Addition of Surfactants to Turf Systems: Effect on Infiltration Rates and Root Zone Water Storage.

D. Goorahoo[1*], G. Carstensen[1], D. F. Zoldoske[1], S. Kostka[2], K. Mauser[2] and M. Franklin[2].
[1]Center for Irrigation Technology. California State Univ.- Fresno. 5370 N Chestnut Ave, Fresno, CA 93740.
[2]Aquatrols Corporation of America. 5 N. Olney Ave. Cherry Hill, NJ 08003
*Contact: Tel.- (559) 278 8448. e-mail: dave_goorahoo@csufresno.edu

Abstract: The projected increase of 15 million in California's population by the year 2020 will result in further competition among various sectors for the State's limited water supply. In an effort to deal with this competition, the turfgrass industry has been adopting management practices that will increase water use efficiency and ensure the industry's sustainability. The overall goal of this research was to evaluate the addition of surfactant to irrigation water as a management strategy for commercial turf systems such as golf courses. The impacts of three surfactant formulations, applied at two rates, on overall turf quality, steady rate infiltration and water storage in the root zone were investigated. Based on visual evaluation, there was generally a positive effect of the surfactants on the overall improvement in turf quality. Surfactant addition significantly affected infiltration rates at both the high and low application rates. However, the surfactant that resulted in the highest infiltration at the low application rates was different from the one that significantly increased infiltration at the high rates. For the low application rates, the surfactant that resulted in the greatest increased infiltration also indicated the potential for maximum water use efficiency. However, for the high application rates, water loss from the root zone for the surfactant treated plots were either greater than or equal to that from the control plots.

Introduction: In the San Joaquin Valley- and in general, California- economic and population growth has resulted in competition for water supply between the agriculture sector and the increasing urban population. Environmental restoration is also placing increased demands for water supplies. For example, the growers of the California's Central Valley West Side recently lost 800,000 acre-feet of water that was redirected for environmental purposes (City of Fresno Dept. of Public Utilities, 1999). The projected increase of 15 million in California's population by the year 2020 will only result in further competition among the various sectors for the State's limited water supply (California Farm Water Coalition, 1999).

Besides the increased competition for a limited water supply, the agriculture sector must also adhere to strict environmental protection regulations. As a result, this sector has been adopting Best Management Practices (BMPs) in order to ensure its sustainability. As defined, a BMP is a practical, affordable approach that will eliminate or minimize air, water and soil degradation without sacrificing productivity of the operation. The approach comprises of a number of strategies, which when implemented either simultaneously or sequentially would maintain the productivity and sustainability of the system. In keeping with this philosophy, members of Turfgrass Producers International (TPI) have acknowledged that (a) water is the single most important resource for every aspect of this green industry, (b) management is the critical factor in water use efficiency, and (c) BMPs should be implemented to enhance water use efficiency (Slack, 1999). Some examples of the strategies currently used in establishing BMPs for the turf grass industry include: laser leveling of fields; lining of ditches; use of soil moisture monitoring devices; use of overhead or drip irrigation systems; use of wind and rain sensors; reuse of water on site; on-site water management analysis; early mornings and late night waterings; higher mowing during the hotter months; and, use of effluent water for irrigation (Slack, 1999).

Another approach being adopted by the turfgrass industry is the application of non-ionic surfactants. The premise behind the use of the surfactant is that it reduces the surface tension of the water, and thus enhances the penetration of the water into the soil profile. For example, Miller (1999) demonstrated in a column study that for six cm of two hydrophobic soils, the infiltration times of an 8000 ppm solution of a non-ionic surfactant blend was 98% lower than the times for distilled water alone. In a subsequent study, involving a San Joaquin sandy loam collected near Bakersfield, CA, it was found that addition of surfactants and gypsum greatly improved infiltration into this soil (Mauser, 1999). At the field scale, Kostka (2000) demonstrated that systematic treatment with a commercially available surfactant reduced soil water repellency, enhanced turf performance, improved uniformity of turf, and increased available water in soils.

Despite the laboratory tests that show a major improvement in infiltration rates of water through a soil column, and the study by Kostka (2000), there is a need to evaluate the use of different surfactants at the field scale, for systems such as commercial turf sites. Such an evaluation will scientifically examine the use of a surfactant on infiltration rate, irrigation efficiency and overall sustainability of the system. These evaluations should also document the impacts (both positive and negative) of the surfactant treatment on the water, soil and vegetation. Hence, the objective of the current study was to evaluate the systematic application of surfactants as a management strategy for commercial turf systems such as golf courses. The impacts of three surfactant formulations, applied at two rates, on overall turf quality, steady rate infiltration and water storage in the root zone were investigated.

Procedure: Trials were conducted at the Riverside Golf course in Fresno California, located in the center of the agriculturally rich San Joaquin Valley. Riverside Golf Course sits along the San Joaquin River in the North West corner of the city. The course is very old and has developed dry spots along the edge of fairways that watering has little or no effect on. The fairways are planted in a Bermuda grass and top seeded in the winter with rye. The soil type ranges from a loam to a sandy loam, with soil pH ranging between 6.5 and 7.9. A water resistant hardpan layer that may occur as shallow as 20 cm from the soil surface also characterizes the area.

The trials comprised of two experiments: (1) A High Rate experiment; and, (2) A Low Rate experiment. A total of 32 experimental plots (2 meters x 2 meters) were used, with 16 plots for the High experiment and 16 plots for the Low experiment. The areas chosen for the experiments were based on the recommendations of the golf course superintendent. The High Rate experiment was conducted in an area characterized by lower water infiltration and by relatively poorer turf quality than the area used for the Low Rate experiment. Both experiments followed a completely randomized design with four treatments replicated four times.

Treatments for Low Rate Experiment:**

(1) L0- no surfactant, Control;
(2) L1- a commercially available non-ionic surfactant blend, applied once a month at 17.5 mls/100m^2;
(3) L2- a commercially available non-ionic surfactant blend, applied once a month at 10mls/100m^2; and,
(4) L3- an experimental surfactant formulation, applied once a month at 250mls/100m^2.

Treatments for High Rate Experiment:**

(1) H0- no surfactant, Control;
(2) H1- a commercially available non-ionic surfactant blend, applied once a month at 25 mls/100m^2;
(3) H2- a commercially available non-ionic surfactant blend, applied once a month at 17.5 mls/100m^2; and,
(4) H3- an experimental surfactant formulation, applied **twice** a month at 250mls/100m^2.

** In keeping with the 2002 Irrigation Association Technical Conference guidelines that presentations be "**non-commercial**" in content, the brand names of the treatments are not reported.

Treatments were applied in 2 liters of water using a portable carbon dioxide pressurized sprayer. Applications were done from July though November 2001, and again in January 2002. All 32 plots were visually evaluated on July, August, October, and November of 2001 and finally in May 2002, approximately four months after the last surfactant application. The resident golf course superintendent conducted visual ratings of the plots for color, density, uniformity, general growth vigor, and overall turf quality. The evaluation method used was a scale of 1 to 9, with 1 to 3 indicating unacceptable quality turfgrass, 4 to 6 indicating acceptable quality turfgrass, and 7 to 9 indicating superior quality turfgrass (Zoldoske, 1994).

Infiltration studies were conducted in June (T0), August (T1) and October (T2) in 2001, and finally in January 2002 (T3). The objective was to determine the effect of the different surfactant on steady rate infiltration, also referred to as *steady-state infiltrability* or as the *final infiltration capacity* (Hilllel, 1998), after one (T1), three (T2) and five (T3) rounds of surfactant treatments. Double ring infiltrometers were used, for a total of 384 infiltration experiments (32 plots x 3 infiltration expts. per plot x 4 rounds of expts.), in order to calculate the average steady rate infiltration (cm h^{-1}) for each treatment.

Four rounds of cumulative volumetric soil moisture content for the 0-20cm depth were taken with a Diviner 2000 portable soil moisture monitoring system (Sentek Environmental Technologies, 1999). The objective was to see how the surfactant treatments could be affecting the water movement or water holding capacity within the root zone, as plots were exposed to similar water application and evapotranspiration rates. These moisture readings were taken two hours apart, and the relative change in moisture content for the various treatments were assessed. Percent changes in moisture assessments were determined at times T1, T2 and T3 corresponding with the infiltration studies, and then at the end of May 2002 (T4) to coincide with the final visual assessment of the plots.

Results and Discussion: As expected, at the start of the trials the plots used for the Low Rate experiment had a relatively higher overall turf quality rating (Figure 1a) than those used for the High Rate experiment (Figure 2a). At the final visual evaluation (May 2002), there was a general improvement in turf quality of all plots (Figures 1b and 2b). More importantly, a positive effect of the surfactant was noticeable in the High Rate experiment. The H3 treatment resulted in the best turf quality rating followed the plots treated with H2, H1, and no surfactant, respectively (Figure 2b). The improved turf quality ratings were due primarily to visual improvements in color (Figures 3 and 4), and growth vigor (Figures 5 and 6). Throughout the experiments, no substantive improvements were observed for mean growth density and growth uniformity.

In this study, the steady rate infiltrations were examined rather than the initial or "early time" infiltration. In general, soil infiltrability is relatively high in early stages of infiltration, particularly where the soil is dry, but tends to decrease monotonically and eventually approach an asymptotic constant infiltration rate (Hillel, 1998). Hence, by comparing the "late time" steady rate infiltrations, care was taken to ensure that the values being compared were not influenced by the initial moisture content of the plots or by the differences in ponding head in the ring infiltrometers (Stephens, 1996). The infiltration experiments were conducted for 120 minutes, and generally, the steady state infiltrability (or " late time" steady rate infiltration) was attained after 90 minutes.

There were no significant differences in the steady rate infiltrations for the plots prior to the addition of any surfactant (T0). In general, the addition of surfactant resulted in an increase in the steady rate infiltrations (Figures 7 and 8). ANOVA tests indicated that with the exception of the treatment 1 (L1 and H1), the surfactants resulted in a significant difference in infiltration rates. For both the Low and High rate experiments, the effects of the surfactant were observed after the first application of the surfactants (T1, August 2001). In addition to the ANOVA, a Tukey's HSD revealed that there were significant differences among the surfactant treatments. For example, within the relatively better quality plots (i.e. at the lower application rates) the treatment H3 had the greatest significant ($p = 0.05$) positive effect (Figure 7), whereas in the High rate experiment H2 was most effective after the first surfactant application (Figure 8, see Aug.01). Then, by the third (Oct. 01) and fifth (Jan. 02) rounds of surfactant application, the treatment H3 (experimental formulation) was having the most significant impact on infiltration for the relatively poorer quality plots. It is also noteworthy that in the Low rate experiment, after the 5^{th} rounds of surfactant application both H3 and H2 resulted in significant differences ($p = 0.05$) in infiltration rates.

It is not clear why the treatment 1 (H1 and L1) had no significant effect on the steady rate infiltration. The nonionic surfactant was expected to reduce the surface tension of the water, and thus enhances the penetration of the water into the soil profile. Laboratory tests involving treatment 1 by Miller (1999) and Mauser (1999) indicated that the addition of this surfactant and gypsum greatly improved infiltration into the soil. A probable explanation for the lack of effect observed in the current study could be that a relatively lower application rate was used in the current study.

The objective of measuring soil moisture was to observe which treatment resulted in the greatest percentage change in moisture within the top 20cm of soil (root zone). By considering the mechanisms by which water can enter, exit, or be stored in the root zone, the net change in water storage, ΔS, over the two hour time interval that the moisture readings were taken can be represented by (Stephens, 1996),

$$\Delta S = I - E - R \qquad \text{Eq.1.}$$

where, I is infiltration or precipitation, E is evapotranspiration and R is runoff or deep percolation. Relative change in root zone water storage was calculated using $\Delta S \div S$. It was assumed the all plots were subjected to similar amount of irrigation or precipitation and evapotranspiration. Since there was no runoff occurring then it can be deduced that any change in moisture was a result of water percolating beyond the root zone.

<u>For the Low rate experiment (Figure 9):</u> There appears to be significantly more "deep" percolation from the plots subjected to treatment L2. Interestingly, the moisture changes observed for the L3 was less than that observed for L2 and similar to the plots receiving no surfactants (L0). Recall that from the steady rate infiltration studies (see above) that L3 resulted in the greatest improvement in infiltration for the Low rate experiment. The enhanced infiltration as a result of L3 application combined the lower deep percolation would mean that the water entering the soil would have been available for uptake by the turfgrass, thereby increasing water use efficiency. It should also be noted that: (1) the L1 treatment had the least amount of water loss, but recall that there was also no significant increase in infiltration for the plots treated with this surfactant; and, (2) the relative change in moisture recorded in May 2002 (four months after the plots received any surfactant) from the plots receiving the L3 treatment was similar to the water loss observed for the treatment L2 and no surfactant. Taking into consideration that both the turf quality and infiltration rate due to L3 were considerably better than that observed for the other treatments at May 2002, then the similarity in water loss would imply that after 4 months from the last surfactant application, there is the potential for increased water use efficiency in the plots receiving surfactant L3.

<u>For the High rate experiment (Figure 10):</u> After the first round of surfactant application, the greatest water loss appeared to have occurred within the plots treated with H1 (see Aug 01, Figure 10). At this time, there was minimum water loss from the H3 treated plots and water loss from the H2 treated plots was intermediate between the control (H0) and the H3 treatments. By the time the trial progressed to the fifth rounds of surfactant application, the water losses from the surfactant treated plots were greater than from the control plots. Also, four months after the last surfactant application (May 02, Figure 10), there were similar water losses from within the root zone by all plots (treated and non-treated).

Conclusions and Recommendations:

- There was generally a positive effect of the surfactants on the overall improvement in turf quality.
- Surfactant addition significantly affected infiltration rates at both the Low and High application rates.
- The L3 surfactant resulted in the highest infiltration at low application rates.
- Both H2 and H3 surfactants significantly increased infiltration at the high rates.
- For the low application rates, the surfactant that resulted in the greatest increased infiltration also indicated the potential for maximum water use efficiency.
- For the high application rates, water loss from the root zone for the surfactant treated plots were either greater than or equal to that from the control plots.
- It is suggested that surfactant treatment L3 can be used on plots that are of relatively high quality to ensure maximum water use efficiency.
- It is recommended that for plots of relatively poor turf quality and reduced infiltration rates, at least one application of H2 or H3, and possibly up to a maximum of three consecutive monthly applications, at the rates used in the current study can be used to increase infiltration rates. More than three rounds of applications in consecutive months may result in water percolating pass the turfgrass root zone.

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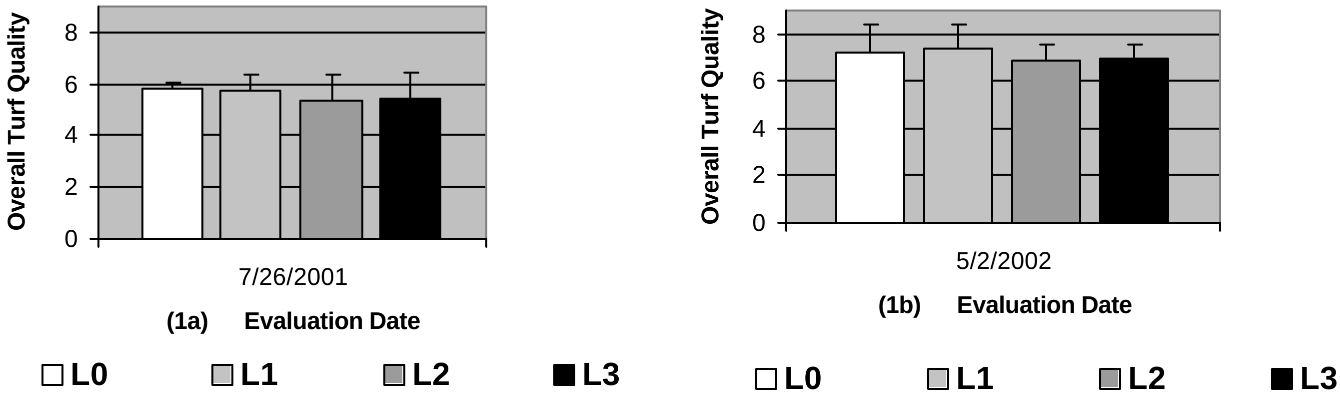


Figure 1: Overall turf quality for Low rate experiment at (a) July 2001 and (b) May 2002.

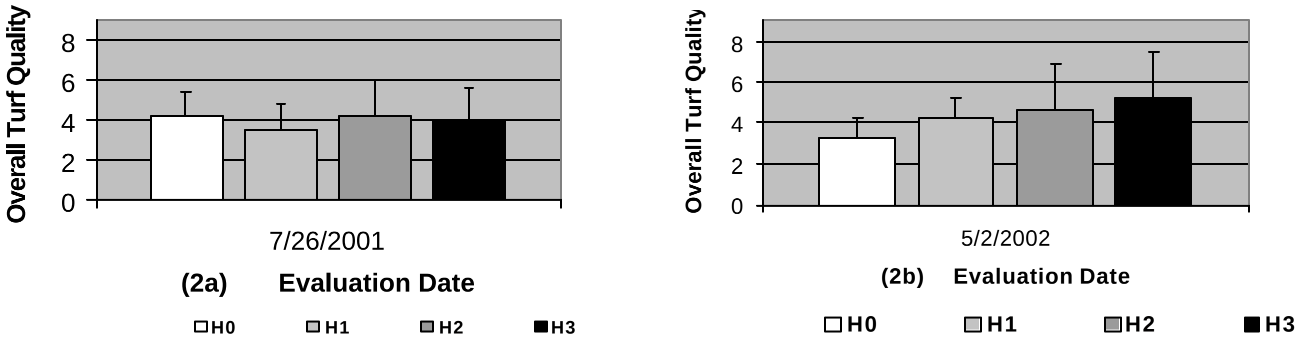


Figure 2: Overall turf quality for High rate experiment at (a) July 2001 and (b) May 2002.

Figure 3: Mean color rating for Low rate experiment at (a) July 2001 and (b) May 2002

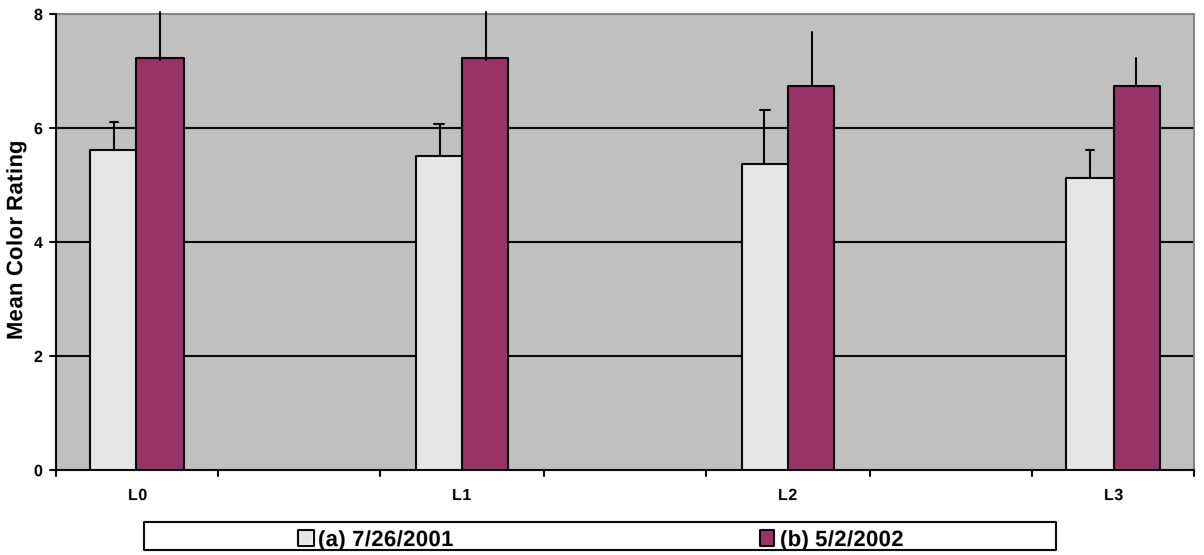


Figure 4: Mean color rating for High rate experiment at (a) July 2001 and (b) May 2002

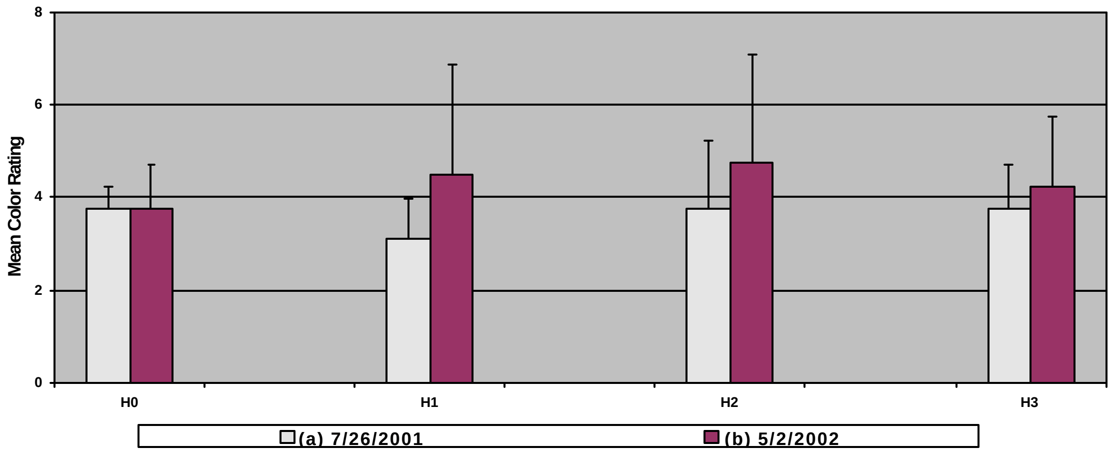


Figure 5: Mean growth vigor for Low rate experiment at (a) July 2001 and (b) May 2002

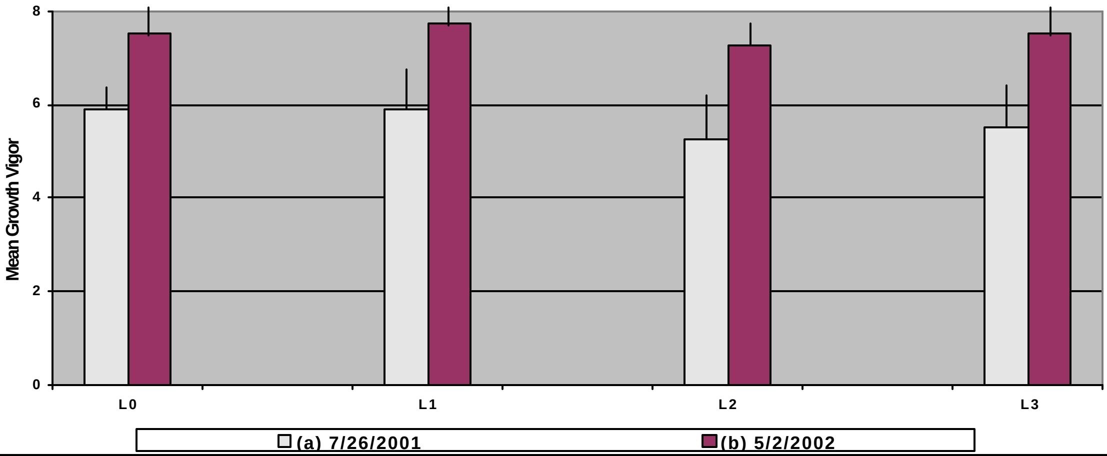
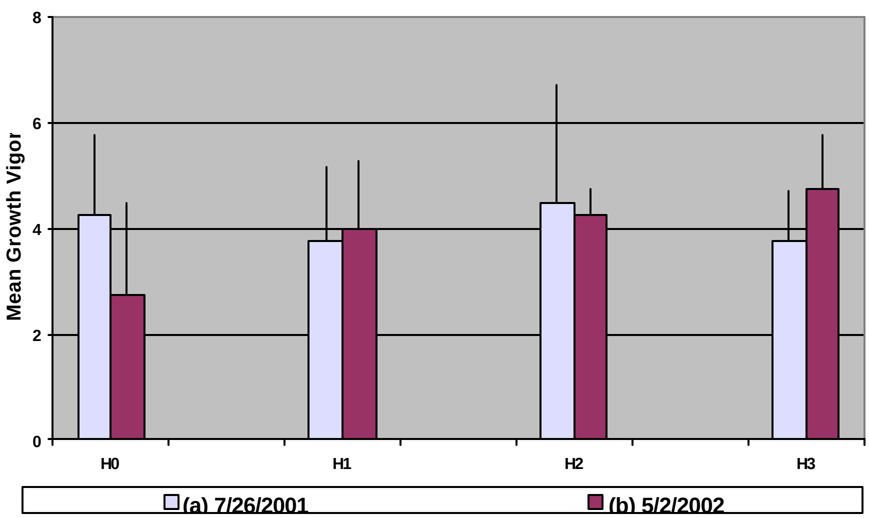


Figure 6: Mean growth vigor for High rate experiment at (a) July 2001 and (b) May 2002



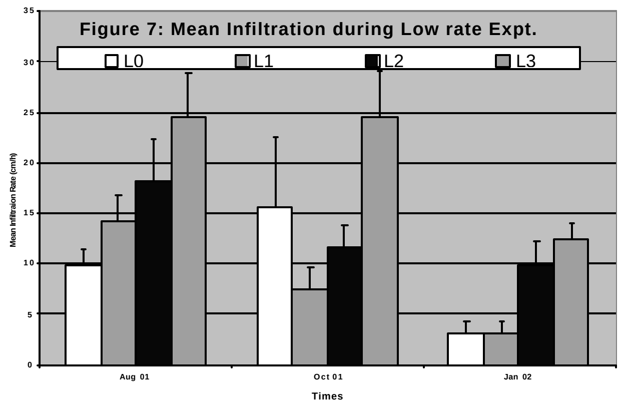
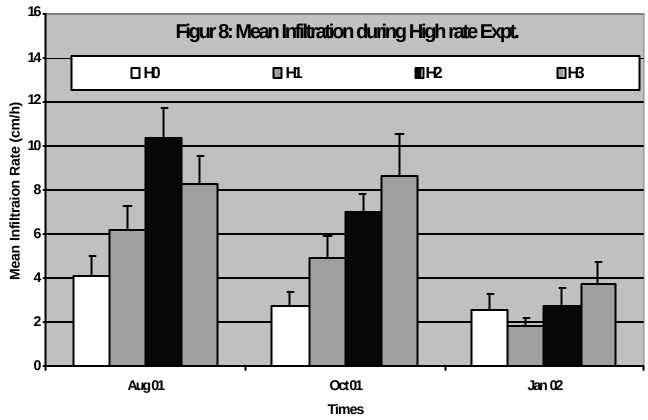


Figure 7: Mean Infiltration during Low rate Expt.
L0
L1
L2
L3
Aug 01
Oct 01
Jan 02
Times


Figur 8: Mean Infiltration during High rate Expt.
H0
H1
H2
H3
Mean Infiltraion Rate (cm/h)
Aug 01
Oct 01
Jan 02
Times

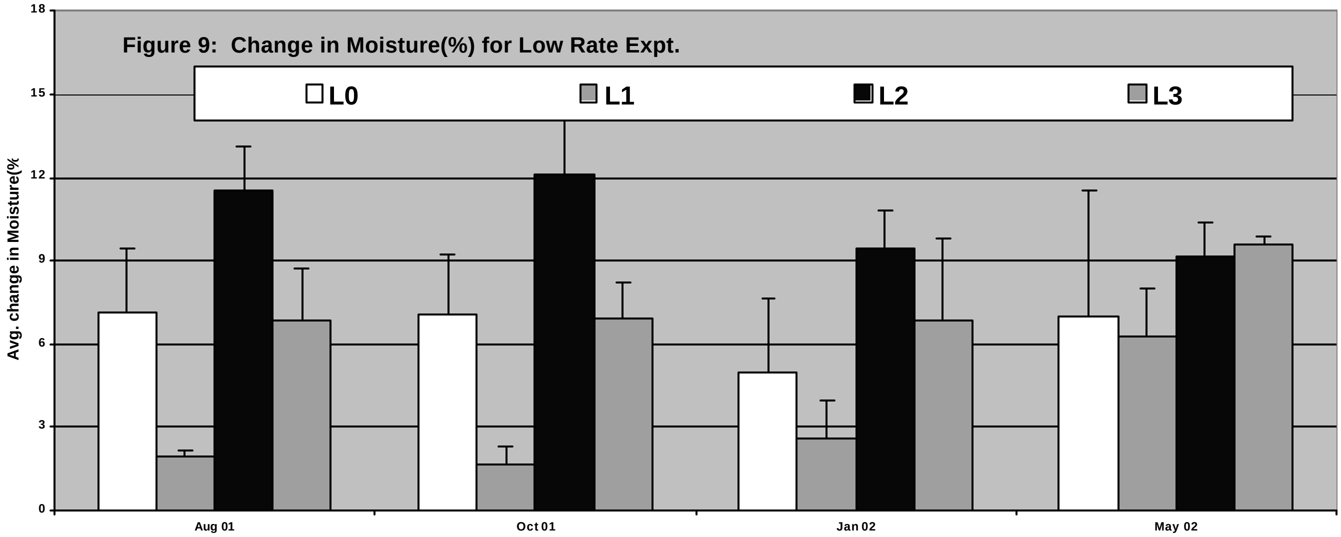


Figure 9: Change in Moisture(%) for Low Rate Expt.
L0
L1
L2
L3
Avg. change in Moisture(%
Aug 01
Oct 01
Jan 02
May 02

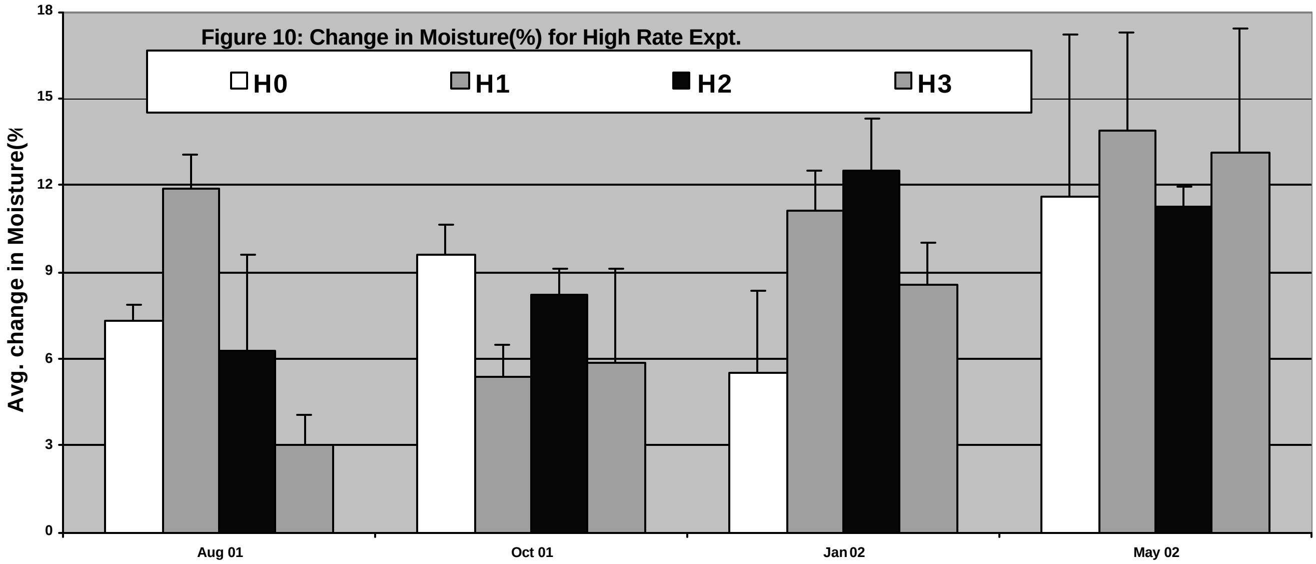


Figure 10: Change in Moisture(%) for High Rate Expt.
H0
H1
H2
H3
Avg. change in Moisture(%
Aug 01
Oct 01
Jan 02
May 02