CHAPTER VI

TALL FESCUE ROOT GROWTH DYNAMICS IN RESPONSE TO DEFICIT IRRIGATION

ABSTRACT

Little is known about the root dynamics of tall fescue (*Festuca arundinaceae* Schreb.) in response to irrigation practices. The objectives of this study were to examine the effects of deficit irrigation on 'Falcon II' tall fescue root characteristics from the first week of June to mid-September 2001 and 2002 using a mini-rhizotron imaging system. The study was conducted under a mobile rainout shelter at deficit irrigation levels of 20%, 60%, and 100% of potential evapotranspiration (ET). Root number, length, and surface area at 17.5 - 18.4 cm deep increased from early June, reached maximum levels in late June to early July, and decreased slightly in August and September in both 2001 and 2002. Fewest roots were counted at 0 to 8 cm, and the greatest numbers occurred at 8 to 23 cm. Root number, length, and surface area below 23 cm remained relatively stable at all irrigation levels, despite declining turf quality through the test. Tall fescue irrigated at 20% ET had significantly higher root numbers, lengths, and surface areas at 13 - 18 cm in both years compared to turf irrigated at other levels. Compared to 100% ET, Irrigation at 60% ET increased root surface area at 22-32 cm at 43 days of treatment (DOT) in 2002. Root diameter was unaffected by deficit irrigation.

ABBREVATION

ET, evapotranspiration;

INTRODUCTION

In recent years, there has been increasing interest in deficit irrigation, returning water in amounts less than potential evapotranspiration (ET), as a water conservation technique (Feldhake et al., 1984; Fry and Butler, 1989; Qian and Engelke, 1999). Extensive research has found that turfgrasses require water in amounts less than potential ET to maintain acceptable visual quality (Fu, Chapter IV; Feldhake et al., 1984; Fry and Butler, 1989; Qian and Engelke 1999). However, severe water deficits reduce turf quality and growth (Fu, Chapter IV). Turf quality declines during deficit irrigation are related to the reductions in root biomass, number, and length (Huang and Liu, 2003; Liu and Huang, 2002).

Quantification of the dynamics of root growth and water absorption in natural environments has been a tedious and often destructive task in the past. Researchers have demonstrated that drying of the soil profile has a profound impact on root function and growth in some plant species (Henson et al., 1989; Jensen et al., 1989; Smucker et al., 1991; Huang, 2001). Huang and Gao (2000) reported that tall fescue root length in the 40- to 60-cm soil layer increased, when a 60-cm deep soil profile was allowed to dry for 35 days . In a separate study, tall fescue root to shoot ratio and the proportion of roots in the deeper soil layer (20-40 cm) increased when the upper 20 cm soil dried (Huang and Fu, 2001).

Most root measurements for research have been taken by destructively sampling soil cores, washing away soil, and determining the total roots present. This process often results in loss of a significant number of roots, and can affect research results. The developed minirhizotron imaging technique allows root growth and development at a particular depth and location to be monitored in a natural environment (Upchurch and Ritchie, 1983; Huang and Liu, 2003). Murphy et al. (1994) demonstrated that root density measured with the minirhizotron was correlated with root length density measured by soil coring for both creeping bentgrass and annual bluegrass (*Poa annua* L.). Huang and Liu (2003) used the technique to monitor creeping bentgrass root production, growth and mortality in the field.

Tall fescue is better able to avoid drought than other cool-season turfgrasses such as perennial ryegrass (*Lolium perenne* L.) or Kentucky bluegrass (*Poa pratensis* L.) by developing an extensive and deep root system (Sheffer et al., 1987). Drought resistance may be affected not only by the capability to develop an extensive, deep root system (Hays et al., 1991; Marcum et al., 1995), but also by maintenance of a viable, functional, multi-layered root system once water deficits are imposed. However, the root dynamics of tall fescue during deficit irrigation have rarely been measured in the field.

The objectives of this study were to investigate the root dynamics of tall fescue during deficit irrigation using the minirhizotron imaging technique.

MATERIALS AND METHODS

Growing Conditions and Treatments

This experiment was conducted using an automated, mobile rainout shelter (180 m^2) at the Rocky Ford Turfgrass Research Center at Manhattan, KS from 4 June to 14 September, 2001 and from 3 June to 13 Sept., 2002. During dry weather, the shelter rested just to the north of the study area. The shelter was triggered by a minimum of 0.38 mm precipitation, and required approximately two minutes to move south on rails and completely cover the test area. One hour after precipitation ceased, the shelter returned to its resting position. A weather station located within 2 km of the study area was used to monitor temperatures (Appendix I). 'Falcon II' tall fescue was established by sodding in spring, 2000, on a river-deposited silt loam (fine, montmorillonitic, mesic Aquic Arquidolls) soil. Treatment consisted of irrigation levels of 20, 60, and 100% of ET. Each plot was bordered by metal edging (set 15 cm deep) to minimize lateral movement of water upon application.

Water was applied twice weekly using a metered, hand-held hose with a fan spray nozzle attached. Deficit irrigation amounts were determined by taking the fraction of water use of lysimeter grown turf receiving 100% ET. Pots (10.1 cm in diameter and 25 cm deep) constructed of PVC were planted with turf sampled in April, 2001 using a 10.1-cm diam. cup cutter to remove a 25-cm deep soil core and accompanying turf. Cores were then placed into the pots to create lysimeters. Each lysimeter had a nylon screen on the bottom end that was secured with duct tape. After planting, lysimeters were placed in holes that had been dug in the center of each sub-plot scheduled to receive 100% ET. Turf in lysimeters was maintained identically to that of the surrounding fetch.

The day before the study began each year, lysimeters were soaked until water was draining through the bottoms. 24 h later, each was sealed on the bottom end with two plastic bags to prevent leakage, and then weighed to determine its reference weight. Lysimeters were then returned to respective holes in the plot area.

Deficit irrigation amounts for field plots were calculated as: Deficit irrigation level x ET x a plot area adjustment factor. Total water applied to turf receiving 100% ET during the study period in 2001 and 2002 was 562 and 598 mm, respectively.

Turf was mowed twice weekly at 5-6 cm using a walk-behind rotary mower, and clippings were collected. Nitrogen was applied at 49 kg ha^{-1} on 3 May, 19 September and 8 November in 2001 and 3 May , 18 September and 15 November in 2002.

Measurements

Root growth and production were monitored from 4 June to 11 September 2001 and from 3 June to 10 September 2002 using the minirhizotron imaging technique (Upchurch and Ritchie, 1983). In May 2001, two cores (90-cm long and 5-cm in diam.) were removed from each plot at a 45 °C angle from the soil surface. Clear butyrate tubes of a size equivalent to the remaining voids were plugged with a rubber stopper at the bottom end, sealed with waterproof silicon sealant, and manually forced into the hole. On the upper side of each tube were etched frames (1.3 by 1.8 cm) that extended along the length of the tube, allowing the camera to return to the exact location when repeated measurements were taken. The tube was positioned in the ground with the upper end of the tube plugged with a rubber stopper about 1 cm above soil surface such that tubes did not interfere with mowing.

Video images of roots visible against the surface of the tubes were recorded using a high-magnification minirhizotron camera (BTX-100, Bartz Technology Company, Santa Barbara, CA) and a camcorder (Sony Electronics, Inc., Park Ridge, NJ). Root images were taken every two weeks through 43 days of irrigation treatments, and then every four weeks each year until the end of the experiment. Video root images were recorded beginning at the 5th frame (3.68 to 4.60 cm in vertical depth) from the soil surface to the 55th frame (49.64 to 50.56 cm in vertical depth).

Root images were captured as bitmap (BMP) files onto a personal computer and analyzed using an image analysis program (RooTracker, Duke University). The length, diameter, and number of roots on each image were traced using the cursor on the computer screen . The root surface area and volume were calculated based on the length and diameter of roots. The greatest effects of deficit irrigation on root parameters occurred in the frames 15 to 30 (12.87 to 27.58 cm). Because similar patterns were observed between this range of frames, only rooting data from 20th frame (17.47 to 18.38 cm) are reported. Vertical distribution of roots is discussed for measurements recorded at 43 DOT.

Data analysis

Treatment effects were determined by analysis of variance according to the mixed procedure of Statistical Analysis System (SAS Institute Inc., 1988). Variation was partitioned into deficit irrigation level and treatment duration (sampling time). Differences among treatment means were separated by a least significant difference mean separation test ($P < 0.05$). Initial number, length, and surface area of roots were considered as covariants to analyze covariance effects according to the general linear models of the Statistical Analysis System. Then, initial roots numbers, lengths, and surface areas of root were adjusted as if each treatment had the same initial value.

RESULTS

In 2001, root numbers over all irrigation levels increased from 0 DOT (4 June) until 29 DOT (3 July) when the highest numbers were observed (Fig. 1). Thereafter, root numbers declined. Tall fescue irrigated at 20% ET had higher root numbers than that receiving 100% ET at 71(14 August) and 99 DOT (11 September) .

Beginning at 29 DOT (2 July) in 2002, root numbers were generally higher for turf receiving 20% ET than that irrigated at 60 or 100% ET (Fig. 1).

Root length at 20%, 60%, and 100% increased from 0 DOT, and reached a maximum at 29 DOT at 20% ET and 17 DOT for 60% and 100% ET in both years. Root length at 20% ET increased from 0 DOT and was highest at 29 DOT (2 July) in 2002. Lowest root length occurred at 43 DOT (16 July) in all treatments, and then increased slightly (Fig. 2). Tall fescue subjected to deficit irrigation at 20% ET had higher root lengths than well-watered turf beginning at 29 DOT (2 July) in both years, except at 43 DOT (16 July) in 2002 when no effect was found.

In 2001, root surface area was highest at 17 DOT (21 June) and then declined slightly and remained steady throughout the rest of the evaluation period (Fig. 3). Tall fescue irrigated at 20% ET had higher root surface areas than well-watered turf beginning at 29 DOT (3 July) .

There was a consistent decline in root surface area from 0 until 43 DOT (17 July, 2001 and 16 July, 2002), and then values remained stable in both years (Fig. 3).

Root diameter reached a maximum value at 17 DOT (21 June) in 2001 (Fig. 4). In 2002, there was a consistent decline in root diameter from 0 DOT (3 June) until the end of the experimental period. No statistical differences in root diameter were observed among deficit irrigation levels in either year.

In both years, root numbers increased from 3.7-4.6 cm and reached highest values at 17.5-18.4 cm over all irrigation levels (Fig.5). There was a decrease in root number below 17.5-18.4 cm. In 2001, root numbers at 12.9-13.8 cm and 17.5-18.4 cm were higher in tall fescue irrigated at 20% ET than well-watered turf (Fig. 5). Likewise, in 2002, irrigation at 20% ET led to an increase in root numbers relative to well-watered turf beginning at 3.7-4.6 cm until 17.5-18.4 cm.

Highest root lengths across all irrigation levels were generally observed at 17.5-18.4 cm in 2001. Tall fescue receiving 20% ET had higher root length compared to turf receiving 100% ET in 12.9-13.8 cm and 17.5-18.4 cm in 2001.

Root length increased from 3.7-4.6 cm and reached the highest value at 17.5-18.4 cm or 22.1-23.0 cm depending upon irrigation level in 2002 (Fig. 6). Turf irrigated at 20% ET had higher root lengths than well-watered turf between 3.7-4.6 cm and 17.5-18.4 cm.

Root surface area increased from 3.68-4.6 cm and reached the highest value at the 17.5-18.4 cm across all irrigation levels in 2001 (Fig. 7). Root surface area of tall fescue irrigated at 20% and 60% ET was similar to that of turf receiving 100% ET in 2001.

In 2002, tall fescue irrigated at 20% and 60% ET had higher root surface areas compared to well-watered turf from 3.7-4.6 cm to 17.5-18.4 cm and 12.9-13.8 cm to 31.3-32.2 (Fig. 7).

No consistent effects of soil depth or irrigation level were observed on root diameter in either year (Fig.8).

DISCUSSION

Root number, length, and surface area at 17.47-18.38 cm increased from early June to late June or early July, and then decreased slightly in August and September in both 2001 and 2002. These observations are in agreement with others who have documented greatest root growth of cool-season grasses in spring and fall, and a decline in midsummer (Beard, 1973; Huang and Liu, 2003; Murphy et al., 1994; Fagerness and Yelverton, 2001). Using the minirhizotron technique, Huang and Liu (2003) observed that total creeping bentgrass (*Agrostis palustris* Huds) root length and number at 5 to 6 cm increased until late July, and then plateaued or even decreased slightly in August and September in Kansas. Murphy et al. (1994) reported the greatest total root number in creeping bentgrass early in the growing season followed by a decline during July in Michigan. Our results and those of other researchers suggest that new root production in cool-season grasses does not cease during summer, but is reduced during the hottest periods.

Development of deep, extensive root systems plays an important role in turfgrass growth and adaptation to environmental stresses. Qian et al. (1997) reported that the extensive rooting of tall fescue resulted in leaf wilt resistance. Percent green plot cover of zoysiagrass grown under severe and moderate drought stress (0 and 35 % ET) was strongly correlated with average maximum root depth, total weight, and root number in twenty five zoysiagrass (*Zoysia* spp.) cultivars and species (Marcum et al., 1995), indicating that the extensive rooting helped plants avoid drought stress. More roots are likely to increase the plant's ability to extract soil water (Price et al., 2002). Tall fescue in Kansas extracted over 50% more water than bermudagrass and zoysiagrass at a 90 cm soil depth (Qian et al., 1997). Price et al. (2002) reported that an early water deficit increased maximum root length of upland rice (*Oryza sativa* L.)(Price et al, 2002). Carrow (1996) found that high root length density in the deeper root zone and the ability to maintain ET as the soil dries are important for drought resistance of tall fescue.. However, decreases in root growth under drought stress have been reported in a mixture of grama (*Boutelua*, spp.), needle grass (*Stipa,* spp.), wheatgrass (*Agropyron,* spp) (Hild et al., 2001), tall fescue (Huang and Gao, 2000), and zoysiagrass (Huang et al., 1997). Huang (1997) found that drought stress caused significant decline in root length in the upper 40-cm of soil under Emerald zoysiagrass grown in a greenhouse. The conflicting results may be related to plant species and the severity and duration of water deficit.

The present study indicated that irrigation at 20% ET enhanced root number and length, primarily at 13 to 18 cm, and increased root surface area in both 2001 and 2002. This occurred despite turf visual quality ratings declining from an average of 7 to 8 in early June (0 to 9 scale, 9 = best) to 3 to 5 by the end of study in September (see Chapter IV). This suggests deficit irrigation at 20% ET in tall fescue may encourage development of more and longer roots to absorb limited water during periods of drought stress even when turf quality is relatively low. Enhanced root growth during soil drying could have led to the increased water uptake rates. Enhanced rooting during drought stress has been shown to be an important adaptation mechanism to plant water uptake efficiency (Molyneux and Davies, 1983; Sharp and Davies, 1985).

My results also indicated that tall fescue root surface area at a 22-32 cm soil depth was higher at 60% ET compared to 20% or 100% ET. This implies that irrigation at 60% ET might promote root growth at this range of depths.

The increase in tall fescue root parameters measured under deficit irrigation vs. well-watered conditions may be attributed to more efficient carbon allocation to roots. Several researchers have shown that carbon reallocation may be an adaptive mechanism to drought stress. (Nicolas et al., 1985; Huang and Gao, 2000; Huang and Fu, 2000). Huang and Fu (2000) reported that when the surface 20 cm of soil dried, tall fescue increased the amount of carbon allocated to roots compared to shoots.

I found that tall fescue has fewest roots at 0 to 8 cm, most at 8 to 23 cm, and an intermediate number at other depths. Total roots below 23 cm in 2001 and 2002, respectively, accounted for 42.6% and 47.0% at 20% ET; 54.7% and 59.6% at 60% ET; and 48.6% and 66.2% at 100% ET. Highest root length density of 'Mustang' tall fescue occurred at 0-30 cm when cores were sampled from turf growing on the same Kansas soil used in my study (Qian et al., 1997). In the same test, 43% of 'Mustang' tall fescue's total root length was located at soil depths below 30 cm. A higher percentage of total root length density was distributed in the upper 30 cm soil for 'MIC18' (75%),'Mustang' (66%), and Kentucky-31 (65%) tall fescue grown in green house (Huang and Fry, 1998).

In summary, irrigation at 20% ET increased root numbers, primarily at 13 to 18 cm, although turf visual quality ratings declined during the same period. This increase in rooting may be a response by the plant to maximize surface area and absorption during periods of water deficits.

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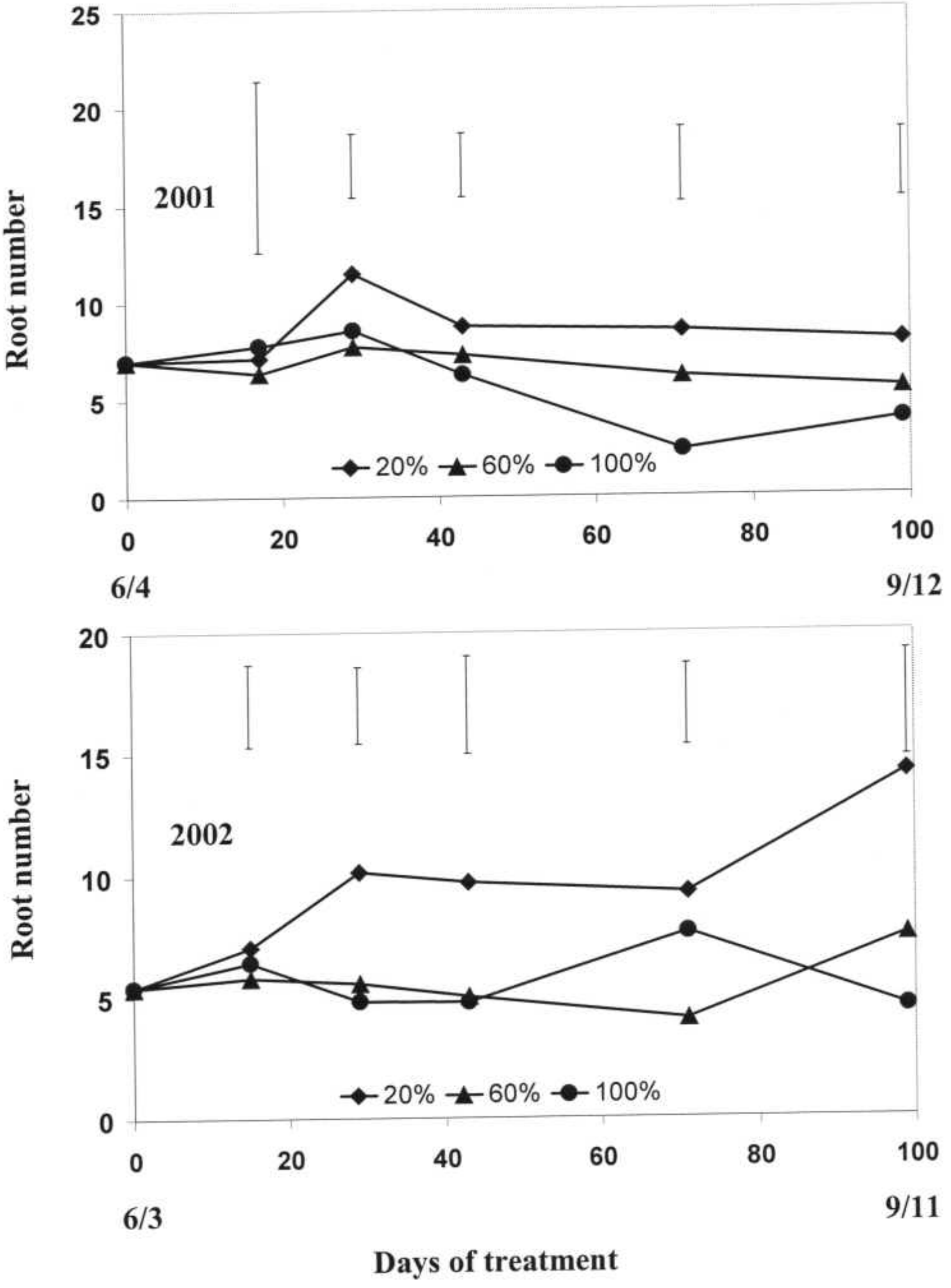

Fig. 1. Tall fescue root number in frame (17.47 to 18.38 cm depth)in response to deficit irrigation. Vertical bars on the top of figures are LSD values P=0.05) for treatment comparison on a given day.

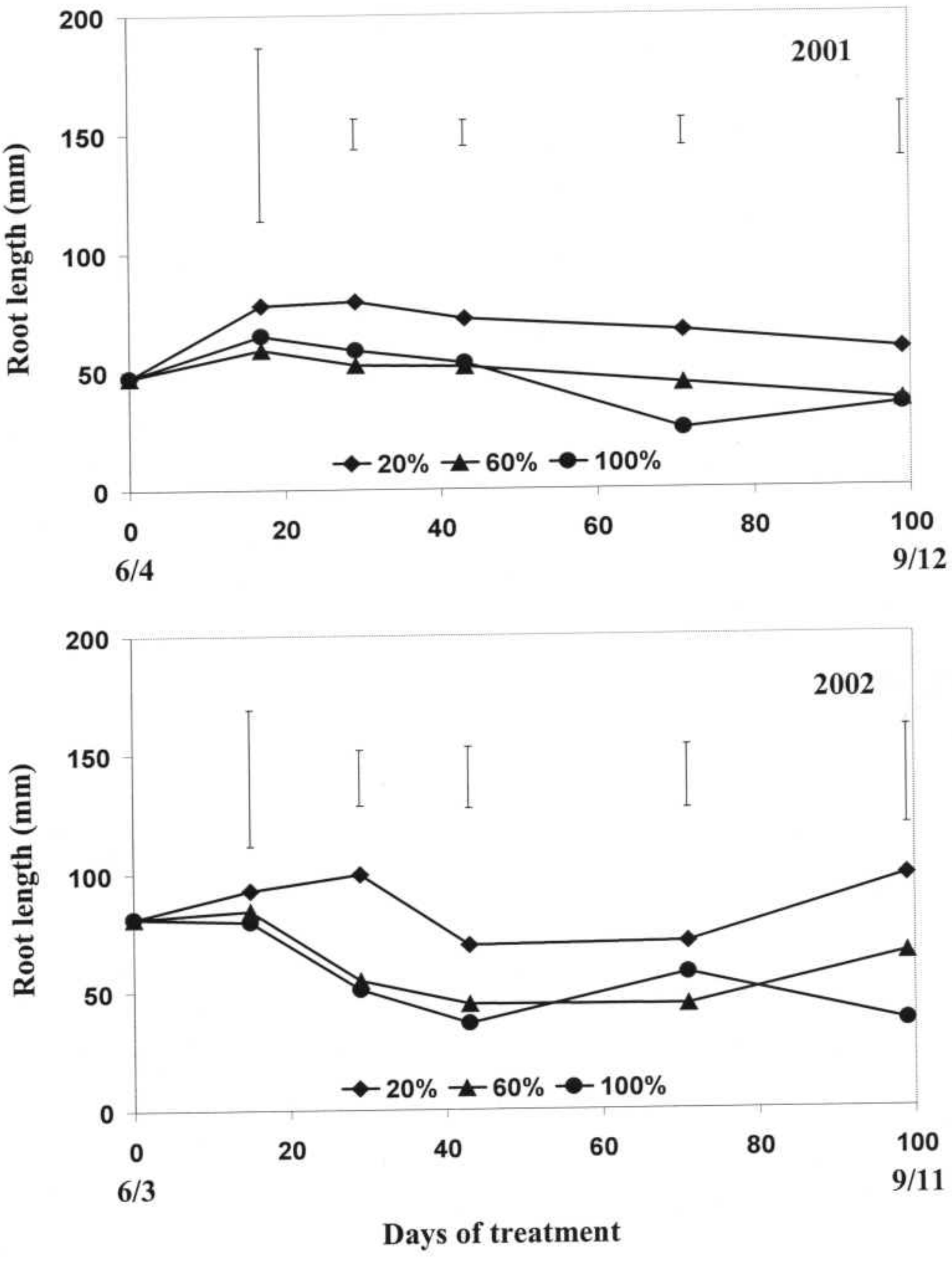

Fig. 2. Tall fescue root length in frame 20 (17.47 to 18.38 cm depth) in response to deficit irrigation. Vertical bars on the top of figure are LSD values (P=0.05) for treatment comparison on a give day.

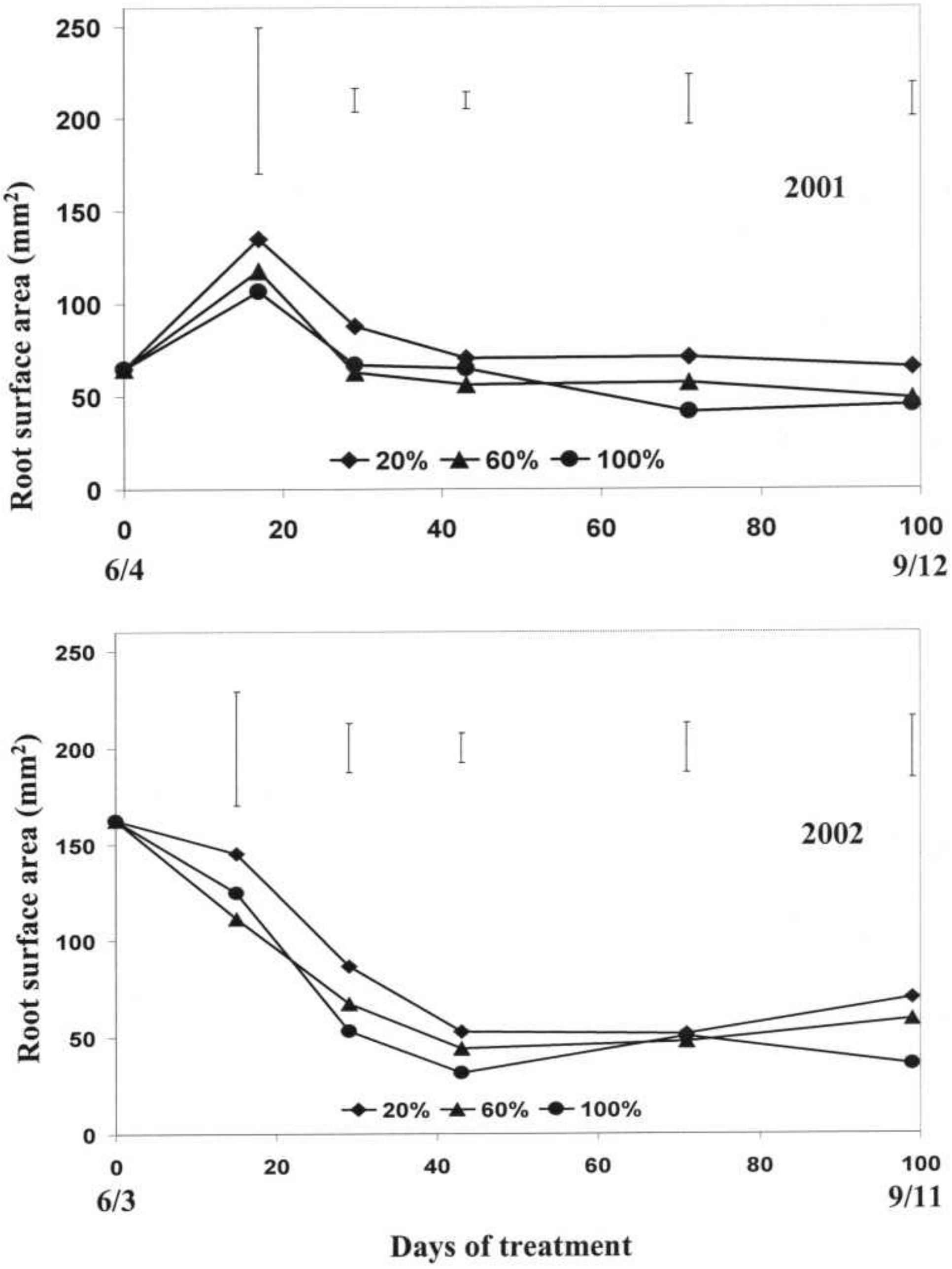

Fig. 3. Tall fescue root surface area in frame 20 (17.47 to 18.38 cm depth) in response to deficit irrigation. Vertical bars on the top of figures are LSD values (P=0.05) for treatment comparison on a given day.

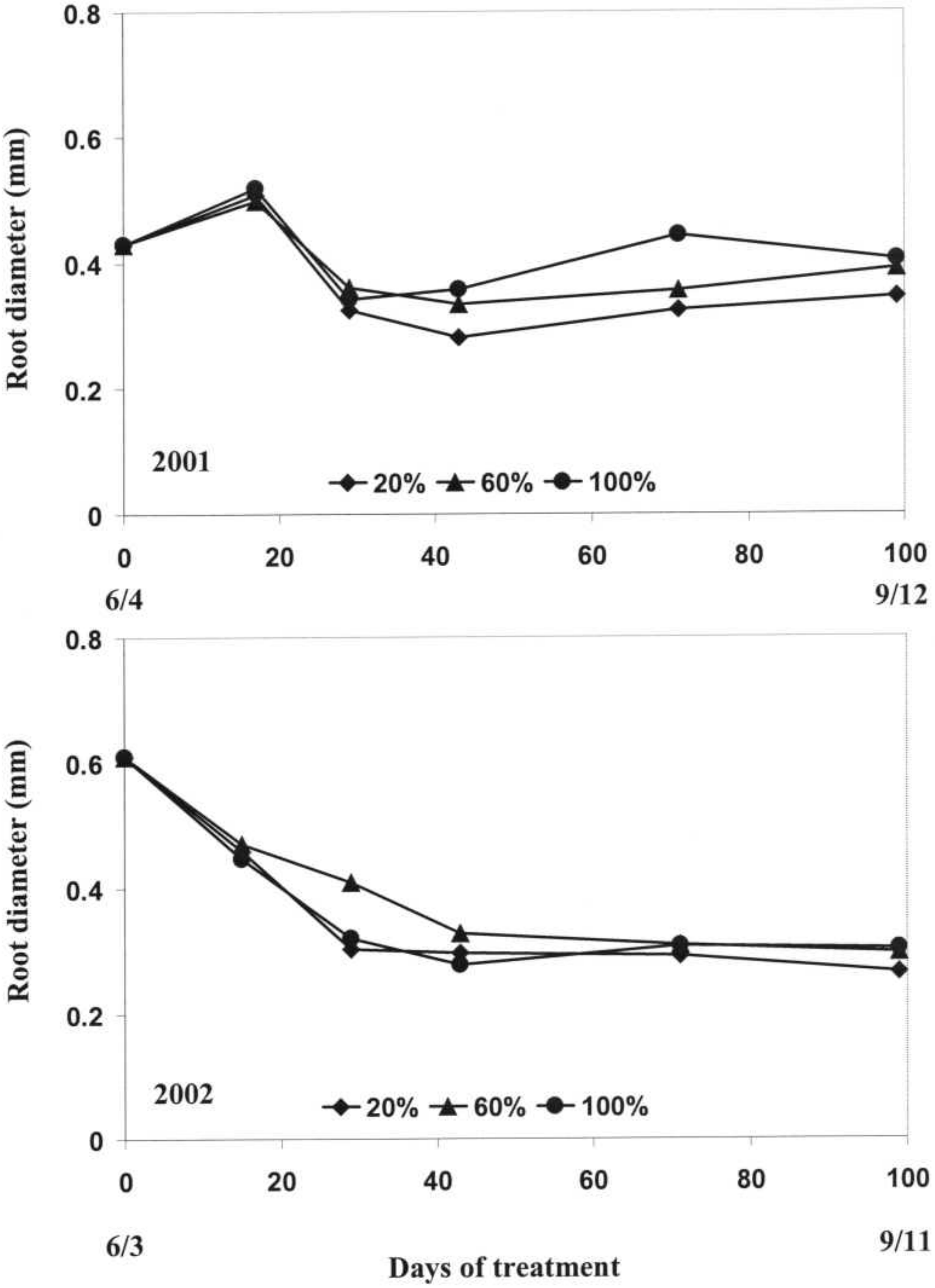

Fig. 4. Tall fescue root diameter in frame 20 (17.47 to 18.38 cm depth) in response to deficit irrigation. Vertical bars on the top of figures are LSD values (P=0.05) for treatment comparison on a given day.

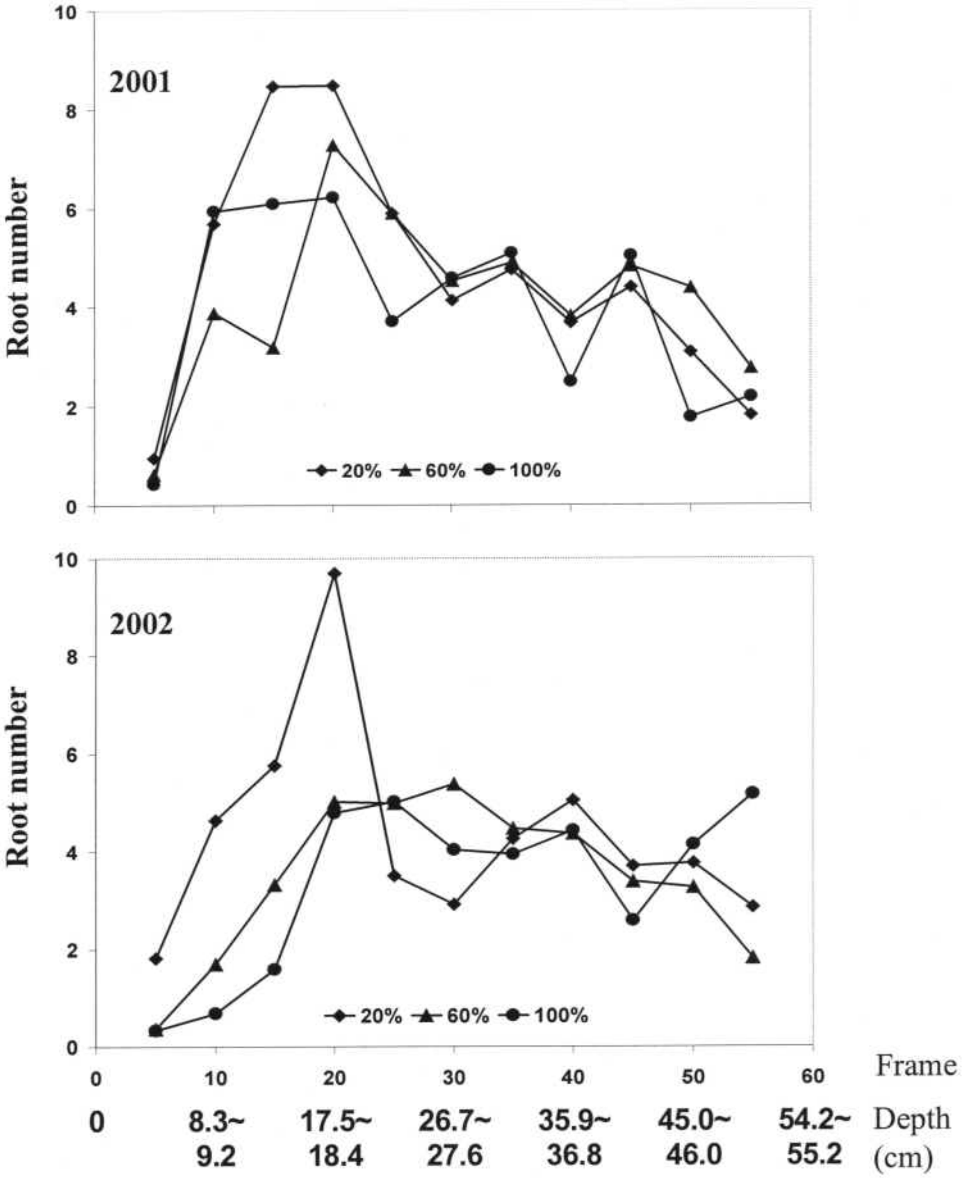

Fig. 5. Vertical distribution of tall fescue root numbers in response to deficit irrigation.

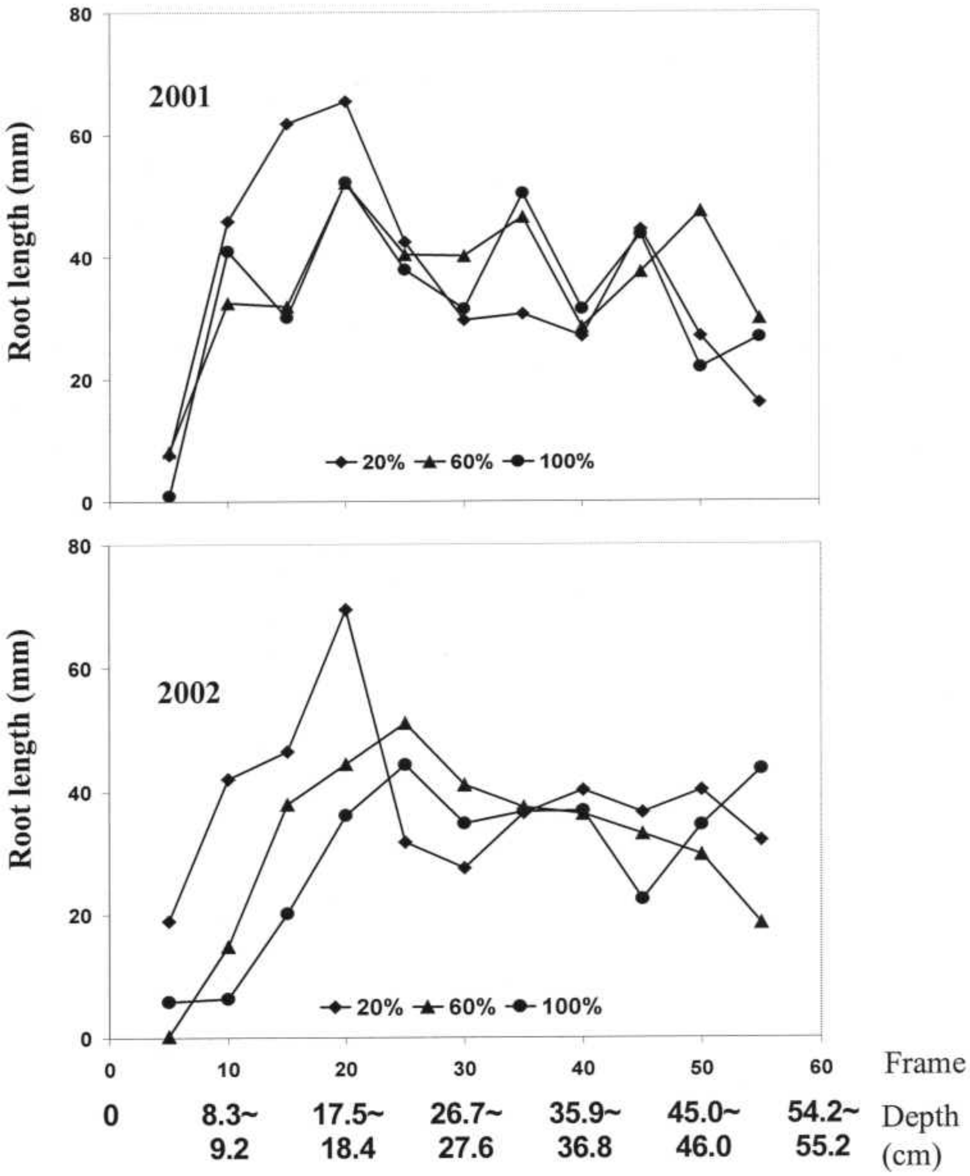

Fig. 6. Vertical distribution of tall fescue root length in response to deficit irrigation.

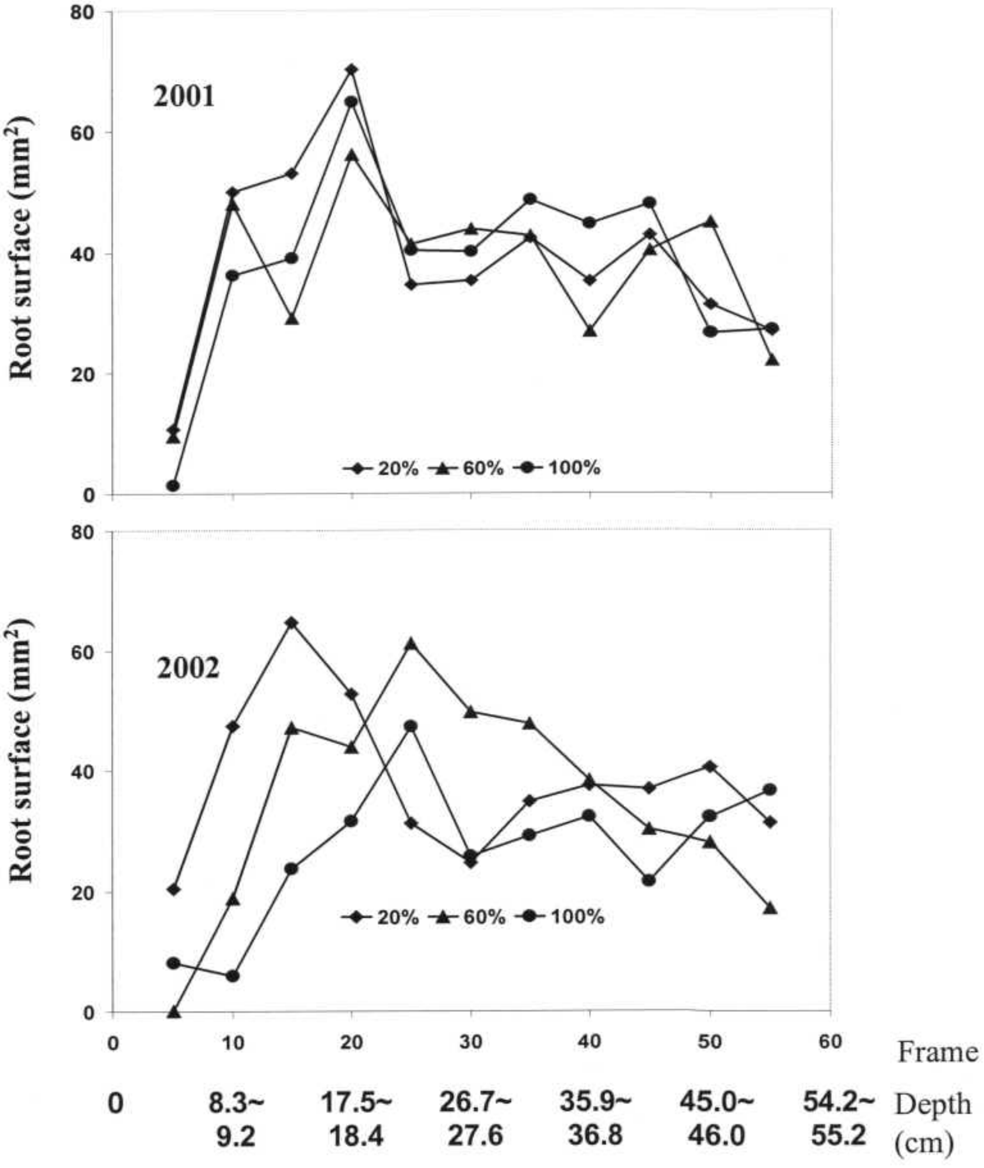

Fig. 7. Vertical distribution of tall fescue root surface area in response to deficit irrigation.

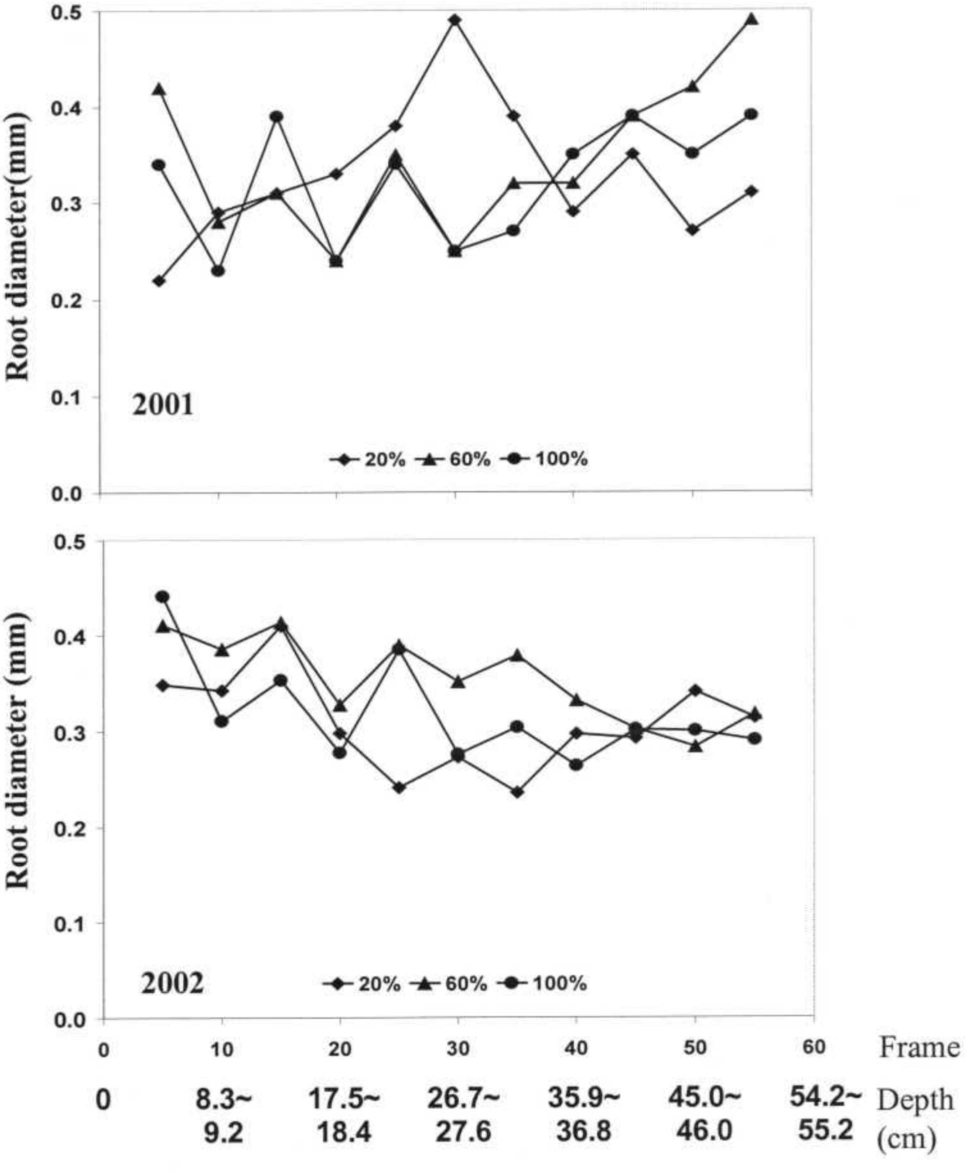

Fig. 8. Vertical distribution of tall fescue root diameter in response to deficit irrigation.