High-quality and sustainable development of soil and water conservation vegetation

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Abstract

The effect of vegetation on soil and water conservation increases with the increase of planting density. At the same time, the degree of soil drought increases with the increase of planting density, and leads to the decline of vegetation or waste resources and then affects the benefit of vegetation on soil and water conservation. However, there is a few research of high-quality sustainable management of easier degraded soil and water conservation vegetation ecosystems. In this paper, the high-quality sustainable management of soil and water conservation vegetation was reviewed. The results showed that the degree of cover of soil and water conservation vegetation increases with increasing density under other things being equal; the canopy interception increases with stand density but there is a peak value of canopy interception. The surface runoff decreases with increasing density with a logarithm relationship; the sediment charge in the runoff increases with reducing density with a logistic relation. There is a limit of soil and water conservation vegetation, which is the cover degree of soil and water conservation vegetation when the existing plant density of indicator species in a plant community is equal to vegetation carrying capacity. When plant density of indicator species in a plant community is more than vegetation carrying capacity, the cover degree of soil and water conservation vegetation is more than the vegetation restoration limit of soil and water conservation vegetation, the plant resources relationship should be regulated based on vegetation carrying capacity to realize high-quality sustainable management of soil and water conservation vegetation.

High quality sustainable development of soil and water conservation vegetation

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Abstract: The effect of vegetation on soil and water conservation increases with the increase of planting density. At the same time, the degree of soil drought increases with the increase of planting density, and leads to the decline of vegetation or waste resources and then affects the benefit of vegetation on soil and water conservation. However, there is a few research of high-quality sustainable management of easier degraded soil and water conservation vegetation ecosystems. In this paper, the high-quality sustainable management of soil and water conservation vegetation was reviewed. The results showed that the degree of cover of soil and water conservation vegetation increases with increasing density under other things being equal; the canopy interception increases with stand density but there is a peak value of canopy interception. The surface runoff decreases with increasing density with a logarithm relationship; the sediment charge in the runoff increases with reducing density with a logistic relation. There is a limit of soil and water conservation vegetation, which is the cover degree of soil and water conservation vegetation when the existing plant density of indicator species in a plant community is equal to vegetation carrying capacity. When plant density of indicator species in a plant community is more than vegetation carrying capacity, the cover degree of soil and water conservation vegetation is more than the vegetation restoration limit of soil and water conservation vegetation, the plant resources relationship should be regulated based on vegetation carrying capacity to realize high-quality sustainable management of soil and water conservation vegetation.

Keywords: soil and water conservation vegetation; planting density; degree of cover; resource use limit by plants; vegetation carrying capacity; vegetation rehabilitation limit; high-quality sustainable management

Introduction

Water resources and soil resources is the most important nature resources, which severe influence the high-quality sustainable development of economy and society (Guo 2020,2021). Water and soil losses are one of the most severe environmental problems worldwide (Wen et al 2019). Among the various practices in water and soil conservation, forest restoration has usually been regarded as critical and effective (Yetemen et al., 2010). High-quality sustainable management of forest vegetation ecosystems had been proven necessary for the protection of regional ecological environments and for the improvement of sustainable development in the society and economy. It is important to consider the balance between resources consumption and resources supply in the course of forest vegetation restoration (Guo 2021a and b).

Once with the soil water loss regions population increasing such as on Loess Plateau, China, the human activities of reclamation, forest denudation, overgrazing and civil wars became frequent, which caused the decline in the density of natural plant populations (Metcalfe and Kunin 2006), the disappearance of indigenous vegetation was leading to the quick decrease of vegetation cover (Guo 2000a and b) and forest area rate (Guo 1996), and the ability of forest vegetation to keep ecological balance. This in turn has resulted in serious soil and water loss. In order to improve the ecological environment and promote healthy development of regional economy, large-scale afforestation has been carried out. However, for the sake of high yield and high return, tree species with deep roots and fast growth have been selected and planted at initially high planting densities such as on the Loess Plateau, plant take up water from considerable soil depths. Because most of Loess Plateau belongs to water-limited regions and the water supply was limited, these issues such as lower survival rate of afforestation, lower preserving rate, lower yield, lower ecologic and economic benefit were caused in the process of vegetation restoration (Jiang 1997; Yang & Shao 2000; Li 2001; Yang 1996; Hou et al 1999).Moreover, soil deterioration occurred on the Loess Plateau in the form of soil desiccation under both perennial grasses and forests (Li 2001; Yang 1996; Hou et al.1999; Li et al.1990; Wang et al. 2000; Chen et al. 2005). Such soil deterioration directly affected the stability of plant community and reduced the soil and water benefits of forest vegetation. So we should manage soil and water conservation vegetation in the way of high quality sustainable to get maximal soil and water conservation beneficial and match the People's yearning for a better life and the need for soil and water conservation(Guo 2021b)

Resource use limit by plants

Generally, as plant grow, plant suck and use resource, and then resource amount reduces because the resource amount in a given space in which plant crown or plant root develop is limit. Therefore, there is a resource use limit by plants in soil and water conservation vegetation, expressed by the indicator species in a plant or population community, and resource use limit by plants can be defined as control amount of plant utilization resources such as soil water resources use limit by plant. For example, soil water is the most important factor influencing and limiting plant growth in water-limited regions. After soil water resources appeared (Budagovski 1986), soil water resources can be used to express soil water condition because root system vertical distribute in the soil and take soil water in a given soil body, see figure 1. Two-curve method can be used to determine maximum infiltration depth (MID) (Guo 2020), see figure 2. The utilization limit of soil water resources by plants refers to the soil water resources with the maximum infiltration depth when the soil water content is equal to the wilting coefficient. Soil water resources use limit by plant changes with species and site condition (Guo 2014). The utilization limit of plants to soil water resources is the control limit plant use soil water in water-limited regions, which change with plant species and location. For example, soil water resources use limit by plant in the 16-years-old Caragana (*Caragana Korshinskii*) shrub land in the fish scale pit on the top of Heici mountain is 252.8mm, see table 1. And soil water resource use limit by plants in caragana shrub land in the middle of the Heici mountain is 222.8mm, see table 2. The soil water resource use limit by plants in red plum apricot plantation is 212.7 mm in the semiarid loess hilly region (Guyuan county, China).

The soil water contents at different soil suctions using a centrifuge or pressure chamber, were measured and established the characteristic soil moisture curve using least square method. And then estimate the wilting coefficient at different soil depths. The wilting coefficient is the soil water content when soil suctions equal 15bar based on the characteristic soil moisture curve at different soil depth, see figure 3. As plant grow, soil water resource reduces (Guo 2010,2014,2020,2021b).

Indicator species is the main cultivation or goal species for artificial vegetation such as caragana in caragana shrubland. If soil and water conservation vegetation is made up 2 or three plant species, the indicator plant is the dominant tree species or the main tree species with large coverage in mixed forest. The resource use limit by plants includes space resource use limit by plants in areas rich in water and fertilizer, soil water resource use limit by plants in the water-limited regions (Guo 2010; Guo 2014,2021a and b) and soil fertilizer resource use limit by plants in the fertilizer -limited regions (Guo 2021b).

Appropriate time of plant- resources relationship regulation

After planting weather planting or sowing, as plant grow, the available resources reduced. For example, the suitable sowing rate of Caragana young forest is $1.5\text{kg}/100\text{m}^2$, and the suitable density is 6500 plants / 100m^2 in the semiarid loess hilly region. As the caragana plant grows, soil water content in the maximal infiltration depth of 290 cm reduces, and soil desiccation has been emerged in perennial non-native shrubland. When caragana is at 5-years old on Jun.15, 2006, soil water resources in the maximal infiltration depth of 290 cm are smaller than 222.8mm, showing that the plant-water relation enters the critical period of plant-water relationship regulation and regulation of plant water relationship should be considered, see figure 5.

Appropriate amount of plant-resources relationship regulation

Plant growth and resource availability relationship can be divided into different stages. For example, caranaga growth and resource use relationship can be divided into four stages in a growing season in semiarid loess hilly region of water-limited regions (Guyuan, China). The first stage is at the dormant period from January 1st to the second ten of April. At this period, plants are dormant and not sensitive to water stress because plant stop growth. The second stage is the period from the second ten of April (caragana bud germination) to the end of Jun. (full-expansion of leaf) and the plant was not sensitive to water stress at this stage because the leaves of plants are not fully developed, and Caragana only absorbs a small amount of water; The third stage started is at the fast growth period from the end of June when the leaves were totally expansion to the end of August. At this stage,plant grow rapidly and need a lot of water. At this stage, plant suck much water and was very sensitive to soil moisture in this period. If the soil water resources in the maximal infiltration depth are lower than soil water resource use limit by plants, the plant-water relation goes into critical period of plant-water relationship regulation. At this time, the plant water relationship in the key period of plant water relationship regulation is very important, because it determines the maximum yield and benefit of a plant community. The fourth stage is leaf fall period, ranging from September to the end of October (complete leaf drop), the plant was insensitive to water stress. After the leaf fall period from November (the beginning of dormancy) to the first ten of April (the end of dormancy), the plant-water relation goes into the dormant period and the influence of soil moisture on plant growth was very little in this period.

Planting density anddegree of cover relation

The degree of vegetative cover is an important index to evaluate the function of a plant community to conserve soil and water. The effective degree of cover is the degree of vegetative cover when soil loss is equal to allowable soil loss, so effective degree of cover should be as the cultivating standard of adult soil and water conservation vegetation or forest (Guo 2000). The degree of cover increased gradually with age at the same condition of species, initially planting density and site condition. In a growing season of a given species and site condition, the degree of cover in a plant community increased gradually from budding in mid-April to the fully expansion of leaf by the end of June. The degree of cover then remained relatively constant in the period from July to October, the degree of cover can be defined as the stable coverage degree (SCD).

The degree of cover increased with the planting density, and the relationship between the stable cover degree (SCD) and planting density at the third ten of July was given by (Guo and Shao, 2013), see figure 4

$SCD = 0.2895 \text{ Ln } (PD) - 1.8197$

Where, SCD is stable cover degree and PD is planting density.

Planting density and canopy interception relation

Canopy interception is the rainwater intercepted and absorbed by the leaves and branches. As for a rain event, the canopy interception increased with rainfall when the rainfall is smaller, the relationship between them is not a linear. Because there is a saturation value of the canopy interception, canopy interception cannot increase with rainfall when the canopy interception approximates the saturation value. Caragana is deciduous and the canopy interception can be ignored as the value is very small during the period of dormancy stage from October through December to April. So the canopy interception is mainly occurred during May to October. The canopy interception and interception rate in dense caragana shrublands with 87 shrubs per $100m^2$ is higher than that in low planting density in 2002. Under the same species, site, gradient, slope position and slope direction, the quantity of branches and leaves per unit ground area is also increased with an increasing plant density, and thus canopy interception is also increased. The relationship between canopy interception of a rain event in a plot (CI) and planting density (PD) was found to be (Guo & Shao, 2004,2013; Guo 2014,2020):

$CI = 0.0158PD^{0.6601}$

Where, CI is canopy interception in mm and PD is planting density.

Surface runoff and planting density relationship

The surface runoff, runoff production in slope, is related to the soil infiltration. On raining, the soil evaporation is too small to neglect due to the relatively low temperatures, greater air humidity and lower air vapor pressure deficit near the ground. Thus, the rainwater that reaches the soil surface through forest canopies infiltrate into the soil or run off as overland flow. In the period from April, 2002 to October, 2003, there were many greater rain events, but there were only five rain events generated runoff in our plots because of the gentle terrain, small rainfall intensity, higher planting density and higher cover degree of Caragana shrublands and the runoff amount ranged from to . The equation describing the relationship between surface runoff SR and precipitation outside caragana forest P_2 was found to be (Guo & Shao 2004,2013), see table 3

$SR = 0.01P_2 + 0.1765$

The runoff in Loess Plateau, China normally is infiltration-excess runoff production and it occurred when the rainfall intensity exceeds the infiltration rate (Guo and Shao 2013). Because vegetation cover can increase surface roughness and vegetation canopy interception reduce the kinetic energy of raindrops impacting the soil surface and the degree of aggregate breakdown and compaction causing surface sealing. The barrier effect of standing forest on runoff can increases the surface runoff resistance, thus vegetation reduces velocity of the surface runoff and increases the rainfall infiltration.

The surface runoff declined with increasing planting density, which is consistent with the reported by Zhang et. al. (2002). The relationship between surface runoff R and planting density PD can be can be written as follows (Guo & Shao 2013), see table 4

$R = 78.454 - 16.899\mathrm{Ln}\ (PD)$

Where, R is surface runoff and PD is planting density

Planting density and soil loss relationship

The main type of soil erosion in Chinese Loess Plateau is water erosion. The influence of planting density on soil losses can be expressed by the sediment concentrations in the runoff plots. The sediment in the runoff gradually increased with the reduction of planting density. The relationship between the sediment concentration SC (gram per liter) in the surface runoff and planting density D can be written as follow:

SC =

Here, SC sediment concentration, g per liter, d is plant density, shrubs per 100 m^2

Under the same species, age and site condition, the biomass, the canopy coverage and the canopy interception per unit area increased with planting density, leading to a smaller surface runoff, suggesting that the benefit of vegetation to conserve soil and water is remarkable (Guo and Shao 2013).

Appropriate amount of plant- resources relationship regulation

The duration of resource scarcity refers to the period when the resource storage is less than resource use limit by plants. If the resource storage is smaller than resource use limit by plants, the plant- resource relation goes into critical period of plant- resource relationship regulation, the plant- resource relation enters the critical period of plant-water relationship regulation; the plant- resource relation should be considered because it decides the maximal yield and benefits of soil and water conservation vegetation.

After the plant-resources relation enters the critical period of plant- resources relationship regulation, if the duration of resource scarcity is more than the critical period of plant resources relationship regulation or the existing plant density is more than the vegetation carrying capacity in the critical period of plant resources relationship regulation, vegetation carrying capacity should be evaluated and plant growth should be controlled by cutting some tree to reduce plant density and regulating plant-resources relationship and get the maximal yield or service.

The vegetation carrying capacity is the ability of land resources to bear vegetation, which changes with vegetation type caused by tree species, time period and location (Guo 2014,2021a and b) and is a suitable measure of assessing the plant-resources relationship. vegetation carrying capacity includes space carrying capacity for vegetation in areas rich in water and fertilizer, soil water carrying capacity for vegetation in water-limited regions and soil fertilizer carrying capacity for vegetation in fertilizer limited regions (Guo 2019). Total coverage of a plant community when plant density of indicator species in a plant community is equal to vegetation carrying capacity is the suitable limit of vegetation restoration.

If the plant density is more than the soil water carrying capacity for vegetation in the critical period of plant-resources relationship regulation, plant-resources relationship has to be regulated to get the maximal yield and benefits and carry out sustainable use of soil water resources and high-quality and sustainable development (Guo 2014,2021b). Even if the goods and benefits produced by non-native ecosystem meet the need of increase in the population, but non-native species change plant-resources relationship of origin vegetation and its self-regulation and resilience is limit and cannot recover to the balance condition once soil water resources with maximum infiltration depth in Caragana forest land is smaller than soil water resources use limit by plants. For example, If the soil water resources in the maximal infiltration depth is more than soil water resources use limit by plant, the plant water relation enters the critical period of plant-water relationship regulation. The soil water sever deficit is the soil water resources in the maximal infiltration depth is more than soil water resources use limit by plant. If the duration of soil water sever deficit is more than critical period of plant-water relationship regulation, the relationship between soil water supply or soil water consumption and plant density and soil water carrying capacity for vegetation in the critical period of plant-water relationship regulation should be estimated. The relationship between planting density and soil water supply SWS, soil water consumption SWC, the amount of water taken up by the plants in the critical period of plant-water relationship regulation in the 16-year-old caragana shrubland of semiarid loess hilly region (Guo and Shao 2004; Guo 2014,2021) was determined by:

SWS = 92.494- 0. 29D

SWC = 0. 0118D^2- 0. 7575D+ 64.759

Where SWS is soil water supply in mm, SWC is soil water consumption in mm.

By solving the equation set, the soil water carrying capacity for vegetation was 72 shrubs per hm^2, and the corresponding cover degree was 0.8 according to the formula:CD= 0.289 5ln72- 0.486 4. The degree of cover is the limit of canaraga restoration. When exceeding this limit, the canaraga shrubland would deteriorate soil water environment, and soil desiccation will be emerged or aggravated, soil degradation and vegetation decline will happen, which in turn influence benefits of water and soil conservation of forest vegetation.

Discussions

Before restoring soil and water conservation vegetation, Excellent tree species are preferred for soil and water conservation vegetation (Guo et al, 1990) and then appropriate sowing rate and planting density shall be adopted (Guo 2014). After sowing or planting, with plant grow, resources reduce, and then degree of cover increases with the increase of planting densities, basal diameter, surface runoff and the sediment concentration declined, but the canopy coverage and interception increased. The planting density was linear related to basal diameter, logarithm relevant to degree of cover and surface runoff, and exponentially related to canopy interception. The relationship between sediment concentrations in runoff and planting density can be described by an "inverse-S shape" curve. Though the dense planting density can increase degree of cover and thus increase benefits of water and soil conservation forestor vegetation, the restoration of artificial forest vegetation should have a maximum limit due to the limited water resource. For example, the limit is the cover degree of 2002 in caragana shrubland in the semiarid loess hilly region of the water-limited region (Guo and Shao 2013; Guo 2021a and b).

With increase in planting density, the degree of canopies' cover and the precipitation intercepted by the canopies increase, but the runoff and sediment concentration decline, the benefit of forest vegetation for soil and water conservation is more obvious (Liu et al. 2008).Under the same rainfall, rainfall intensity and rain even duration condition, with increase in planting density, the rainwater intercept by the forest canopies and water loss increase, the evaporation and transpiration increases at the same time, and then soil consumption increase, soil water supply reduces, which lead to serious soil degradation in the form of soil desiccation in the woodland and vegetation degradation. It is hostile to the heath and stability of forest vegetation ecosystem, but the heath and stability of the ecosystem is the foundation to maintain sustainable and stable ecological benefit. So, in the long-term, there should be a balance between water supply and consumption in the process of forest vegetation restoration. The planting density of indicator plant, such as Caragana in this study at the balance point was called soil water carrying capacity for vegetation (Guo 2014,2021a and b). The cover degree of forest vegetation at the point was the maximum degree of restoration. It should be drafted as the basis for determining the target of forest vegetation for soil and water conservation. The maximum yield and benefits of soil and water conservation is the rational maximum yield and benefits of soil and water conservation when plant density is equal to soil water carry capacity for vegetation in the critical period of plant-water relationship regulation. If the plant-water relation goes into critical period of plant-water relationship regulation and planting density is more than the vegetation carrying capacity, then the degree of restoration exceeded the limit, more production and more soil and water conservation may be obtained temporarily at the expense of environment, which caused soil degradation in form of excessive soil drying under both perennial grasses and forests and finally lead to desertification in dry years or soil water resources waste in wet years, which did not correspond with strategy of high-quality and sustainable development, so we should ensure the cover degree of soil and water conservation meets the requirement of 60% of the construction standard of Soil and water conservation in Spring (Guo 1996), and then investigate the soil water condition and plant growth. Once soil water resources within maximum infiltration depth of the forest land is lower than soil water resources use limit by plants. Soil water influence plant growth and soil and water conservation. The relationship between soil water supply or soil water consumption and plant density and soil water carrying capacity for vegetation in the critical period of plant-water relationship regulation was estimated. The condition of caragana growth in the critical period of plant-water relationship regulation decide the benefits of soil and water conservation in the whole growing season. The soil water carry capacity for vegetation change with vegetation type, period and location (Guo 2014,2021a and b). If the plant density is more than soil water carry capacity for vegetation in the critical period of plant-water relationship regulation, we must regulate plant-water relationship be reducing the density and give full play to the maximum benefit of soil and water conservation forest to ensure sustainable use of soil water resources and the high-quality and sustainable development of soil and water conservation vegetation in water-limited regions.

Conclusions

Along with time going by, plant growth, the plant-resources relation should be considered. In a growing season, as plant grows, plant growth goes into the fast growth stage, the leaves were totally expansion and the plant-resources relation may goes into the critical period of plant- resources relationship regulation If the available resources are lower than resource use limit by plants (Guo 2021a and 2021b). Plant was very sensitive to resources storage in this period. If the duration of resource scarcity is more than the critical period of plant- resources relationship regulation or plant density is more than soil water carrying capacity, showing that resource shortage is serious and serious influence soil and water conservation vegetation restoration and the plant-resources relation must be regulated by cutting some trees and reduce plant density in this stage based on vegetation carry capacity to realize high-quality and sustainable development of soil and water conservation vegetation.

In view of the important of the potential of soil and water conservation vegetation restoration in the process of high-quality development and soil and water conservation vegetation restoration is close related with vegetation carrying capacity and vegetation carrying capacity change with forest age because precipitation change with years (Guo 2014) and vegetation types and location, we should strengthen the studies of the plant-resources relationship and decide vegetation carrying capacity and the limit of forest vegetation restoration at different years in order to promote the high-quality sustainable management of soil and water conservation vegetation and get maximal soil and water conservation beneficial to match the People's yearning for a better life and the need for soil and water conservation(Guo 2020,2021a and b).

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Contributors' statement

Zhongsheng Guo wrote the paper. Dandan Chen, Ting Ning and Wenwen Zhang collected and analyzed these data

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Competing interests statement

There is no conflict of interest.

Data availability statement

The data underlying this article are available in the article and in its online supplementary material.

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