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SENSITIVITY OF GOSSYM COTTON GROWTH MODEL TO SOIL VARIABILITY AND SITE-SPECIFIC MANAGEMENT

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Abstract

Site-specific crop management is delivering ever increasing amounts of information about yield variability to producers. Crop models represent one method for explaining causes of variability and helping producers better manage their fields to accommodate it. Crop models should be tested for their ability to handle the extra stringency that site-specific applications place on them. This work examines the sensitivity of the GOSSYM crop model to soil texture, seasonal water application level, and beginning soil moisture. Variation in yields between soil textures varied with yearly weather, water application level, and beginning soil moisture. The effects of beginning soil moisture were most pronounced at lower seasonal water application levels.

Introduction

The ability to vary agronomic inputs across farm fields has become feasible with the advent of new technologies over the past decade. Global positioning systems allow for constant accurate identification of points in a field, while geographic information systems can store and index multiple layers of information about these points. These technologies have been coupled with variable rate applicators and yield monitoring systems to provide farm managers with ever increasing amounts of detailed information about their production systems. This combination of technologies is allowing managers to observe variability in crop yield with increasing detail. The increased ability to identify variability in yields will lead to more producers trying to determine the causes of the variability and to want to optimize their management to account for this variability.

Crop models are one tool that could potentially aid producers with answers to questions about variability causes and optimized management. Crop models such as CERES-Maize and CROPGRO-Soybean (Paz et al., 1998 and 1999) have been used to relate soil moisture variability to spatial yield variability for corn and soybean crops. Crop models have been advocated for determining the source of yield variability because they are dynamic in nature and include temporal interactions of multiple factors in their predictions. Other techniques (such as regression analysis) for determining causal relationships between yields and possible causative factors lack this characteristic. Another crop model use has been the determination of long-term management strategies for water and nitrogen across multiple years of historic weather (Braga et al. 1998, Hook, 1994). In addition to long-term management strategy determination, crop models have been used for making in-season decisions for crop management. An example of a crop model being used for this purpose is the GOSSYM cotton model which was coupled with the COMAX expert system (Whisler et al. 1986).

Despite evidence of the usefulness of crop models for explaining the causes of yield variability and as decision aids, further work and development on them is needed for them to be applied to site-specific management applications. Crop model development has focused on prediction of mean field level averages. For site-specific crop management applications, models will need to account for variability across fields in their predictions. To be effective for site-specific crop management applications, crop models should be designed to meet the following criteria (Sadler et al. 2000): (1) have the ability to be used with spatial data, (2) be able to account for variables that are important to site-specific crop management and (3) be sufficiently accurate so that their results are reliable.

Site-specific crop management with its potential to better match crop inputs to the needs of individual locations in a field could potentially increase the efficiency of the use of agronomic inputs. More efficient use of agronomic inputs is especially important in areas where these inputs are limited. One such area is the High Plains of Texas where water availability is often a limiting factor in the production of cotton. The High Plains region is important economically to the state of Texas in its production of cotton. Cotton production in this region is dependent on water from the Ogallala aquifer. The aquifer has shown marked declines over the past decades, thus water withdrawals from it are increasingly limited. The ability to spatially vary water applications across fields have been developed at several locations in the United States (Evans et al., 1996, Perry et al., 2002, Camp et al., 1998). Knowledge of how to best vary irrigations is still being developed with crop models being a potentially valuable tool for this development.

This work assesses how well the GOSSYM crop model meets criteria two from the Sadler et al. (2000) list when applied to an irrigation scenario for the Texas High Plains climate.

Methodology

The sensitivity of model predicted yield to soil texture, seasonal irrigation quantity, and beginning soil moisture levels was examined. Soil texture represents a potential cause of yield variability, while irrigation quantity and beginning soil moisture are parameters that can potentially be managed. Model scenarios were created with uniform soils with depths from 0-1.83 m. Eight soil textures from the interior of the soil textural triangle were included in the tests. GOSSYM inputs that corresponded to each of these soil textures were obtained from a soil water characteristic calculator based on a paper by Saxson, et al. (1986). Inputs for each of the soil textures are shown in Table 1. Weather inputs for the model were obtained from the South Plains Evapotranspiration Network (n.d.). Weather data for five years (1997 – 2001) was used with the model. A summary of the average daily maximum and minimum temperatures and the cumulative rainfall for the years used for the simulations is shown in Table 2.

Management parameters specified in the model include planting rate, planting date, harvest date, fertilization rate and time, and irrigation rate and time. The inputs used for planting and harvest date and planting rate are listed in Table 3. Fertilization rate and timing were specified so that nitrogen stress was avoided in the model. A constant interval irrigation schedule was used for the modeling scenarios. Irrigations were scheduled on a biweekly basis in May and weekly from June through August. Irrigation rates on each date were varied from 0 to 50.8 mm in 10.2 mm increments. Irrigations of 40.6 mm were adjusted to account for rainfall on the previous four days. Irrigation quantities for the other four levels were adjusted proportional to the 40.6 mm rate.

In the High Plains regions, pre-plant irrigations are often needed for seed germination. The ability of the model to account for varying initial levels of soil water was thus tested. Initial soil water levels from 20 to 100 percent in 20 percent increments were tested for water application rates of 10.2 mm and 30.4 mm.

Discussion

Yields for each soil type for varying seasonal depths of applied water are shown in Figures 1 and 2. The curves generally increase from 0 mm applied water and approach an asymptote at 250 mm of applied water. The magnitude of the yield at 0 mm of applied water and at the asymptote varied depending on the year. The average yield across all soil textures for 0 mm of applied water varied from 525 kg/ha in 2001 to 969 kg/ha in 1999. The yield at the asymptote ranged from 1359 kg/ha in 1997 to 1995 kg/ha in 1999. The observed trend in the model predicted applied water – yield relationship generally follows an expected applied water-yield relationship.

Ranges in yield across soil types were greater at 0 mm of applied water than at the asymptote. At 0 mm of applied water, the yield range across all soil textures ranged from 342 kg/ha in 2000 to 600 kg/ha in 2001. At the asymptote the range of yield across soil types varied from 22 kg/ha in 1997 to 196 kg/ha in 2000. Variation in model predicted yields by soil texture indicate that at higher irrigation levels there is little difference in soils. At lower levels of irrigation, such as occur in deficit irrigation systems, more pronounced differences exist in the soils.

The results of the beginning soil moisture tests for the 10.2 mm application depth are shown in Figures 3 and 4 while the results for the 30.4 mm application depth tests are in Figures 5 and 6. The general trend in the graphs for the 10.2 mm application depth tests was a flat line between 20 and 60 percent filled with large increases in yield from 60 to 100 percent filled. The initial and final yields in the graphs varied by several 100 kg/ha depending on the simulation year. Variation across soil textures was approximately 200 kg/ha at 20 percent beginning soil moisture. The soil texture variation increased as the percentage of the root zone increased to 100 percent full. Yield variation across soil textures was more pronounced in some years than others. For the 1998 simulation, yield between all eight soil textures varied by nearly 1200 kg/ha with the root zone 100 percent filled at the beginning of the simulation. The graphs for the beginning soil moisture level tests with the 30.4 mm application depths were nearly constant and showed very little variation between soil types. The 1998 simulations had very constant yield responses over different beginning soil moisture levels, but had a much larger variation among soil textures than the other simulation years.

Some anomalous yield predictions appeared for several soil types in the beginning soil moisture tests for the 10.2 mm irrigation depth tests. The yield decreased for an increase in initial soil moisture for the sandy loam soil in 1997, the loamy sand and sandy loam soils in 1998 and the loamy sand, sandy loam, and sandy clay loam soils in 2001. A similar decrease in yield occurred for the silt loam soil in 1997, 1998, and 2001. Since these unexpected yield predictions occurred several times, the cause is likely from the response of the model rather than erroneous inputs.

The results of the sensitivity analysis can be used to make broad estimates of the changes in profitability due to site-specific irrigation management. The yield response results for the 1998 weather year (Figure 1b) can be used to examine the range of potential yield changes between site-specific and uniform rate irrigation. For this hypothetical case, the loamy sand and silt loam soils are examined at seasonal application depths of 133, 200, and 265 mm. Yields for this case at the three application depths are presented in Table 4. Uniform irrigation management for a field composed of two equal areas of these two soils at an application depth of 200 mm produced a simulated yield for the field of 1523 kg/ha. If the management of this field were converted to site-specific irrigation with 133 mm of water applied to the silt loam soil and 265 mm applied to the loamy sand soil the yield for the field would be 1741 kg/ha. The difference in simulated yield for the two management practices is 218 kg/ha. This yield would produce $155.87 in additional revenue for site-specific management as compared to uniform management for that year of weather. Management results for actual farms will vary depending on the actual soil variability and weather, but this example indicates that revenue increases are possible with site-specific irrigation.

Conclusions

Simulated yield response curves showed a gradual rising trend followed by a leveling off of yield at higher application depths as would be expected for such curves. Many of the initial and ending values on the curves varied with the yearly weather data used for the simulation. The sensitivity of the model to yearly weather data exhibited a strength of crop models in general which is to predict yield variability with different weather inputs. Some variation in yields across different soil textures were predicted by the model. The model showed greater sensitivity to beginning soil moisture levels at lower seasonal irrigation rates as would be expected. The model lacked sensitivity in predicted yield at the lowest level of beginning soil moisture.

Site-specific irrigation will be affected by differences in yield response for different soil textures. These differences include the magnitude of yield for a given irrigation level and the rate in change in yield response between different irrigation levels. For the irrigation level tests, the model predicted moderate levels of yield response variation for four out of the five years simulated. The remaining year, 1998, showed greater variation in the magnitude of yield for a given irrigation level and showed more variation in the yield response slopes between different irrigation levels. These results indicate the benefits from site-specific irrigation will likely be dependent on differences in yields in a few years rather than every year.

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Table 1. GOSSYM inputs by soil texture.

Symbol	**Diffusivity at - 15 bar (cm^2/day)**	**Hydraulic Conductance (cm^3 soil/ cm^3 water)**	**Saturated Vol. Water Content**	**Vol. Water Content at FC**	**Vol. Water Content at -15 bar**	**Residual Vol. Water Content**	**Air Dry Vol. Water Content**	**Bulk Density (g/cm^3)**	**% Sand**	**% Clay**
Loamy Sand	0.007403	65.25	0.382	0.155	0.075	0.073	0.071	1.64	82	8
Sandy Loam	0.00012	66.14	0.422	0.200	0.100	0.098	0.095	1.53	65	13
Sandy Clay Loam	0.000997	60.02	0.470	0.258	0.158	0.154	0.150	1.41	56	27
Sandy Clay	0.049321	30.11	0.498	0.323	0.224	0.218	0.213	1.33	49	41
Loam	1.27E-07	66.55	0.457	0.255	0.113	0.110	0.107	1.44	38	17
Clay Loam	0.000166	40.66	0.500	0.326	0.183	0.178	0.174	1.32	30	33
Silty Clay Loam	0.000409	34.21	0.515	0.366	0.206	0.201	0.196	1.28	18	37
Silt Loam	1.53E-10	70.05	0.464	0.285	0.105	0.102	0.100	1.42	18	15

Table 2. Average weather conditions for Lubbock, Texas from May 1 to October 15 for 1997 – 2001.

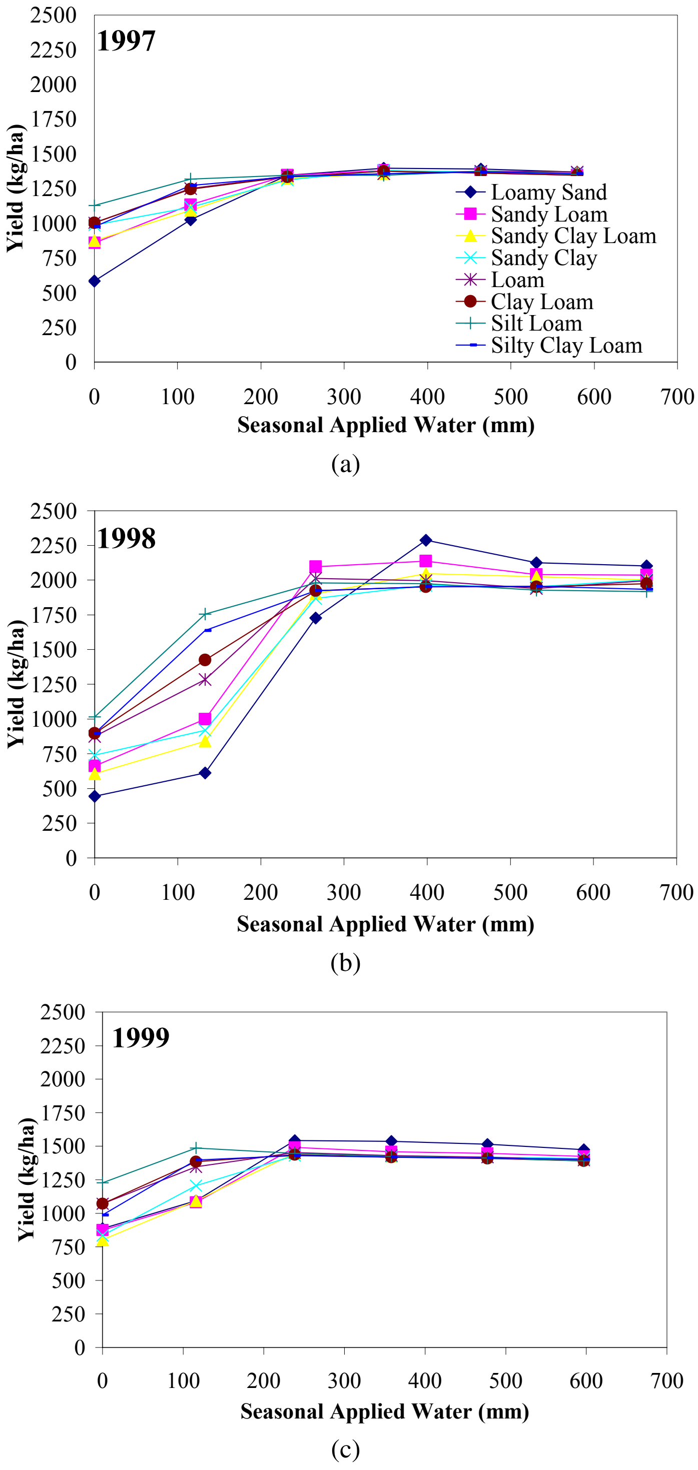
Year	Average Daily Maximum Temperature °C	Average Daily Minimum Temperature °C	Total Rainfall mm
1997	29.6	16.4	295
1998	33.1	17.8	141
1999	30.2	16.5	421
2000	31.4	16.7	216
2001	31.5	16.7	183
Historic Average	30.4	16.3	314

Table 3. GOSSYM management input parameters.

Planting Date:	May 1
Emergence Date:	May 7
Simulation End Date:	October 15
Variety:	Mid
Row Spacing	0.108 m
Plants per meter	9.62

Table 4. Yield differences between site-specific and uniform irrigation management for 1998 weather.

Season Water Depth (mm)	Loamy Sand (kg/ha)	Silt Loam (kg/ha)	Yield for Uniform Management (kg/ha)	Site-Specific Yield (kg/ha)	Yield Difference Between Management Practices (kg/ha)
133	611	1755			
200	1177	1869			
265	1727	1980			
			1523	1741	218

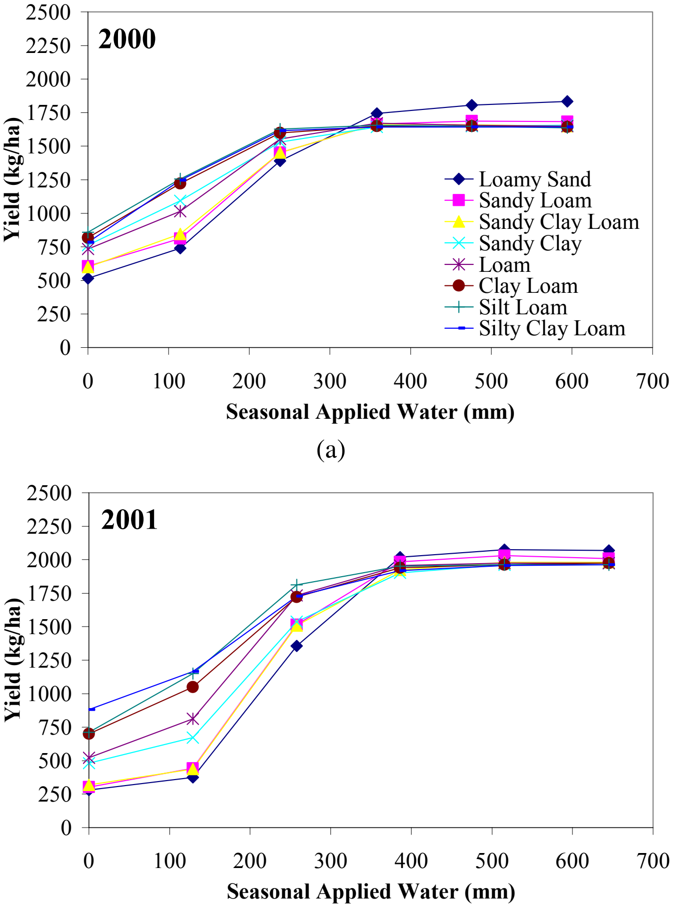


(a)

(b)

(c)

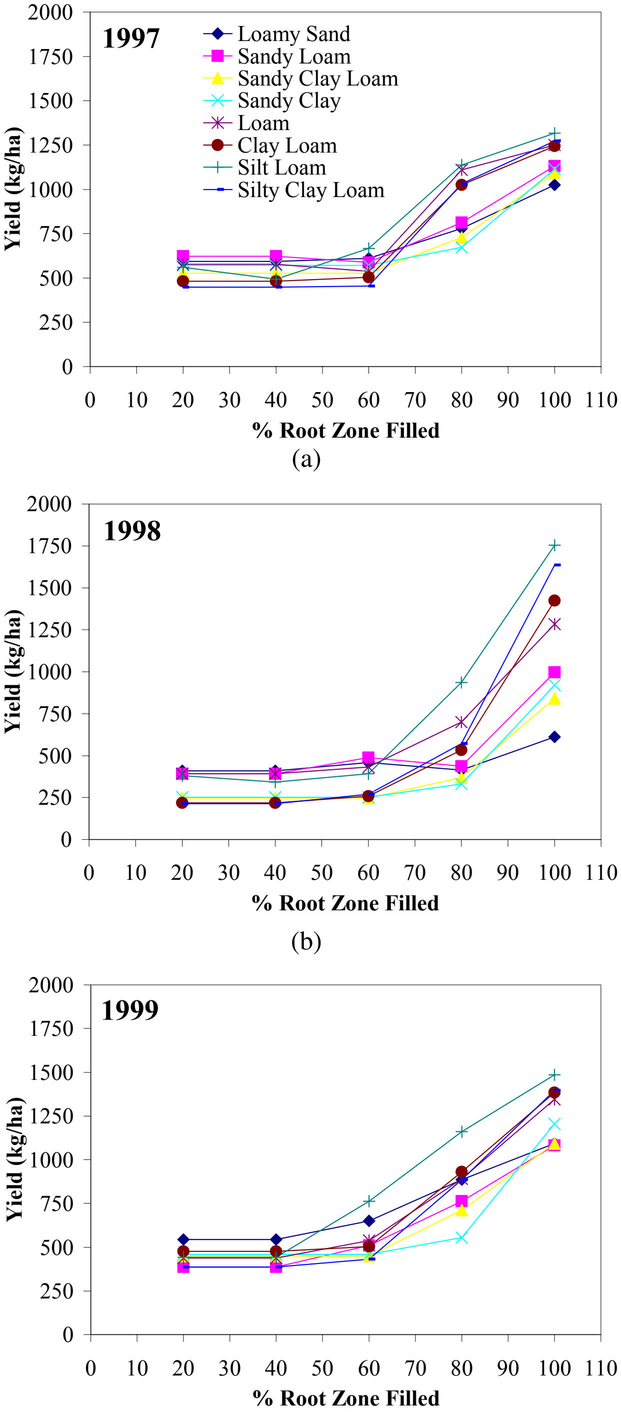
Figure 1. Irrigation level test results for (a) 1997 (b) 1998 and (c) 1999.



(a)

(b)

Figure 2. Irrigation level test results for (a) 2000 and (b) 2001.



(a)

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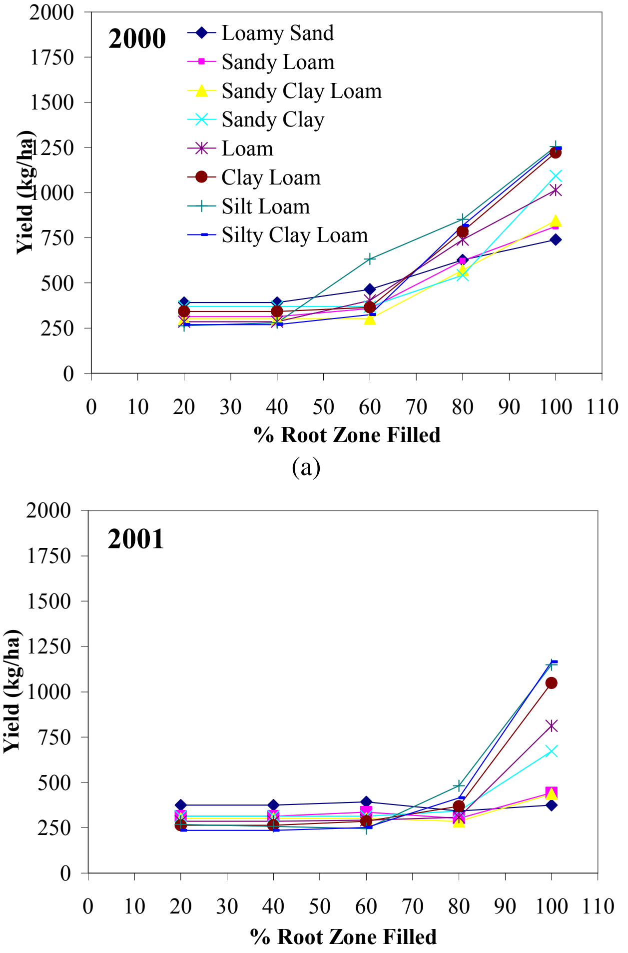
Figure 3. Beginning soil moisture level tests for 10.2 mm application depth for (a) 1997 (b) 1998 and (c) 1999.



(a)

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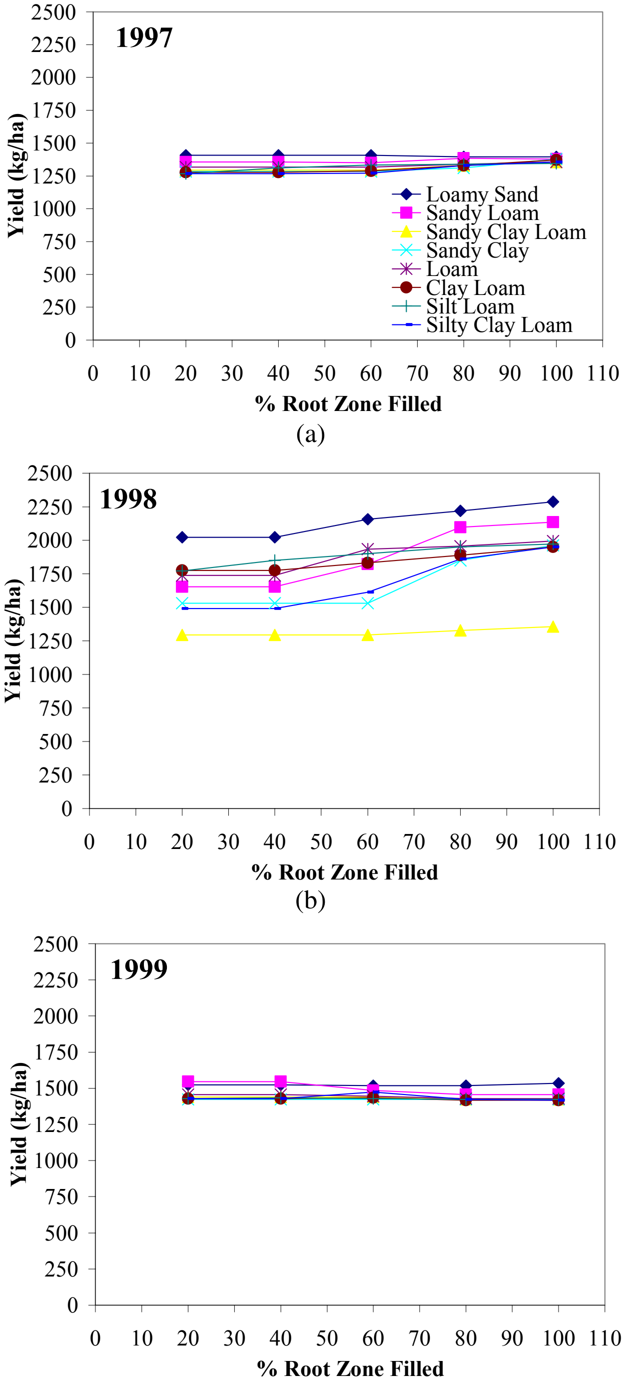
Figure 4. Beginning soil moisture level tests for 10.2 mm irrigation depth for (a) 2000 and (b) 2001.

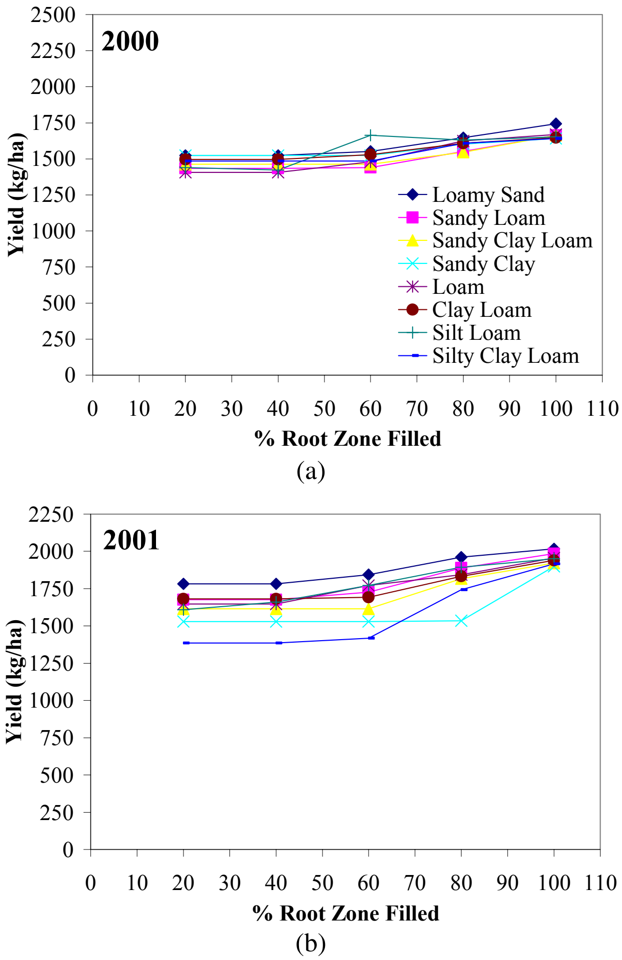


(a)

(b)

(c)

Figure 5. Beginning soil moisture level tests for 30.4 mm irrigation depth for (a) 1997, (b) 1998 and (c) 1999.



(a)

(b)

Figure 6. Beginning soil moisture level tests for 30.4 mm irrigation depth for (a) 2000 and (b) 2001.