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ORIGINAL ARTICLE

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Impacts of ground cover on laws of temporal and spatial variation of soil moisture

Abstract In order to describe and compare intuitively the impact of different kinds of ground cover on temporal and spatial variation of soil moisture, an experiment was carried out by continuous observations to obtain soil potential data of different treatments. Based on the data, isogram maps were drawn by a regression isogram method. The results indicate that the isogram of treatment A (*Paspalum notatum* Flugge-covered) is the most complicated among the three treatments with its significant transverse levels, while the isograms of treatment B (mulching of *P. notatum* Flugge) and C (bare slope) are relatively simple but have clear vertical levels. The variation of soil moisture 30 cm deep in the A treatment is the largest, while that at 60 cm is the second largest and that of 90 cm is the smallest. The variation of soil moisture at all levels of B is fairly small, while that at 30 and 60 cm of C is greater than that 90 cm deep.

Keywords regression isogram method, soil moisture, temporal and spatial variation, *Paspalum notatum* Flugge

1 Introduction

Moisture content in soil does not remain stable but changes over time and space as a result of the combined effects of rainfall, transpiration, soil evaporation, surface runoff, underground seepage, etc., which is affected by soil features. Our country has an estimated $2.18\times10^6\,\mathrm{km}^2$ of red soil areas, where heat and rain are quite abundant but not evenly distributed, bringing seasonal drought, soil erosion, and water shortage in agriculture (Zhao et al., 2000; Li and He, 2002). Ground cover plays an important role from the aspect of conservation of soil and water, changes in soil temperature and moisture, air and hydrology in soil, and state of soil-vegetation-atmosphere continuum. Given identical rainfall and soil background conditions, soil moisture depends largely upon ground cover because of the interaction between soil and plants (Yang and Yu, 1991). This has attracted the attention of an increasing number of scientists in soil conservation and soil science, which have launched studies on the functions of detritus to reduce surface runoff and soil evaporation and increase soil seepage. However, the scope of these studies was limited to the effect of detritus on surface runoff, soil seepage, ground evaporation, and soil moisture distribution by observing the different covering modes or whether the detritus in the woodland was present or not (Liu et al., 1989; Wu et al., 1992; Chen et al., 1996; Yang and Shi, 1997; Zhao et al., 1997; Hou et al., 2007), while plant material and seepage devices remained unused. We have used *Paspalum notatum* and its detritus and applied plot testing and a regression isogram method to study the temporal and spatial changes under different ground cover conditions (Zhou et al., 1997; Bu et al., 2004) to provide a scientific basis for the suitable utilization of the southern red hills.

2 Study site

The study site was located in the ecological zone for soil conservation of Jiangxi Province (29°16′–29°17′N, 115°42′–115°43′E), where a subtropical monsoon climate prevails and the rainy seasons largely overlap with hot summers. The average annual precipitation is 1350.9 mm, the average annual temperature is 16.7°C, the cumulative annual hours of sunshine range between 1650 and 2100 h, and the average annual frost-free period is 249 days. The landforms of this ecological zone belong to the typical low hills of quaternary red clay, which are generally seen in

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Jiangxi and other red soil areas. Exploitation over long periods of time has resulted in severe soil erosion (mainly water erosion) and vegetation degradation, which essentially refers to a set of secondary plant communities (e.g., heath and scrub) as well as plantations of *Pinus elliottii* Engelm and *Cunninghamia lanceolata* (Lamb.) Hook and naturally restored forests of wetland pine. An experimental plot was selected on the middle-lower slope, where the soil is over 1.5 m deep with a pH of 5.0, organic matter 1.55%, total N 0.08%, total P 0.07%, total K 1.7%, and C/N 7.5; the soil is acid, clayey, hard, and poor.

3 Materials and methods

3.1 Test design

A uniform slope of 14° with an area of 225 m^2 was selected and divided into three plots (5 m × 15 m each), where plot A was fully encrusted with grown *P. notatum*, plot B was covered with cut *P. notatum* (15 cm thick), and plot C was kept bare for control.

For observing the dynamics of soil moisture, nine tension meters served to measure soil water potential were placed separately at distances of 3.5 m (upper), 7 m (middle), and 10.5 m (lower) from the top of the slope and in each plot at depths of 30, 60 and 90 cm, respectively.

3.2 Methods

In order to obtain the data of soil water potential, the nine tension meters had to be observed twice daily at 08:00 and 14:00. The average value of the upper, middle, and lower parts of the slope formed the water potential at any depth, while the average value of the three layers on the same plot formed its water potential value. In the end, we obtained 36 sets of data for treatments and layers respectively, including those of the 5th, 15th, and 25th days of each month in 2006, as well as the monthly average values.

In order to describe and compare intuitively the temporal and spatial patterns of soil moisture, regression equations were fitted where soil potential was a function of depth and time. The time interval was set as 0 to 365 days, the space interval as 0 to 100 cm, and the potential intervals as 1 kPa. The Surfer 7.0 mapping software was used to draw the temporal-spatial isograms of soil moisture (Shao and Yan, 2005) from data at different levels: treatment A, *P. notatum* Flugge-covered; treatment B, mulching of *P. notatum* Flugge; and treatment C, bare slope (as shown in Figs. 1–3).

Since there is an inverse correlation between soil potential and soil moisture, a decrease in light on the isogram indicates a decrease in soil moisture. Otherwise, the density of isolines has a positive correlation with changes in soil potential or soil moisture.

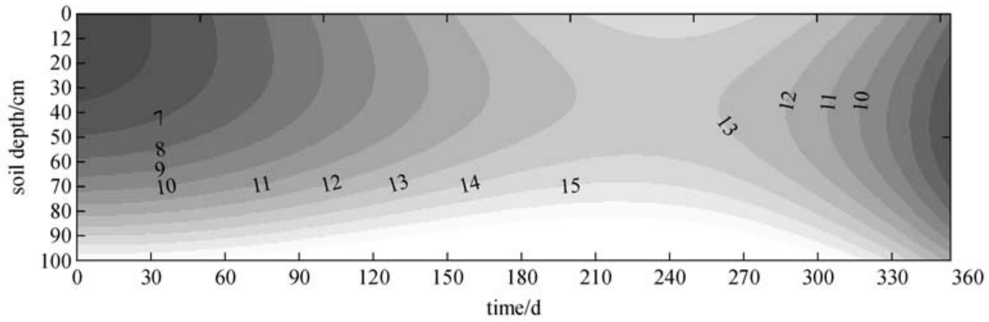

Fig. 1 Isogram of soil water potential (kPa) in treatment A

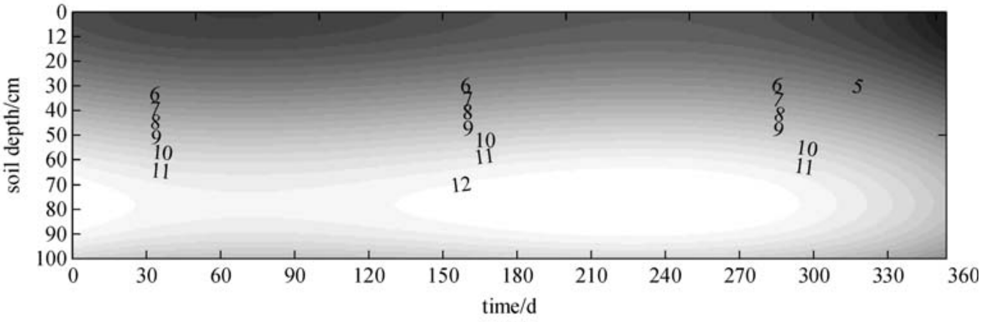

Fig. 2 Isogram of soil water potential (kPa) in treatment B

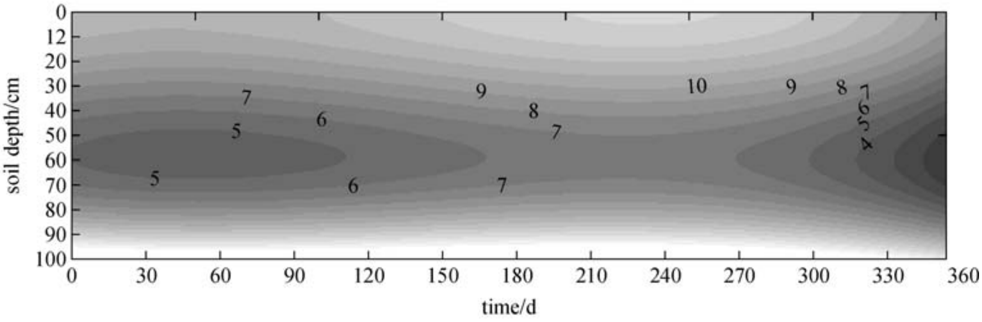

Fig. 3 Isogram of soil water potential (kPa) in treatment C

4 Result and analysis

4.1 Analysis of general trends

4.1.1 Seasonal change in soil moisture

Soil moisture shows considerable change with rainfall, temperature, and depth among soil layers, in the three to four phases of seasonal change and the three layers of depth, as described in many articles (Wang and Fu, 2000; Wang et al., 2006). Figures 1 to 3 show that, from the beginning to the middle of 2006, the darkness (i.e., soil moisture) decreased, while, from the middle to the end of the year, the darkness returned to its previous state. Accordingly, the seasonal dynamics of soil moisture could have four periods as a function of rainfall and temperature (Fig. 4), i.e., a relatively stable period, a consumption period, a dry period, and a recruitment period.

The relatively stable period. From the beginning to about the 60th day, the isograms are dark and sparse, indicating that soil moisture is high and does not change appreciably. This might be attributed to low temperature (mean ground temperature was 9.9°C) and low evaporation with dormant vegetation and additional rainfall.

The consumption period. After the first period until about the 180th day, we observed a decrease in darkness, which indicates reduced soil moisture. In spite of abundant rain (54% of annual precipitation), the evaporation rose with temperature (mean ground temperature of 23°C) and plant growth and depleted the water in the soil to an extremely low level.

The dry period. Between days 180 and 270 (June to September), the isograms remained light, i.e., the soil moisture was quite low. This could be the consequence of a drought during the summer, when rainfall accounted for 24.8% of the annual precipitation, while the mean ground temperature rose to 34.7°C.

The recruitment period. From the 270th day to the end of the year, the isograms returned to dark, indicating an increase in soil moisture, which resulted from a decrease in temperature (mean ground temperature of 15°C), the end of the growing season, a decrease in evapotranspiration, and a small amount in recruitment from rainfall.

4.1.2 Changes in soil moisture with soil depth

For all treatments, we observed the trend in light-dark-light from the top to the bottom, which indicated the rise and fall of soil moisture, for water at the surface layer evaporates and seeps downward, which increases the soil moisture deeper in the soil. When the supply from the upper layer balanced seepage and the potential-caused transportation,

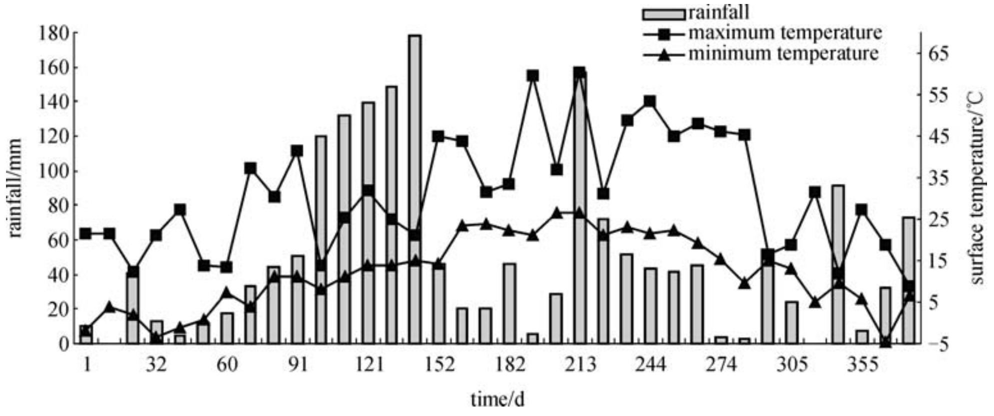

Fig. 4 Variations of precipitation and temperature in experimental zone

the soil moisture reached its maximum value. With an increase in soil depth, moisture tended to fall because of soil surface runoff.

4.2 Temporal and spatial patterns of the three treatments

The isogram of treatment A seems complicated since it is shaped as a typical saddle with the largest change in moisture over time at a depth of 30 cm and gentle at depths between 60 and 90 cm as seen from the dense transverse isolines. A further analysis showed that, at 30 cm deep, soil moisture was affected by climate factors (especially rainfall), transpiration of *P. notatum*, ground evaporation, and underground seepage. These factors have active movements and considerable amplitude. The isograms of treatment B and C are relatively simple. It might be that mulching reduces evaporation and moisture fluctuation in B, while the gentle, saddle-shaped variation among the upper layers (30 and 60 cm) suggest an unstable moisture regime. At the bottom (90 cm), the supply from seepage is small and forms a low but stable moisture regime.

The horizontal levels of isogram A are clear, especially in the middle and upper layers, indicating the fluctuations of moisture as a function of season and the growth of *P. notatum*. However, the isolines are fairly sparse along the axis depicting depth and reflect the gentle gradient of moisture among layers and the buffering performance of this treatment. In contrast, the vertical levels of B and C are also obvious, which indicates that depth has a greater effect on moisture than time. The line-density difference between B (lower) and C (higher) reflects a gentle fluctuation and good buffering performance in treatment B and an unstable moisture regime in C.

4.3 Analysis of regression isograms

From our statistical data analysis, the coefficients of variation show the variation in the gradient from 30 cm to 90 cm of treatments A and C and a slightly different change from 30 cm to 60 cm and from 60 cm to 90 cm in treatment B. The order of variation in moisture treatment is $A > C > B$, which is similar to what we concluded from our isogram analysis that proved itself capable of reflecting the temporal and spatial trends of soil moisture (Table 1).

5 Conclusions

There are two trends in soil moisture changes, i.e., the fall-rise from the beginning to the end of the year at all three levels of depth and the rise-fall from the top to the bottom of a profile. The transverse isolines and their density indicate that the isogram of A is the most complicated among the three treatments with a typical saddle shape, while those of B and C are relatively simple. The variation in soil moisture at 30 cm of A is the largest, while that at 60 cm comes in second and that of 90 cm is the smallest. The variation of soil moisture in all layers of B is fairly small, but that at 30 and 60 cm depths in C is greater than at 90 cm and forms a gentle saddle shape. The horizontal levels of isogram A are obvious, especially in the middle and upper layers, but the isolines are very sparse along the axis depicting depth to reflect a gentle gradient of moisture among layers. In contrast, the vertical levels of B and C treatments are clear, which indicates that depth has a greater effect on moisture than time. The line-density difference between B (lower) and C (higher) reflects a gentle conversion among layers of treatment B and a steep gradient along the depth-axis of treatment C.

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Table 1 Coefficients of variation for three soil depths at different treatments

	P. notatum Flugge-covered				mulching of *P. notatum* Flugge				bare slope (CK)			
	30 cm	60 cm	90 cm	mean	30 cm	60 cm	90 cm	mean	30 cm	60 cm	90 cm	mean
coefficient of variation	0.873	0.402	0.179	0.485	0.467	0.178	0.182	0.276	0.871	0.404	0.123	0.466

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