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Soil water characteristics in mountain poplar stand and its benefits to soil and water conservation in loess hilly region

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Abstract— The soil physical properties, its water characteristics and the benefits to soil and water conservation in mountain poplar stand were determined and studied. The results of the study show that the compaction in soil profile is relatively homogeneous, the specific gravity and volume weight of soil increase with deepening of soil horizon. The water infiltration rate of soil in the stand is 17.6 times as high as in rangeland. Owing to the intense absorption of water by root system of plants, a drying layer is formed in soil horizon from 2.3 m to 2.7 m, showing that the subsoil moisture is in the state of deficit. The annual water storage capacity in 2 m of soil horizon is 360 mm–370mm, or 63%–65% of annual precipitation. Compared with farmland, mountain poplar stand reduces the surface runoff and soil loss by 70% and 99%, respectively, indicating the great benefits to soil and water conservation.

Keywords: mountain poplar; soil water characteristics; soil and water conservation.

1 Introduction

Mountain poplar (*Populus davidiana*) is a pioneer species for afforestation and widely distributed in the loess hilly region. Usually, when the coniferous stand is cut down the mountain poplar will soon replace it, then develop a secondary stand. Mountain poplar mostly grows on north, northwest and northeast slopes. Now a large number of existing mountain poplar stands in this region mainly are formed after closing hillsides to facilitate afforestation.

The present experimental study was conducted for evaluating the eco-environmental significance of the common and wide-spread species with the aim of rational management and utilization of mountain poplar stand.

2 Site

Experimental area is situated in the Songyu gully of Teilongwen Forest Station in Yichuan, Yanan prefecture. It is classified as semihumid loess hilly region; the elevation is 900 to 1000 m, slopes are 20 to 25 degrees. The air temperature averages is 9.8°C a year; the mean annual precipitation is 574 mm. The soil under the mountain poplar stand is gray-cinnamonic soil. Conditioned by the parent material, the soil horizon is deep, its humus laycr spongy and rich in organic matter which has great significance in making soil structure. Besides mountain poplar, its natural deciduous broad-leaved vegetation consists mainly of *Quercus liaotungensis, Platycladus orientalis, Rosa xanthina, Lonicera ferdinandii, Spiraea pubesces, Elaeagnus umbellata* and so on.

The mountain poplar stand for experimental study is about 30 years old and typical of its kind in the region. Its canopy density is measured as 0.7, average height 10 m, average diameter 11 cm, and the number of trees amounts to 2100 per ha.

3 Soil physical properties

According to the measured by routine method results the main soil physical properties are shown in Table 1.

Table 1 Main soil physical properties in mountain poplar stand

Depth of soil horizon, cm	Specific gravity	Volume weight, g/cm³	Porosity, %			Max. water holding capacity, %	Capillary water holding capacity, %	Soil texture
			General	Capillary	Non-capillary			
0-1								Litter
1-24	2.3	1.05	55.55	40.85	14.70	52.9	38.9	
24-49	2.37	1.21	48.90	41.40	7.50	40.4	34.2	Middle
49-101	2.42	1.23	49.10	43.00	6.10	40.0	35.0	loamy
101-151	2.53	1.25	50.60	44.00	6.60	40.5	35.2	soil
151-200	2.70	1.27	52.89	44.29	8.60	41.7	34.9	

The soil compaction in profile shows relatively homogeneous, the soil specific gravity and volume weight are increased with the deepening.

The general porosity of soil is developed, and does best in surface layer, amounting to 55.55%. In other horizons it varies in about 50%.

The soil capillary pore is relatively developed, its porosity reaches 40%-50%. The non-capillary pore is developed in surface layer, and its porosity amounts to 14.7%, but in the other horizons it varies in 6.1%-8.6%.

The maximum and capillary water-holding capacities converted into millimeter in

2 m soil horizon come to 1018.4 mm and 858.4 mm, or 10184.3 t/ha and 8584.4 t/ha, respectively, showing that the soil in mountain poplar stand has a great capability of regulating and storing rainfall. The amount of regulating and storing water depends on the soil moisture, the less is soil moisture, the more is storage capacity.

4 Soil water infiltration capability

The process of water entrance into soil is a complicated hydrological process which has relation to surface soil structure, volume weight, soil humidity, surface runoff and other factors. It is also affected by such factors as litter cover, root system distribution, herb condition for woodland. Because the infiltration influences the runoff and the supply of soil water, it takes up an important position in forest hydrology and is also an important index for evaluating the capacity for regulating water by woodland. In view of the above, the soil infiltration capacity for the forest land of mountain poplar and natural rangeland as control is measured by using ring-knife method. According to R. A. Horton's general experimental formula for infiltration:

$$f = fc + (fo - fc)e^{-kt}.$$

where f is instantaneous infiltration rate in time t; fc is minimum infiltration rate when $t \to \infty$; fo is infiltration rate when $t = 0$; k is constant representing the soil characteristics.

The infiltration rate and its time are in the relation of exponential function. At the beginning, the infiltration rate is more great. Later it lowers with the changes in soil surface layer, such as a drop in matrix potential caused by soil water saturation, the diminution of soil pore space in which the clay expansion resulted and others, and tends to stable at last. The soil water infiltration rate measured on the woodland of mountain poplar and natural rangeland is shown in Table 2 and Fig.1 drawn on the basis of the data in the table. The difference $fo - fc$ in the equation of infiltration rate only shows different progressively decreasing process of infiltration rate before reaching to value fc because of different dry level of soil. The drier is the soil, the greater is the initial infiltration rate, the longer is the time taken for reaching the stable infiltration rate.

From the Fig.1 we can see that in infiltration rate of woodland and rangeland there is a distinct difference caused mainly by unequal number of soil pore. In the similar conditions of soil and landform the structure of soil surface layer in mountain

Table 2 Soil water infiltration rate in different land types

Land type	Initial infiltration rate fo, mm/m	Stable infiltration rate fc, mm/m	Infiltration rate equation $f=fc+(fo-fc)e^{-kt}$
Mountain poplar stand	13.40	8.82	$f=8.82+4.58e^{-0.0640t}$
Rangeland	4.26	0.50	$f=0.50+3.76e^{-0.1121t}$

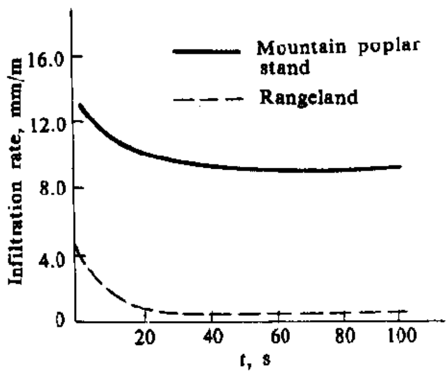

Fig.1 Comparison of soil water infiltration rate between mountain poplar stand and natural rangeland

poplar stand is favorable to water infiltration because of ameliorating soil effect of litter, and it is known that the developed root system of trees also strengthens the infiltration capacity of soil body. However, for rangeland the compact texture of soil, more great volume weight, especially the frequent trample of livestock result in the deterioration of the structure of soil surface layer, thus decreasing the soil infiltration capacity.

5 Soil water distribution

The source of soil water in experimental area is rainfall, and there is not any ground water supply. So the main factors effecting the water state in soil are rainfall and its season distribution which with the plant transpiration determine the whole soil water change on woodland.

5.1 Time and space distribution of soil moisture and its characteristics

The results measured indicate that the soil moisture is different and in dynamic change in the different years, seasons and depths of soil horizon (Fig.2), and this change shows even more evidently, especially in the horizon of root system distribution. Taking 1 meter of soil horizon as an example, from May the evapotranspiration of stand intensifies with a rise in air temperature and leaving of trees, while the rainfall is less, so the moisture content in soil is reduced gradually. This process is still in progress up to July and August, sometimes to Sep. even if in rainy season, when the soil evaporation and plant transpiration become stronger, the soil moisture approximates to 10% to 20% as a minimum in the whole year. After that it begins going up gradually and is increased with a drop in temperature, the fall of leaves and weakening of evapotranspiration, reaching to 18% to 20% in March or April of the next year. But under the horizon of plant root system distribution, in the present case below 3 meters the soil moisture changes no obviously and keeps in a relatively stable state. It is noteworthy that whether in 1989s drought year or in 1990s rainy year the change tendency is similar though the annual precipitation in both years is unequal.

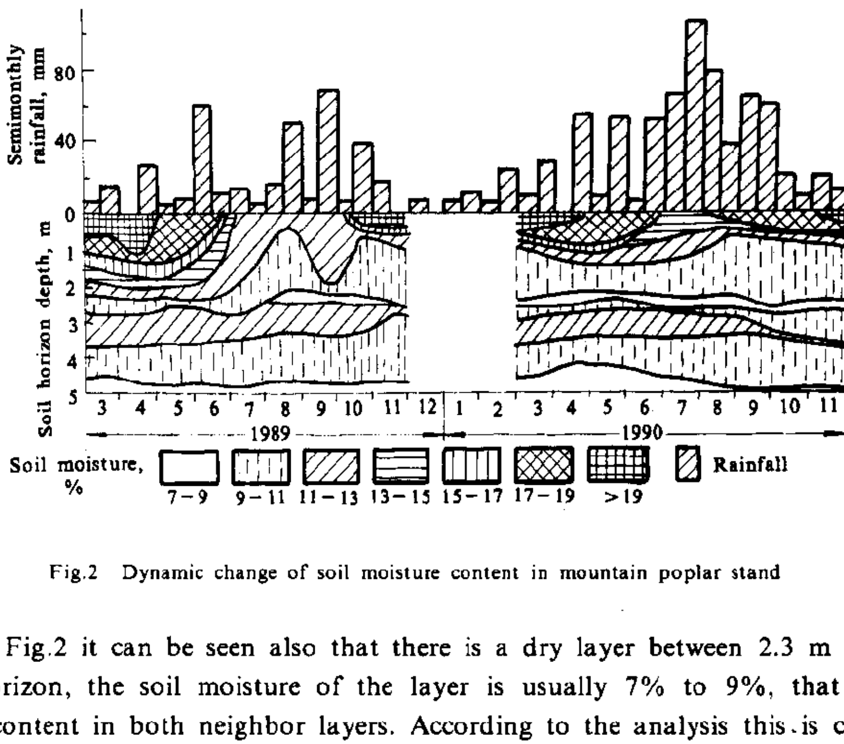

Fig.2 Dynamic change of soil moisture content in mountain poplar stand

From Fig.2 it can be seen also that there is a dry layer between 2.3 m to 2.7 m of soil horizon, the soil moisture of the layer is usually 7% to 9%, that is lower than the content in both neighbor layers. According to the analysis this is caused by water shortage as a consequence of absorbing water by roots and lack of water supply in time. The observations for 3 years show that the water supply depth in mountain poplar stand in a rainy year may reach to 2.4 m, and after the supply the soil moisture can be increased by 3% to 9%.

5.2 Influence of the stand on soil moisture

In order to elucidate and analyze the influence of the stand on soil moisture and its process the regular observation of soil water change has conducted in mountain poplar stand and its cleared space. The results show that the moisture content in cleared space is usually higher than that in the stand. The comparison of soil moisture in May and October between two land types is shown in Fig.3, from which we can see that in the upper horizon of soil (above 140 cm), the difference in moisture content is small, and a little more of it in the cleared space mainly is the result of lacking in canopy interception of rainfall; but in the lower horizon of soil (160 cm to 280 cm) it is relatively obvious, reaching to 5% to 6%. This absorbing water horizon formed in forest land results from absorbing water from soil by plant root system. According to the systematic observations, if the soil moisture of the horizon to which the root system reaches is similar to the soil moisture of the same horizon in controlling plot, this depth of soil horizon usually is the depth of root system distribution. The root system of mountain poplar goes deep into soil horizon, reaching to about 3 meters. The depth of root system distribution determined by using this correlation is conformed to reality on the whole, and this has a significance for keeping informed on the dynamic state of soil moisture and studying on root system.

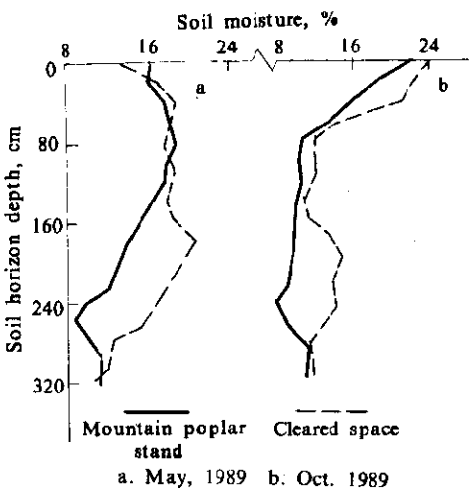

Fig.3 Soil moisture change in mountain poplar stand and its cleared space

5.3 Soil water storage capacity in woodland

The soil water storage capacity calculated on the basis of soil moisture and volume weight in different depths of soil horizon and different months in 2 m soil horizon under the mountain poplar stand in 1989 (March to November) is shown in Table 3 and Table 4. From the tables it can be seen that the soil water storage capacity in 2 m soil horizon is about 350 mm. If we take into account of January, February and December, in which the soil moisture little changes because of a little precipitation and low temperature resulting in freezing of soil and strong weakening of evapotranspiration, i.e. in January and February it is similar to that in March, and in December to that in November, it may be agreed that the annual water storage capacity in 2 m soil horizon in the stand may reach to about 370 mm. Judged by the distribution of water, the storage capacity in surface layer is the most, it averages 2.3 mm per cm soil horizon and with the deepening of soil horizon it decreases, reducing to 1.5 mm in lower horizon. Judged by the month, the water storage capacity is more in March, reaching to 487 mm, and is the least in September, only 270 mm. The difference between them reaches more than 200 mm.

Table 3 Soil water storage capacity in different depths of soil horizon in mountain poplar stand

	Depth of soil horizon, cm					
	1-24	24-49	49-101	101-151	151-200	Total
Soil moisture,%	21.80	16.47	14.43	13.13	12.00	
Volume weight, g/cm^3	1.05	1.21	1.23	1.25	1.27	
Water storage capacity, mm	52.77	49.82	92.29	82.06	74.68	351.62

Table 4 The change of soil water storage capacity in different months in mountain poplar stand

	Month								
	3	4	5	6	7	8	9	10	11
Average soil moisture, %	19.97	18.67	16.41	14.53	11.24	11.75	11.08	12.74	14.20
Volume weight, g/cm^3	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
Water storage capacity in 2m soil horizon, mm	487.27	455.55	400.00	354.53	274.26	286.70	270.35	310.86	346.48

6 Benefits of stand to soil and water conservation

The effect of the soil on regulating and storing rainfall is an important hydrological function of stand. In order to quantitatively evaluating the benefits of mountain poplar stand to soil and water conservation, the runoff plots with the area of 100 m^2 were laid in its forest. The plots are distinguished into 3 treatments, they are natural stand, its cleared space and farmland as a control, and the surface runoff and soil loss in the plots are measured, respectively. According to the observation for 3 years from 1988 to 1990, except 1989 as only a little runoff was produced for a small amount and unintensity of rainfall during the rainy season, the results measured in other two years are shown in Table 5.

The data in Table 5 indicate that under the similar landform, soil and rainfall the benefits of the stand to soil and water conseration are marked. Compared with

Table 5 Benefits of mountain poplar stand to soil and water conservation

Year	Rainfall in rainy season, mm	Surface runoff, m^3/km^2			Soil loss, $t/(km^2 \cdot a)$		
		Mountain poplar stand	Cleared space	Farmland	Mountain poplar stand	Cleared space	Farmland
1988	248.0	1543	1549	4710	4.17	2.75	253.88
1990	479.6	1689	1250	5999	3.63	2.52	432.61
Average,	363.8	1616	1400	5355	3.90	2.64	343.22
%		100.0	86.8	331.4	100.0	67.7	8800.5

Note: The slope of all runoff plots is 21°

farmland, mountain poplar stand reduces runoff and soil loss by 70% and 99%, respectively. By comparison, the runoff and soil loss in the stand and its cleared space vary slightly as mountain poplar after cutting down can sprout many branches from its stump and by then form a dense young growth. It is shown that so long as the rational management and utilization of mountain poplar forest resources are put into practice, the adverse effects to soil and water conservation in the region are possible to avert.

It is necessary to point out that a large soil and water loss in loess hilly region mainly is caused by only a few rainstorms. As an example, the runoff and soil loss brought about by a rainstorm in 21－22 of July, 1990 in experimental area made up 60.2% and 84.6% of total runoff and soil loss during the rainy season in that year, although its rainfall is only 47.7 mm, or about one tenth of total one for the season. This has a great significance for understanding and seizing the regularity of soil and water loss in this region.

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