CHINESE GEOGRAPHICAL SCIENCE
Volume 15, Number 2, pp. 186–192, 2005
Science Press, Beijing, China

SLOPE LITHOLOGIC PROPERTY, SOIL MOISTURE CONDITION AND REVEGETATION IN DRY-HOT VALLEY OF JINSHA RIVER

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ABSTRACT: The dry-hot valley of the Jinsha River is one of the typical eco-fragile areas in Southwest China, as well as a focus of revegetation study in the upper and middle reaches of the Changjiang River. Due to its extremely dry and hot climate, severely degraded vegetation and the intense soil and water loss, there are extreme difficulties in vegetation restoration in this area and no great breakthrough has ever been achieved on studies of revegetation over the last several decades. Through over ten years' research conducted in the typical areas—the Yuanmou dry-hot valley, the authors found that the lithologic property is one of the crucial factors determining soil moisture conditions and vegetation types in the dry-hot valley, and the rainfall infiltration capability is also one of the key factors affecting the tree growth. Then the revegetation zoning based on different slopes was conducted and revegetation patterns for different zones were proposed.

KEY WORDS: revegetation; lithologic property; soil moisture; plant growth; dry-hot valley; Jinsha River

CLC number: Q142.3; S154.4 Document code: A Article ID: 1002-0063(2005)02-0186-07

1 INTRODUTION

The dry-hot valley is one of the unique physiographic types in Southwest China, which is characterized by its dry and hot climate, Savanna-like vegetation and its sharp contrast with the surrounding landscape units (ZHANG, 1992). The dry-hot valley of the Jinsha River, one major tributary of the upper reaches of the Changjiang River, is referred to the valley belts below the elevation of 1600m, from Jinjiangjie Section (located at Yongsheng County, Yunnan Province) to Duiping Section (located at Butuo County, Sichuan Province) (Fig. 1). It extends between 25°20′–27°25′N and 99°50′–104°10′E, with a total length of 802km and an area of 3260km^2, accounting for 67.4% of the total area of dry-hot valleys in Southwest China (ZHANG, 1992).

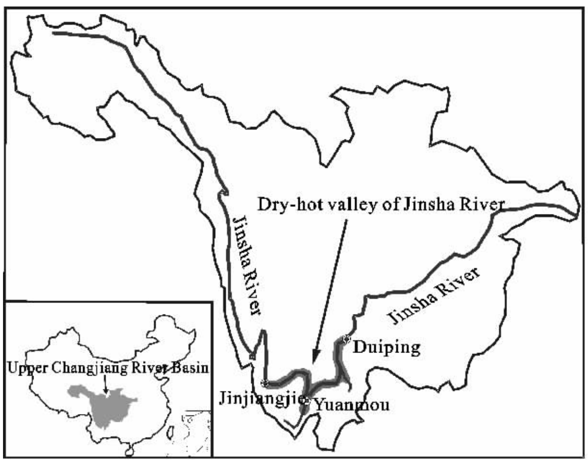

Fig. 1 Location sketch for the dry-hot valley of Jinsha River

The dry-hot valley of the Jinsha River belongs to the mid-mountain, and moderately cutting valleys, with a topographical feature of alternation between narrow valleys and wide valley basins (ZHANG, 1992). Due to the closed relief, the foehn effect is considerably violent in the dry-hot valley, which results in a unique south subtropical climate. The annual average temperature is 20–23℃, the accumulated temperature of ≥10℃ is high to 7000–8000℃, while the evaporation is so intense that reaches 2500–3800mm, 3–6 times of the amount of the annual precipitation (about 600–800mm), and the dry season is about 7 months long. Influenced by the dry-hot

Received date: 2005-01-05
Foundation item: Under the auspices of the National Natural Science Foundation of China (No. 30470297) and the National Basic Research Program of China (973 Program) (No. 2003CB415201)
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climate, the dominant vegetation in the dry-hot valley areas is Savanna-like vegetation, being chiefly composed of shrubs and grass with few trees (WU, 1987). And dry red soil is the zonal soil in the region.

The dry-hot valley of the Jinsha River is one of the typical eco-fragile regions with severely degraded environment. The hot and arid climate and the unreasonable anthropogenic activities, together with the vulnerability of the environment, caused the serious removal of the native vegetation and intense water loss as well as erosion. Taking Yuanmou County located in the watershed of the Longchuan River, a major tributary of the Jinsha River, as an example, the percentage of forest coverage for the whole county was only 5.2%, while that of the dry-hot valley area below 1500m was even lower with the rate of 0.06%, and also the vegetation coverage was only 15%–20%. The area of water loss and soil erosion with a medium and above degree, occupied nearly 50% of the whole area of the county.

Since the 1960s, several large-scale afforestation projects had been carried out in the dry-hot valley areas by the national and local governments, however, no great progress has ever been achieved owing to the great difficulty of revegetation. At present, there are many different views on the revegetation problems in the dry-hot valley held by researchers at home. Some believed that the reforestation in the dry-hot valley can succeed once the proper tree seeds and the planting techniques are solved (CHEN *et al*., 1995); some argued that due to the arid environment, the dry-hot valley can only restore such vegetation as grass and shrub (ZHOU, 1987); others contented that the problems of afforestation were caused by the extremely-low-nutrient soil and the afforestation can succeed only after the restoration of grass and shrub and the improvement of soil(ZHANG, 1992). In recent years, contrary to the case of humid area, the afforstation practice achieved better effect in such litho-slopes with thin soil layers, as schist slope, gravel slope, while it experienced frustration in the mudstone slope, whose soil layer is much thicker. Therefore, to study the relationships between the slope lithologic property, soil moisture conditions and the vegetation growth, and on the basis of them to conduct the revegetation zoning are of great importance to the revegetation works in the Jinsha River Valley.

2 LITHOLOGIC PROPERTIES, SOIL MOISTURE AND VEGETATION TYPES

Soil moisture is one of the vital factors affecting plant growth. WALTER (1979) concluded that in arid areas, the case of water supply to plants was exactly contrary to that in the humid areas: the clayey soil creates the driest habitat while the sandy soil possesses better soil moisture conditions and the litho-mountain can even provide the most humid habitat in which tall arbors are even able to grow well while they can not grow in the clayey soil.

Since the 1990s, the authors have been conducting a series of researches on the mutual relationship among the lithologic properties, soil moisture and plant growth, and found that, the lithologic-compositions greatly affected soil moisture conditions, vegetation types and even determinated revegetation's success in the hilly slopes.

According to the lithologic compositon, soil structure, soil moisture conditions and their impacts on the plant growth, four slope-types in the Yuanmou dry-hot valley were divided (YANG and ZHANG, 1995; ZHANG *et al*., 1998; ZHANG and CHENG, 1997): Ⅰ. the mudstone slope derived from Yuanmou Formation of the Early Pleistocene series (mudstone slope); Ⅱ. the schist slope derived from the metamorphic rock of the Proterozoic erathem (schist slope); Ⅲ. the granulite slope derived from Shagou Formation of the Pliocene series (grit slope); Ⅳ. the slope derived from the terrace gravel layer (gravel slope). The results of the field investigation and laboratory analysis indicate that, the soil physical properties differ greatly in the various slope-types (Table 1).

Owing to its high clay content and the low aeration porosity, the soil in mudstone slope, especially for the intensely eroded one, forms its fairly poor permeability (some saturation penetration coefficients even reach 10^{-3}–10^{-4} order) and low infiltration capability (some stable infiltration rates only of 0.03–0.06mm/min), which result in the less infiltrating rainfall and the less effective supply to soil moisture. Much of the rainfall is stored in shallower soil layer, which directly caused the greater loss of soil water by evaporation. Therefore, at the final stage of dry season, the soil of mudstone slope is of excessive deficit of water, with the moisture content often below wilting percentage within the depth of 40cm layer. Clearly, the fierce soil moisture condition is not suitable for the growth of tall arbors, but can only form the sparse grassland such as *Heteropogon contortus* community or *Bothriochloa pertusa* community as its secondary natural vegetation.

The soil of gravel slope, because of its much well-developed crevice, the higher aeration porosity, better permeability and higher stable infiltration rates of 0.62–2.20mm/min, is much easier for rainfall to infiltrate into the deeper layer to store and more difficult to evaporate. Compared with that of mudstone slope, the soil of gravel

Table 1 Soil physical properties of different lithologic-composition slopes in Yuanmou dry-hot valley

Slope type	Soil depth (cm)	Soil density (g/cm^3)	Bulk density (g/cm^3)	Mechanical composition (%)					
				>30mm	30–10mm	10–2mm	2–0.02mm	0.02–0.002mm	<0.002mm
Intensely eroded mudstone slope	0–10	2.55	1.42	0	0	0.05	72.17	9.75	18.03
	10–30	2.62	1.36	0	0	0.08	47.43	15.00	37.49
	>30	2.68	1.63	0	0	0	40.20	18.42	41.38
Slightly eroded mudstone slope	0–30	2.65	1.35	0	0	0.68	55.09	23.15	21.08
	30–70	2.61	1.16	0	0	0.63	57.59	20.36	21.22
	70–110	2.62	1.38	0	0	0.48	49.67	21.30	28.55
	>110	2.62	1.55	0	0.29	3.51	37.08	15.96	43.17
Gravel slope	0–20	2.66	1.79	8.54	37.00	12.56	22.93	9.14	4.63
	20–100	2.62	1.75	21.70	30.60	15.29	27.42	2.72	2.26
	>100	2.66	1.61	0	0	0.07	21.87	8.17	69.88
Schist slope	0–25	2.70	1.68	9.98	37.32	8.87	23.11	13.52	7.22
	25–140	2.67	1.81	13.18	42.51	13.98	18.47	7.36	4.56
	140–360	2.67	–	–	–	–	–	–	–
Grit slope	0–300	2.65	1.72	0	10.00	26.02	50.10	7.20	6.68

Slope type	Soil depth (cm)	Total porosity (%)	Capillary pore (%)	Aeration pore (%)	Effective pore (%)	Saturation penetration coefficient (mm/min)	Stable infiltration rate (mm/min)
Intensely eroded mudstone slope	0–10	44.31	25.27	19.04	12.26	0.1472	0.03–0.63
	10–30	48.09	39.89	8.29	21.58	0.0080	
	>30	39.18	32.15	6.85	6.30	0.0014	
Slightly eroded mudstone slope	0–30	49.06	32.54	22.46	20.66	0.1411	0.60–1.31
	30–70	55.56	36.17	19.50	27.69	0.2358	
	70–110	47.33	32.22	15.09	15.39	0.1014	
	>110	40.84	35.75	5.12	11.46	0.0006	
Gravel slope	0–20	32.71	23.03	9.57	16.29	0.0401	0.62–2.20
	20–100	33.21	22.00	11.25	12.82	0.0601	
	>100	39.47	31.61	7.02	4.84	0.0042	
Schist slope	0–25	37.78	27.39	10.56	13.37	0.1915	1.40–8.67
	25–140	32.21	23.29	9.01	19.51	0.2247	
	140–360	11.20	–	11.20	–	–	
Grit slope	0–300	35.09	22.54	12.58	10.54	–	6.33

Notes: Soil depth was measured by digging soil file in fields; soil density was determined by density-bottle method; bulk density was determined by cutting ring method; soil mechanical composition was determined by pipette method; soil porosity parameters, saturation penetration coefficients and stable infiltration were determined by the methods introduced by Soil Physics Research Division, Nanjing Institute of Soil Science, Chinese Academy of Sciences, 1978

slope can supply more water for plants during dry seasons, which forms a better soil water condition for the tall arbors. Therefore, its native vegetation is forest.

As for schist slope, its lithologic property varies greatly with the different slope gradients, the degree of the fragmentation of surface rocks, and the crevice development, and so does the soil moisture condition. Generally, the well-developed-crevice rock stratum with steep bed helps to the infiltration of rainfall and so plant roots can grow along with the crevices by absorbing the stored water inside them, and thus its native vegetation is arbor-shrub mixed communities. Conversely, the rock stratum with low degree of fragmentation and poorly-developed crevice, can grow only the sparse hassock consisting of dominant species of *Heteropogon contortus*.

Grit slope, thanks to its richness of grit, relatively coarse grains, and its looser structure, has a relatively higher aeration porosity of 12.58% for the whole soil profile, thus possesses a good infiltration capability and its stable infiltration rate reaches 6.33mm/min. So rainfall is far more prone to infiltrate into the deep soil layers, but unfortunately, it is also easy to lose soil water by evaporation in dry season. Therefore, the soil moisture condition of grit slope is poorer than that of gravel slope and schist slope, but better than that of mudstone slope, and its native vegetation is the sparse forest with shrubs and grass.

The above research findings, therefore, can offer the theoretical support not only for the revegetation patterns of the arbor-shrub-herb spatial arrangement in the various lithologic-composition slopes, but also how to efficiently utilize rainfall to restore vegetation in the Jinsha dry-hot valley areas.

3 RAINFALL INFILTRATION AND ITS EFFECTS ON TREE GROWTH

3.1 Infiltration Capability for Different Lithologic Slope Types

Studies show that in the dry-hot valley areas, the infiltration capability of slope is closely concerned with its lithologic property. The infiltration capabilities of various lithologic-composition slopes differ significantly because of the great difference on soil porosity. The stable infiltration rates of different lithologic-composition slopes are respectively: 1.40–8.67mm/min for schist slope, 6.33mm/min for grit slope, 0.62–2.20mm/min for gravel slope, 0.60–1.31mm/min for slightly eroded mudstone slope and 0.03–0.63mm/min for intensely eroded mudstone slope (Table 2).

Table 2 Fitted equations for infiltration rates of different lithologic slopes in dry-hot valley of Jinsha River

Slope type	Fitted equation	Stable infiltration rate
Intensely eroded mudstone slope	$Y=0.07X^{-1.03}$ $R^2=0.80$	0.03–0.63
Slightly eroded mudstone slope	$Y=1.42X^{-0.34}$ $R^2=0.95$	0.60–1.31
Schist slope	$Y=9.58X^{-0.16}$ $R^2=0.89$	1.40–8.67
Grit slope	$Y=5.90X^{-0.26}$ $R^2=0.87$	6.33
Gravel slope	$Y=3.34X^{-0.34}$ $R^2=0.93$	0.62–2.20

Notes: X represents the infiltration rate (mm/min) ; Y represents the infiltration time (min); Infiltration rate was determined in the fields by Double-ring-infiltrometer Method

Hence it can be concluded that infiltration capability varies greatly with lithologic-composition slopes. Infiltration capability of mudstone slope is the lowest, especially for the intensively eroded one and some even lower than 0.1mm/min and it is, therefore, extremely difficult to infiltrate into deeper soil layers and less water is supplied to soil moisture. The litho-mountain, however, with infiltration capability higher by far than that of mudstone slopes, some even approach 8–10mm/min, affords much more supply to soil moisture.

3.2 Slope Infiltration Capability and *Eucalyptus camaldulensis* Plantation Productivity

Through long-term field investigation combined with laboratory analysis, the *Eucalyptus camaldulensis* plantation productivity proved to be closely related to infiltration capability. We can see from the Table 3, the *Eucalyptus camaldulensis* plantation productivity (here symbolized by the net production) differs significantly in different lithologic-composition slopes: the intensely eroded mudstone slope 2.24t/(ha·a), the slightly eroded mudstone slope 3.921t/(ha·a), gravel slope 5.94t/(ha·a), grit slope 5.46t/(ha·a) and schist slope 8.44t/(ha·a). Statistical analysis shows that the relationship between the growth rate of height, growth rate of DBH (diameter at breast height), leaf area index, stand biomass, net production, net assimilation rate, and the slope stable infiltration rate, appears significantly linearly correlative (Table 4). So the *Eucalyptus camaldulensis* plantation production capability behaves basically uniformly with the infiltration capability, which also shows: the well-developed-crevice schist slope > gravel slope> grit slope > slightly eroded mudstone slope>intensely eroded mudstone slope.

Therefore, we can conclude that the infiltration capability varies greatly with the different slope types, among which mudstone slope is the lowest, and it also exerts a great effect on tree growth. So the rainfall infiltration ca-

Table 3 Infiltration rates of different lithologic-composition slopes and *Eucalyptus camaldulensis* plantation productivity in dry-hot valley of Jinsha River

Slope type	Quadrat number	Infiltration rate (mm/min)	Stand age (a)	Average height (m)	Growth rate of height (cm/a)	Average DBH (cm)	Growth rate of DBH (mm/a)	LAI	Stand biomass (t/ha)	Net production (t/ha·a)	Net assimilation rate (g/m·a)
Intensely eroded mudstone slope	YM23	0.63	6	4.22	70.3	3.01	5.02	1.18	13.46	2.24	190.00
Slightly eroded mudstone slope	YM11	1.23	6	5.90	98.3	4.57	7.62	1.60	23.51	3.92	245.44
Gravel slope	YM06	2.20	8	6.63	82.9	6.11	7.64	1.63	47.51	5.94	363.52
Schist slope	YM21	6.33	10	7.88	78.8	5.81	5.81	2.21	54.60	5.46	246.97
Grit slope	YM22	8.33	5	5.34	106.8	5.19	10.38	2.54	42.19	8.44	332.91

Notes: DBH is the abbreviation for diameter at breast height; LAI is the abbreviation for leaf area index

Table 4 Fitted equations for *Eucalyptus camaldulensis* plantation productivity and slope infiltration rates in dry-hot valley of Jinsha River

Index for plantation productivity	Fitted equation	Correlation coefficient
Growth rate of height (m/a)	Y=0.22X+0.58	R=0.74
Growth rate of DBH (mm/a)	Y=1.37X+3.41	R=0.76
LAI	Y=2.19X+4.29	R=0.75
Stand biomass (t/ha)	Y=21.17X+8.93	R=0.81
Net production (t/ha·a)	Y=2.63X+1.73	R=0.82
Net assimilation rate (g/m·a)	Y=41.12X+213.21	R=0.59

Notes: X represents the slope infiltration rate (mm/min); Y represents the index for plantation productivity in the corresponding blank

pability of slope is one of the vital factors affecting tree growth in dry-hot valley areas.

4 REVEGETATION ZONING AND REVEGETATION PATTERNS

As we discussed above, the lithologic property is one of the crucial factors determining soil moisture conditions and vegetation types, and the rainfall infiltration capability is also one of the important factors affecting the tree growth in the dry-hot valley. So the revegetation works conducted in dry-hot valleys should obey the order of nature, and pay much attention to the influence on vegetation types by lithologic-compositions and the influence on vegetation growth by slope infiltration capability. Because soil moisture conditions differ greatly in various lithologic-composition slopes, the revegetation patterns are also required to be different: gravel slope, as its most humid soil moisture condition, is available to restore the relatively complete and dense forest cover; then followed by schist slope and grit slope, which are available to restore sparse forest and shrub-herb cover. And mudstone slope, owing to its poorest soil moisture condition, is available only for shrubs and grass mixed with few trees.

Based on the combination of climate zones and lithologic types, five availability zones for artificial revegetation are divided (ZHANG *et al*., 2003) (Fig. 2).

(1) Suitable zone for forest restoration. It covers an area of 24 470.6ha, accounting for 21.74% of the total area of the whole region. It includes the flood land on

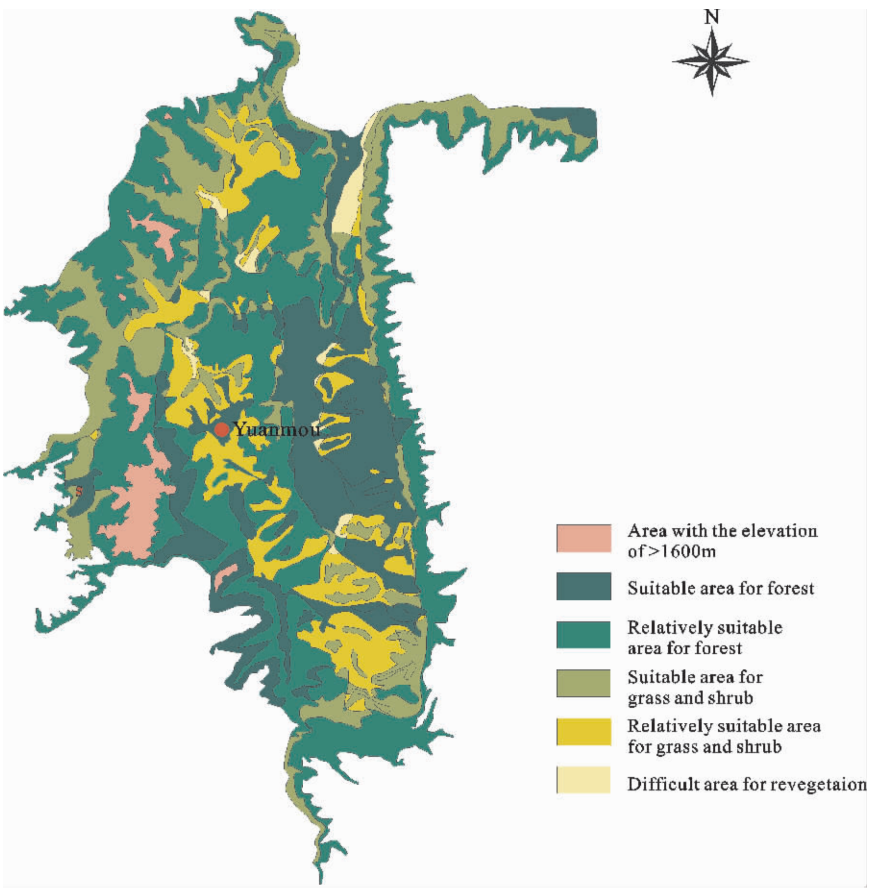

Fig. 2 Sketch of revegelation zoning for Yuanmou dry-hot valley

both banks of the Longchuan River, grave slope on Ⅰ–Ⅲ grade terraces and the area of well-developed-creviced schist slope above the elevation of 1350m. The zone is suitable to restore arbor-shrub-herb forest cover, but chiefly composed of arbors. The revegetation can be conducted as the following mixed pattern: arbor (*Eucalyptus camalulensis*, *Acacia confusa*, *Albizzia mollis*, *Trema angustifolia* etc.) +shrub (*Leucacna glauca*, *Cajanus cajan*, *Tephrosia candida*, *Phyllanthus emblica*, *Acacia mantana*, *Dodonaea viscose* etc.) +herb (*Macroptilium atrepurpureum*, *Vetiveria zizanioides*, *Rvolvulus alsinoides* var. *dacumbens* etc.). The configuration for the pattern is composed of one line of arbors, one to three lines of shrubs, and herbs between lines, while the specification for planting is that: arbor, (6–12m)×3m, shrub, (3–4m)×2m.

(2) Relatively suitable zone for forest restoration. It covers an area of 48 504.88ha, accounting for 43.1% of the total area of the region. It includes grit slope above the elevation of 1350m, schist slope between the elevation of 1100–1350m and gravel slope below the elevation of 1100m. The zone is suitable to restore the shrub-arbor-herb forest cover, but chiefly composed of shrubs. The revegetation can be conducted as the following shrub-arbor-herb mixed pattern: shrub (*Leucacna glauca*, *Cajanus cajan*, *Tephrosia candida*, *Phyllanthus emblica* , *Acacia mantana*, *Dodonaea viscose* etc.)+arbor (*Eucalyptus camalulensis*, *Acacia confusa*, *Albizzia mollis* etc.) +herb (*Macroptilium atrepurpureum*, *Vetiveria zizanioides*, *Rvolvulus alsinoides* var. *dacumbens* etc.). The configuration for the pattern is composed of one line of arbors, three to five lines of shrubs, and herbs between lines, while the specification for planting is that: arbor, (12–20m)×4m, shrub, (3–5m)×2m.

(3) Suitable zone for grass and shrubs restoration. It covers an area of 23 027.8ha, accounting for 20.46% of the total area of the region. It includes grit slope below the elevation of 1350m, mudstone slope above the elevation of 1350m, gravel slope above the elevation of 1100m and schist slope below the elevation of 1100m. The zone is not so suitable for forest restoration, but suitable for shrubs and grass with few trees. The revegetation can be conducted as the following shrub-herb-arbor mixed pattern: shrub(*Leucacna glauca*, *Phyllanthus emblica*, *Tephrosia candida*, *Acacia mantana*, *Dodonaea viscose*, *Cajanus cajan* etc.) +herb (*Macroptilium atrepurpureum*, *Vetiveria zizanioides*, *Rvolvulus alsinoides var. dacumbens* etc.) + arbor (*Eucalyptus camalulensis*, *Acacia confusa*, *Albizzia mollis* etc.). The configuration for the pattern is composed of one line of arbors, five to ten lines of shrubs, and herbs between lines, while the specification for planting is that: arbor, (2–2.5m)×8m, shrub, (3–5m)×2m.

(4) Relatively suitable zone for grass and shrubs restoration. It covers an area of 14 704.48ha, accounting for 13.07% of the total area of the region. It includes mudstone slope between the elevation of 1100–1350m and grit slope between the elevation of 1100–1350m. The zone is not suitable for forest restoration, but only to shrubs and grass restoration, chiefly composed of grass. The revegetation can be conducted as the following shrub-herb mixed pattern: large shrub (*Leucacna glauca*, *Tephrosia candida*, *Phyllanthus emblica*, *Acacia mantana* etc.)+ small shrub (*Dodonaea viscose*, *Cajanus cajan* etc.) + herb (*Agave angustifolia*, *Vetiveria zizanioides*, *Macroptilium atrepurpureum*, *Rvolvulus alsinoides* var. *dacumbens* etc.). The configuration for the pattern is composed of one line of large shrubs, three to five lines of small shrubs, and herbs between lines, the specification for planting is that: large shrub, (10–15m)×4m, small shrub, 3.5m×2.5m.

(5) Difficult zone for vegetation restoration. It covers an area of 1827.4ha, accounting for 1.62% of the total area of the region. It includes the mudstone stone below the elevation of 1100m in the banks of the Jinsha Rviver and the lower reaches of the Longchuan River. The zone is too difficult not only to restore the forest cover, but also to restore grass and shrubs. The only way at present for vegetation restoration is to take enclosure management together with artificially planting grass.

5 CONCLUSIONS

Through over ten years' experimental studies in the Yuanmou dry-hot valley, the authors found that lithologic property of slopes greatly influenced soil moisture and vegetation types among such five lithologic slope-types as intensely eroded mudstone slope, slightly eroded mudstone slope, gravel slope, schist slope and grit slope. Mudstone slope possesses the poorest soil moisture conditions and its vegetation types mainly consist of sparse grassland; schist slope with well-developed crevice is provided with the best soil moisture conditions and thus can grow vegetation types as arbor-shrub mixed communities. The infiltration capability is one of the important factors affecting tree growth, and plantation productivity proved to be proportional to slope infiltration capability. The study shows the infiltration capabilities of five slope types as follows: the well-developed-crevice schist slope > gravel slope> grit slope> slightly eroded mudstone slope>intensely eroded mudstone slope. Meanwhile, based on the different properties of various slope types, the exploration on revegetation zoning in Yuanmou dry-hot valley was made and the revegetation pattern for each zone was also proposed, which provides explicit directions for the revegetation works in dry-hot valley areas. All these are of great reference for the revegetation study in other arid or semi-arid areas in China.

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