system is a useful study in determining the competitive ability as a plant species. There founded that rhizome weight of maize was significantly affected by fertilizer application. Data shows that NPK treatments increased the rhizome weight of maize. Overall data indicated that application of fertilizers increased the growth parameters of maize. However, N, P and K combinations were more effective to increase the growth instead of using alone (Hussain and Khan 2012). Brohi *et al.* (1998)

reported that different rates of N and P applied to rice plant under greenhouse conditions have significantly increased the uptake of macro and micro-nutrients in rice grain.

Rhizome growth is effected to the acquisition, distribution, and consumption of water and nutrients of plants. If we want to understand of rhizome branching complexity. Mathematical models using fractals and computers can be applied to accurately understand the growth and from complexity of plant rhizome systems. Because these we can use the Fractal Dimensions software’s box-counting method of fractal analyses. This method was used to examine the developmental responses of rhizome systems in upland rice genotype (Hong *et al.* 2009). Furthermore, In study, rhizome system structures of heterogeneous plant communities were recorded as integral systems by using the trench profile method. Fractal dimensions of the rhizome images were calculated from image files by the box-counting method. They founded similar results (Margitta and Arthur 2005).

In this study, fractal analysis was used to quantify the rhizome system architecture of rice plants grown under different NPK fertilized and two soils conditions. This was similar another studies on rice plant (Wade *et al.* 2000; Azhiri-Sigari *et al.* 2000). Fractal dimensions can also be calculated based on interception of three-dimensional boxes by the rhizomes (Eshel 1998; Walk *et al.* 2004). This kind of fractal dimension is called mass fractal (Obert *et al.* 1990) because it relates to the volume occupied by the object, but not to its perimeter alone. It would be of great interest to perform fractal analysis at three-dimensional level to evaluate the functional significance of the rhizome system responses to soil water stress.