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Agriculture High-Quality Development in Semiarid Loess Hilly Regions

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Abstract

Since 2017, high-quality development was put forward in China, so, agriculture development enters the new stage, high--quality development. The high-quality development of agriculture is to take some measures and methods to make the land produce the maximum output and services to meet people's yearning for a better life and the needs of agricultural production services. However, because overuse of fertilizer, pestcide and introduction of un-native plant species or vatiaries, exotic plant species or varieties, unbalace plant water relationship result soil dryness, soil degradation and crop failure in dry years or waste of soil water resources in wet year in water-scarce areas, both are unfavorable for the sustainable utilization of soil water resources and crops high-quality production. Therefore, it is necessary to adjust the plant water relationship and obtain the maximum yield and services to realize the sustainable utilization of soil water resources by plants and crops high--quality management. However, there is not a universally accepted theory to provide guidance of regulation of plant water relationship in practice. Here we show that the theory of sustainable use of soil water resources includes the soil water resources use limit by plants (SWRULP) and soil water vegetation carrying capacity (SWVCC). The SWRULP is the soil water resources in the maximum infiltration depth (MID) in which the soil water content in every soil layer equal to wilting coefficient. The wilting coefficient is expressed by the wilting coefficient of indicate plant in a plant community. SWVCC is the population or density of indicator plants in a plant community when the soil water supply is equal to soil water consumption in the root zone in the critical period of plant water relationship regulation（CPPWRR）, which changes with plant community type, site condition and time. When soil water resources in the MID is lower than SWRULP, the plant water relation enters the CPPWRR. The ending time of CPPWRR is the ineffective time of plant soil relationship regulation. we have to select best plant species or variaties, take Suitable initial planting density and effective measures or methods to ensure plant normal grow and get the cultivate goal. If in the process of plant growth, the plant density in the critical period of plant soil relationship regulation is more than the SWVCC, plant water relationship has to be regulated based on SWVCC to get the maximum yield and service to realize sustainable use of soil water resources and high-quality production. As for fruit or crops, the leaf and fine fruit has to be regulated according to the quantity of leaf when the plant density is equal to the SWVCC in the critical period of plant soil relationship regulation. The fine fruit is the fruit for goal market.

Keywords: Soil Water Resources; Soil Desiccation; Soil Degradation; Crop Failure; Maximum Infiltration Depth, Soil Water Resources Use Limit By Plant; Water Carrying Vegetation Capacity; The Critical Period Of Plant Soil Relationship Regulation; Sustainable Use Of Soil Water Resources; High Quality Production

Introduction

Since 2017, the term high-quality development was put forward By Xi Jinpin in 2017 in China, which shows that China enters the new stage of agriculture development, high-quality development. The high-quality development of agriculture is to take some measures and methods to make the land produce the maximum output and services to meet people's yearning for a better life and the needs of agricultural production services [1].

In most parts of the world, human activities, such as overgrazing, deforestation, denudation and reclamation have greatly changed the type of vegetation that dominates the landscape because the productions and services produced by original forest cannot meet the need of the peoples. Now, the man-mad vegetation such as plantation, pasture, orchard and crop occupied more than 80% of forest. These have accompanied the increasing demand for food, fruit, timber and biofuels due to local population increases, which historically have frequently occurred in water-limited regions such as the Loess Plateau of China. Intense and poorly managed agricultural practices have often caused a decline in the density of natural plant populations [1,2]. Consequently, the original forest has disappeared and there has been a decrease in the level of forest cover and in the ability of forests to maintain a balanced ecosystem, which led to severe soil and water loss and continual degradation of the natural environment on the Loess Plateau and severely affects the high-quality development of agriculture.

In order to conserve soil and water and improve the ecological environment, since 1950, large-scale afforestation has been carried out on the Loess Plateau. This has been especially supported since 1978 by implementation of projects of the 'Three-north Protection Forest' that involves planting trees and establishing protection forest in north-eastern, north-western and northern regions of China to control soil and water loss and improves the ecological environment. Consequently, forest area and degree of cover has dramatically increased, as has the efficiency of forest and vegetation in conserving soil and water. For example, the sediment discharge on the Loess Plateau was reduced in recent years, runoff has halved and the environment has improved.

In the process of vegetation restoration, tree species, selected for their capacity to extend deep roots and for fast growth and conserving soil and water, were planted at high initial planting densities to rapidly establish high degrees of ground cover and higher biomass and yields, and thereby to quickly realize ecological, economic and social benefits in the process of vegetation restoration. It is advantageous that the roots of these plants grow quickly and thus they take up water from considerable soil depths, such as 5.0 m for 16-year-old Caragana shrubland (*Caragana korshinskii* Kom.) in the semiarid loess hilly region in Guyuan County, Ningxia Hui Autonomous Region of China and 22.4 m for 23-year-old Caragana (*C. microphylla* Lam.), another related species in Suide County, Shaanxi Province of China [2]. However, soil water mainly comes from precipitation; and the maximum infiltration depth (MID) and soil water supplies are limited in this region[3]. Thus, root depth can exceed the depth of soil water recharge from rainwater, leading to severe desiccation of soil in root soil layer [3-5]. Consequently, the combination of increased water use by plants and low water recharge rates has led to soil deterioration after one month or a year or a couple of years, receding vegetation and crop failure on the Loess Plateau in the perennial artificial grass and forest land [6-8]. Such soil deterioration can adversely affect ecosystem function and services and the stability of manmade forest and vegetation ecosystems, and consequently reduces the ecological, economic and societal benefits of forest and other plant communities. In turn, this suggests that the plant water relationship in these perennial artificial grass and forest lands is not harmony and should be regulated.

Water is the main factor influencing vegetation restoration and plant growth in most of the water-limited regions. Soil water resources are the most important resources. The carrying capacity of land for vegetation in this region is the vegetation carrying capacity (SWVCC) [9-10]. It can be divided into space vegetation carrying capacity in soil water and nutrient rich regions, soil water vegetation carrying capacity in soil water limited regions and soil fertility vegetation carrying capacity in soil nutrient limited regions [11]. Therefore, the balance between the consumption and supply of water to the soil should be considered when restoring vegetation cover after some months or a couple of years in order to realize the goal of sustainable use of soil water resources (SUSWR) and high-quality sustainable development of forest including soil and water conservation.

The Chinese Loess Plateau is the most serious soil and water losses in the world. It is located in the center part of China, and has an area of 642 000 km^2 of which 454 000 km^2 experiences soil and water loss and has scarce water resources. Soil in this region is very deep in the range of 30–80 m from the surface [12], and the groundwater table is also deep [13]. Without irrigation, the best measure to solve issues of soil drought, which led to soil degradation, vegetation decline and crop failure is to regulate the plant water relationship by reducing the population quantity of indicator plants in a plant community to match SWVCC on the Loess Plateau, thus balancing the soil water recharge and SWC is most important in plantations restoration in water limited regions [14-15].

Plant water relationship is the most important relation in the water-limited regions. Drought is a recurring natural phenomenon. The complex nature and widespread impact of drought on forest and grass land with high coverage and production – driven by artificial vegetation consuming more than a permissible quantity of soil water resources in water-limited regions – means that regulating the RBPGSW is needed to maintain SWC of restoring vegetation at levels that sustainably use the soil water resources because man-made forest often use alien species and change the plant water relation, which easily lead to soil degradation and vegetation in dry years or waste in wet years. However, there is a lack of a universally accepted theory or method for regulating the plant water relationship and realizing sustainable use of soil water resources (SUSWR) in forest, grass land and farm land in these regions. In this study, we aimed to develop the theory for regulating the plant water relationship in water-limited regions, including (1) the SWRULP and SWVCC and the critical period of plant water relation regulation and realize the sustainable utilization of soil and agriculture high-quality development [16].

Soil Water Resources

Soil is a loose medium with many apertures and a complex system. Soil can hold much water, which is the water existing in the soil space, which is divided into capillary and non-capillary pores that change with soil depth and is a state variable controlling a wide array of ecological, hydrological, geotechnical and meteorological processes by means of soil evaporation and plant transpiration. Soil water forms include crystalline water, solid water, vaporous water, tight or loose bound water, free water, gravitational water and anastatic water. Soil water cannot be transferred by humans from one place to another but can be used by plants. The amount of water held in the soil is the soil water resource. Soil water resources come from the concept of overall soil moistening proposed by M. I. Lvovich [17].

Soil water resources can be defined for the needs of different disciplines such as forestry, agriculture, pedology and hydrology. For pedology, hydrology and Architecture, it is the water stored in the soil from surface soil to the groundwater table- generalized soil water resources. For agriculture, forestry and ranching, it is the water stored in the root zone soil- Soil water resources in narrow sense, and the dynamic soil water resources - the antecedent soil storage in the root zone plus the SWS from precipitation in the plant growing period or a year for evergreen plants – because soil water from precipitation in the growing season can be taken up immediately by live plants and influence their growth after rain event.

Soil water resources are the most important component of water resources and renewable water resources, which can be divided into two parts: plant-unavailable water resources and plant-available water resources because some soil water resources can be used by plants, which is plant-available water, but the remainder is plant-unavailable water. Soil water adsorbed by solid soil different sizes of soil particles or held in the soil space. Soil water potential increases with increasing water molecule layers and the outside water molecules have higher water potential than the inside water molecule layer. Plant evapotranspiration including plant transpiration and film water evaporation on the surfaces of leaves, branches and stems when raining and after a rain event is a hydrological effect that induces soil suction. With water absorption by roots and evapotranspiration, soil water content and soil water potential are reduced but soil water suction is increased. When soil water content in every soil layer is reduced to designate soil moisture content, such as the wilting coefficient, the suction of soil particles to water exceeds that of plants to soil water and the water stored in all soil layers, soil water cannot be further taken up by plants in the MID. When soil water content in every soil layer is higher than wilting coefficient, the suction of soil particle to water is lower than that of plants to soil water, even the water plants sucked from the root soil does not meet the need of flowering and fruiting of plants for economy crop. The soil water resources in root zone when soil moisture content more than wilting coefficient is plant-available soil water resources.

SWRULP

Plant water relationship is the most important relation in the forest restoration and agriculture development of water-limited regions. Soil drying often happens in the soil under the man-made vegetation such as plantation, orchard, fruit or crop in water-limited regions. A tree or plant is a complex organism with a series of regulatory mechanisms to keep vital systems operating within appropriate restrictions, and with mechanisms to repair damage that may occur when these limits are exceeded. A tree or plant transports water from the soil to the atmosphere along a water potential gradient; its survival depends on maintenance of this transport system, which is important for maintaining hydration and efficient exchange of water for the carbon dioxide required for photosynthesis in a dynamic and often water-limited environment [18]. Plants also have some self-regulation function in the opening degree of stomata in leaves and the number of leaves retained during water stress; however, this self-adjustment is limited and cannot meet the need of regulating plant water relation in the process of plant growth in some extreme conditions, such as severe drought and hot days on the Loess Plateau. While a plant grows, individual size expands, Canopies effect on soil water supply (SWS) and soil water consumption (SWC) strengthens and roots deepen but soil water resources in plantation forest and grass land often decline in water-limited regions, even if there are some increases after rain events, and then root water uptake declines. Water stress begins when transpiration demand exceeds root water uptake, resulting in a loss of turgor. Subsequent short- and long-term responses include declines in cell enlargement and leaf expansion rate, reduced photosynthesis and transpiration. When soil water resources reduce to the degree, that results in severe soil drought, and finally leads to soil degradation, plant growth ceases and vegetation recedes or even dies.

It is important to regulate the water-plant relation for the prevention of soil drying and soil degradation, and the SUSWR in water-limited regions. In practice, regulating the the water-plant relation is not required once soil drought happens in forest and grass land. This is because soil water mainly come from precipitation and there is a dramatical monthly and yearly change of precipitation in the water- limited region such as in the semiarid loess hilly region. According to weather data for 1983–2002 collected in Shanghuang Ecological Experimental Station and our study data for 2002–2016, Annual precipitation ranged from 284.3 mm in 1986 to 634.7 mm in 1984, see figure 1,.and soil drying is a natural phenomenon and often occurs, and varying degrees of soil drying have different effects on plant growth especially at different growth stages, and there may be some water, which can buffer some effect of drought on plant growth when soil desiccation occurs. In addition, in the Loess Plateau, labour power is lacking and the level of mechanization is low. Machinery available for regulating the water-plant relation is inadequate for the huge areas of forest and grass land and crops, often with rough terrain unsuited for much machinery.

Soil water resources are precious natural resources and only used by plants, and then transferred into products such as fruit, food, fibre, forage, fuel and services, such as soil and water conservation, fixing carbon that is important for people's health.

The soil water resources are renewable natural resources and only used by plants, but it cannot be overused be plants. There are two important soil water deficit criteria: SWRULP and lethal soil water resources (LSWR). The concept of SWRULP was first proposed by Guo in 2010 and it is the limit of soil water resources use by plants [19]. SWRULP can be defined as the soil water storage in the MID when the soil water content in all soil layers of the MID equals wilting coefficient. LSWR is the soil water storage in the root zone depth when all soil layers within this zone have reached the wilting coefficient. Generally, the root zone depth is more than the MID.

Two-Curve Method for Estimating Infiltration Depth

Infiltration depth is one of the most important indexes for estimating soil water deficit criteria, SWRULP. The infiltration depth for one rain event can be determined by the two-curve method – the infiltration depth equals the distance from the surface to the crossover point (wetting front depth) between the two respective soil water distribution curves of soil water with soil depth before and after the rain event (Figure 2a). The MID will occur after a continuous heavy rainfall event and a long-term cumulative infiltration process, and can be determined by a series of two-curve methods (Figure 2b).

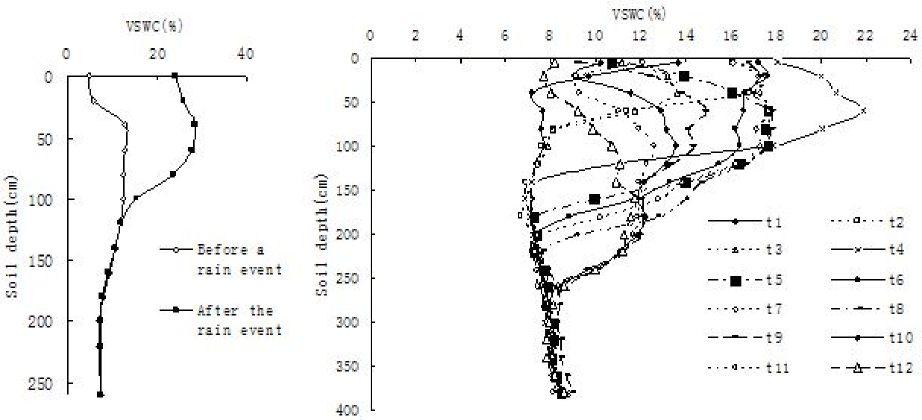

Figure 1: Monthly (figure above) and yearly change (figure below) of precipitation with time in the semiarid regions of Loess planteau, Guyuan, China

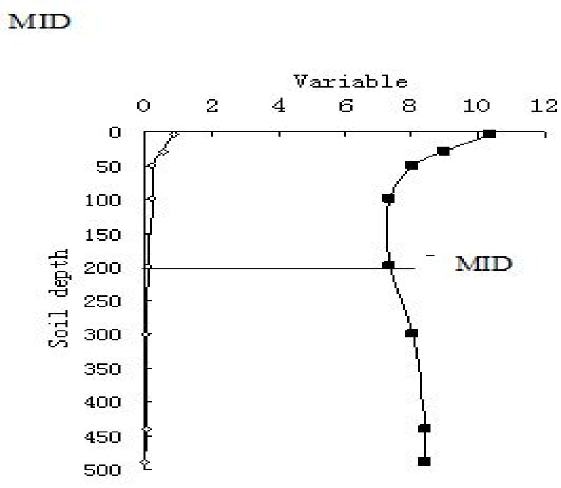

Figure 2: Two-curve method for estimating infiltration depth and maximal infiltration depth. a, infiltration depth and soil water supply for one rain event. b, the maximal infiltration depth is estimated by a series of two-curve methods in the semiarid loess hilly region, China. VSWC is volumetric soil water content

For example, the MID was 290 cm, which happened on 1 August 2004 after some heavy rain in August 2003– 55.0 mm on 1 August, 45.7 mm on 25 August and 56.4 mm on 26 August for Caragana shrub land in the semiarid loess hilly region of the Loess Plateau.

The root is the most important organ for terrestrial plants to access water. Thus, root vertical distribution is another important index for estimating SWRULP. The root distribution can be investigated using soil pits. For example, the majority of Caragana root biomass was distributed in the 0–200 cm soil layer even though roots extended to 5.0 m, MID was 2.9 m, SWRULP was 222.8 mm and LSWR was 405.7 mm in Caragana shrub land of the semiarid loess hilly region (Figure 2). The amount of water carried from the soil through plants to the atmosphere depends on weather, plant growth and soil water conditions.

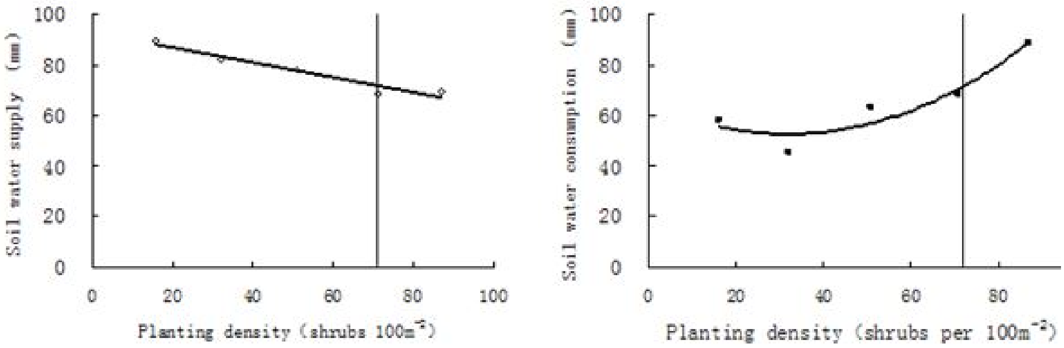

Figure 3: The change of root distribution depth (RDD) and wilting coefficient (WC) with soil depth in 16-year-old Caragana shrubland in the semiarid loess hilly region of China. MID is the maximal infiltration depth

-20097750RDD00RDDConsequently, plants cannot withdraw more soil water than what is available. If the soil water supply is smaller than soil water consumption then soil water resources will reduce and eventually reach the LSWR. When this occurs, if there is no timely soil water supply from rain, then plants will die because the plant-available soil water in the root zone is exhausted.

SWRULP is one of the most important criteria for plants to use soil water rationally and soil water management in forest and grass land in water-limited regions. When the soil water resources in the MID equal the SWRULP, the plant water relation enters the critical period of plant soil relationship regulation, even if plants withdraw some water in soil layers deeper than the MID because the root depth is more than MID, the amount of root water uptake is small and will not meet the needs of plant transpiration. Therefore, this is the starting time of the critical period of plant soil relationship regulation to regulate the plant water relation. For example, when caragana shrubland is at 2006, the soil water resources in the 0-290 cm soil are equal to SWRULP, it is the time to begin considering regulate the plant water relation. The starting age of the plant water relation is the fifth year after sowing in the degradation and receding vegetation. The amount of regulation is the difference between plant density and SWVCC in the critical period of plant soil relationship regulation, because SWVCC is the measurement of sustainable use of soil water resources by plants. When the existing plant density is less than or equal to SWVCC, plant soil relationship should not be regulated. When existing plant density exceeds the SWCCV, suggesting that available soil water resources will not support the existing plant population to grow well and the amount of plant population should be reduced to increase SWS and reduce SWC. The difference between existing plant density and SWVCC indicates the amount of regulation required, which changes with time.

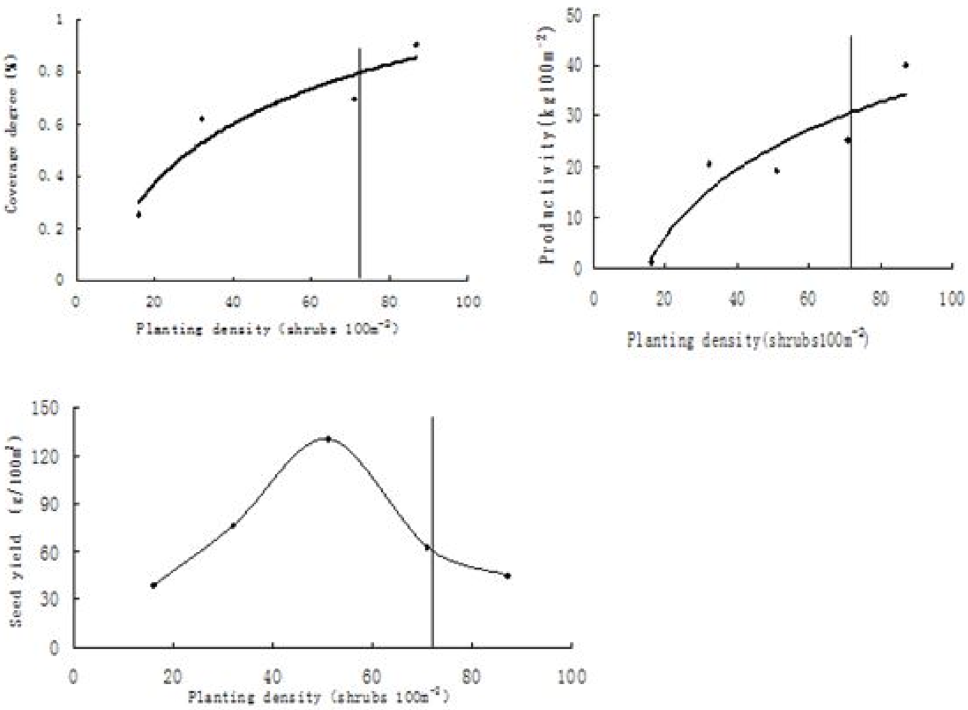

Figure 4: The changes in soil water supply and soil water consumption with planting density and SWVCC in the kay period of plant water relation regulation of Caragana shrubland in the semiarid loess hilly region, China. a, The change in soil water supply with planting density and SWVCC; b, The change in Soil water consumption with planting density and SWVCC

SWVCC

Natural resource change with climate change, time and location. natural resource constraints set a maximum size that a population can safely attain. The maximum population is the carrying capacity, which is a key issue for high quality and sustainable development of forest, grass and crops. The idea of carrying capacity has its origin in the doctrine of Thomas Robert Malthus, who considered that society had the ability to increase agricultural production only at an arithmetic rate but the number of people to be fed increased at a geometric rate. Therefore, to some degree, population was likely to exceed food supplies, with calamitous results [20].

Range managers [21] and U.S. Department of Agriculture researchers [22] first used the concept of carrying capacity. After Verhulst put forward the logistic curve in 1838. Pearl and Reed in 1920 reasoned that there must be an absolute limit beyond which further population growth would be impossible, Odum (1953) related the term carrying capacity with the constant K in logistic equations [21-22].

Since the 1960s, about ten years after planting forest, soil drought has occurred during the process of vegetation restoration in the water-limited region of the Loess Plateau in China. Severe soil drought causes soil degradation, vegetation decline and large-scale forest death, which reduces forest productivity and efficiency in controlling soil and water losses. Control of soil degradation and keeping large-scale artificial vegetation healthy and stable has become one of the most important issues in soil and water conservation and ecological civilization construction in these water-limited regions.

Due to the clear difficulties in restoring forest and vegetation in these regions, the public and national leaders of China and the Prime Minister have called for control of this kind of soil degradation to preserve stability of existing artificial vegetation. The need for better understanding of soil water resources, promoting vegetation restoration and realizing SUSWR in water-limited regions and sustainable development led to the concepts of vegetation carrying capacity and SWVCC.

The concept of SWVCC was first proposed by

Guo in 2000 [23-24]. SWVCC is soil water vegetation carrying capacity and was defined as the highest density of the vegetation community when SWC is equal to SWS in the root-zone soil layers from which roots can take and utilize water on an annual basis [25-26].

Vegetation includes different plant communities that consist of different plant species within a region or a country. In nature, no plant community is formed by a single plant species, instead many plant species live together and form the community. Although any one species in a plant community can express SWVCC in this situation in theory, but the different plant species differ in their positions and roles in the community. Constructive species for natural vegetation and principal or purpose species of trees or grasses are selected drought resistant plant species – principal species are the main afforestation tree species and account for the majority of the trees planted in a region, and purpose species of trees or grasses are those cultured or managed by people in a region. Generally, principal species of trees or grasses are also purpose species in a region; for example, Caragana is a principal as well as a purpose species of trees in the Loess Plateau, which is the regulated tree species.

Planting trees is a purposeful human activity; and Caragana is planted where vegetation is sparse and soil erosion is serious. Such plant species are often exotic, sensitive to water deficits and play the most important roles in preventing wind erosion, fixing sand and controlling soil and population quantity of a plant species in plant communities; and become the goal of cultivation, management and regulation. Thus, an indicator (plant) species is the representative of a plant community to express SWVCC – either a constructive species for natural vegetation, or a principal or purpose species for artificial vegetation. The SWVCC can be further and clearly defined as the maximum plant population quantity (absolute index) or plant density (relative index) of an indicator species in a plant community when SWC is equal to SWS in the root-zone soil layers from which roots can take up water in one year. The value of SWVCC is a function of indicator species, connected with plant community type, time (expressed in forest age or planting age) and sites [21].

Methods of Evaluating SWVCC

It is important to develop a suitable method to evaluate SWVCC. There are some equations to estimate SWVCC, such as classic carrying capacity models [26], general models of population growth [21] and so on; however, soil water–plant density models are best [24].

Classic SWVCC model Classic carrying capacity models were proposed by German geographer Albrecht Penck. In 1925, he stated a simple formula that has been widely used [26]. According to the models, the classic SWCCV model is presented in the following form:

$$Q = \frac{C}{D} \quad (1)$$

Where, C is soil water resources per unit area and D is individual water requirement. Ma *et al.* estimated SWVCC for eight tree species using this formula in a dry and warm valley of Yunnan, China [27]. Because there is no universally accepted definition of individual plant water requirements and which change dramatically with the same tree, this affects application of the equation in computing SWVCC. The minimum water consumption that an individual plant consumes water over a season or year when growing in a normal and healthy way should be used as the individual water requirement – because water consumption of an individual plant over a year change with time, weather, plant growth and soil water conditions. If the minimum water consumption is used as the individual plant water requirement, which is suitable for saving water and precise soil water management in forest and grass land even the individual water requirement index, that is, the minimum water consumption is too high.

Soil Water–Plant Density Model

Verhulst put forward the logistic curve in 1838. Pearl and Reed in 1920 reasoned that there must be an absolute limit beyond which further population growth would be impossible:

$$N(t) = \frac{K}{(1+e^{(a-rt)})} \qquad (2)$$

Where, N (t) is the population at time t, K is carrying capacity and r is the growth rate; and parameters a and e are constants. Given a population N(t) at different times, at least there are three sets of populations and time data, such as N_1 at t_1; N_2 at t_2, and N_3 at t_1, then the carrying capacity can be obtained using equation 2. Because there is no soil water resources term, the equation does not express the impact of soil water resources on carry capacity, it is difficult to obtain the SWVCC. So, the equation requires some improvement.

Even regulating the plant water relationship can ensure plant healthy grow and get maximal yield and benefit, but the benefit of regulating plant water relationship different at different growth stage is different because plant water relationship is different at different plant growth stages [25]. Only regulating the plant water relationship in the key period of plant water relationship regulation can get maximal yield and benefit because degree of soil water on plant growth is smaller when soil water resources is more than SWRULP.

If we established a set of different population quantities (or densities) of indicator plants PD_1, PD_2, PD_3, PD n at the same condition and the same plot areas (e.g. 5 m × 20 m plots for Caragana in the Loess Plateau), PD_i is the plant density at different time, so these plots have the same radiation, temperature, annual precipitation and its distribution in a season or a year, slope, slope aspect, slope position and soil type would be almost the same. However, they would have differing population quantity or density and so different effects on soil water supply and soil water consumption. The precipitation, throughfall, runoff, plant growth, deep seepage and soil water changes with soil depth and time in the root zone are measurable variables, thus the soil water supply and soil water consumption for the different population quantities or densities on smallest time scale plant least death day or growing season or an annual basis can be measured, collected and statistically analyzed. Soil water supply reduces with increased planting density (Figure 3a); and the relationship between soil water consumption and population quantity or density can be described by a parabolic equation (Figure 3b). The quantitative relationship between SWS or SWC and population quantity can be established using a least squares method. Generally, the soil water and plant density model can be expressed in the following form (Figure 2):

For example, in 2002 in 16-year-old Caragana shrub land (Guo 2004,2021),

$F_1 = 92.494 - 0.2913$ PD (see Figure 3a),

$F_2 = 0.0118$ PD $^2 - 0.7575$ PD + 64.759 (see Figure 3b) and SWVCC is 72 bushes per 100 m^2 or 7200 bushes per ha. Stem number, S, changes with plant density E, and the S and E relationship is: $S = 42.88E - 62783$, with $R^2 = 0.9632$.

Currently, the soil water and plant density model are the best model to estimate SWVCC. Once a set of different density experimental plots is established, SWVCC can be estimated at different tree ages and annual precipitation. The parameters a–e changes according to time and site.

The Critical Period of Plant Water Relationship Regulation

Plant water relationship change with plant species and variaties, time and location. Although we cannot estimate SWVCC in the critical period of plant water relationship regulation at sowing or planting, plant water relationship can be regulated at different time, but effect of regulation at different time is different. When the soil water resources in the MID is more than SWRULP, plant grow well, for example in Red Plum apricide, plant water relationship should not be regulated. If the soil water resources in the MID is smaller than SWRULP, and the plant water relationship enters the critical period of plant water relationship regulation. The ending time of the critical period of plant water relationship regulation is the ineffective time of the plant water relationship regulation. At this period, soil water severe influence plant growth and decided the maximum yield and service because most of plant has lower self-regulation is small. If the soil water resources shortage period is more than the critical period of plant water relationship regulation or present density is more than SWVCC, it is time to regulated the plant water relationship based on SWVCC to get the maximal yield and service of a plant community (Guo 2021). So, the critical period of plant water relationship regulation is the important period of plant growth in the water-limited regions.

The soil water resources in Caragana shrub land are reduced with increased planting density and time (forest age) under rain-fed conditions, except during wet years, because SWS is reduced with increased planting density (Figure 4a) but SWC increases with planting density and time (Guo and Shao 2010) (Figure 4b). When the density of the indicator species, Caragana, exceeds its SWVCC value, soil water content under the shrub land is reduced and threatens the health and stability of the shrub vegetation ecosystem. When the soil water resources drop to the SWRULP, water-plant relation enters the soil water seriously impedes plant growth (Guo 2010). Thus, the plant water relationship needs to be regulated using SWVCC in water-limited regions. The start time to regulate the plant water relationship is at the fifth year for Caragana in the semiarid Loess Plateau [9].

If the population quantity or density of an indicator or purpose species of tree in a plantation exceeds the SWVCC value, the higher ecological, economic and social benefits and productivity in the plant community will be obtained at the expense of the environment (more serious soil drying, soil degradation and vegetation decline). Even if a soil water deficit in the plant community or forest vegetation does not immediately destroy the ecosystem, this situation will not well sustain the vegetation. If density of the indicator species is less than the SWVCC value, the plant community does not make the most of natural resources. Thus, the present productivity, ecological, economic and social benefits of the plant community does not reflect the maximum services and benefits the rain-fed ecosystem function can provide and wastes the soil water resources.

SWVCC is the foundation to determine the amount of regulation needed. The cover degree is an important index to express the function of vegetation in reducing raindrop dynamic energy and wind velocity near the ground and conserving soil and water. The degree of cover (Figure 5a) and productivity (Figure 5b) in Caragana shrub land increases with planting density. Because the main erosive force is runoff in the Loess Plateau, when Caragana density exceeds the SWVCC value there is higher cover degree (Figure 5a) and canopy interception (Figure 6a), as well as lower runoff (Figure 6b) and then lower soil loss (Figure 6c). However, this is at the expense of the soil water environment because soil water consumption exceeds water supply from rainfall when planting density is more than SWVCC, which is not good for SUSWR and SFM. Keeping the planting density of Caragana at the level of SWVCC is required to balance soil water supply from rain and the plants' water requirements and make the most of soil water resources and carry out Agriculture high-quality production. In many cases. To carry out Agriculture high-quality production, we should select better plant species and variaties, take suitable Initial plant density and effect measure or method to ensure plant grow healthy and get the cultivate goal. The initial plant density is equal to or more than SWVCC. But it is difficulty to add the plant density when plant grow. When the density of the indicator species in a plant community is more than SWVCC, in order to avoid soil degradation and vegetation recession and get the maximum yield and services, we have to regulate the plant water relation to get the maximum yield and benefit. As for some fruit tree or crop, such as Red Plum apricot and corn, we have to further regulate the leaf and good fruit according to the suitable leaf when the plant density is equal to SWVCC and the good fruit for market.

Agriculture High-Quality Development

Since 1992, SFM has become a highly relevant topic in both forest and environmental policy [25,28], after 2017, China put forward high-quality development, so forest, grass and crops should carry out high-quality management and crop should carry out high-quality production (24).

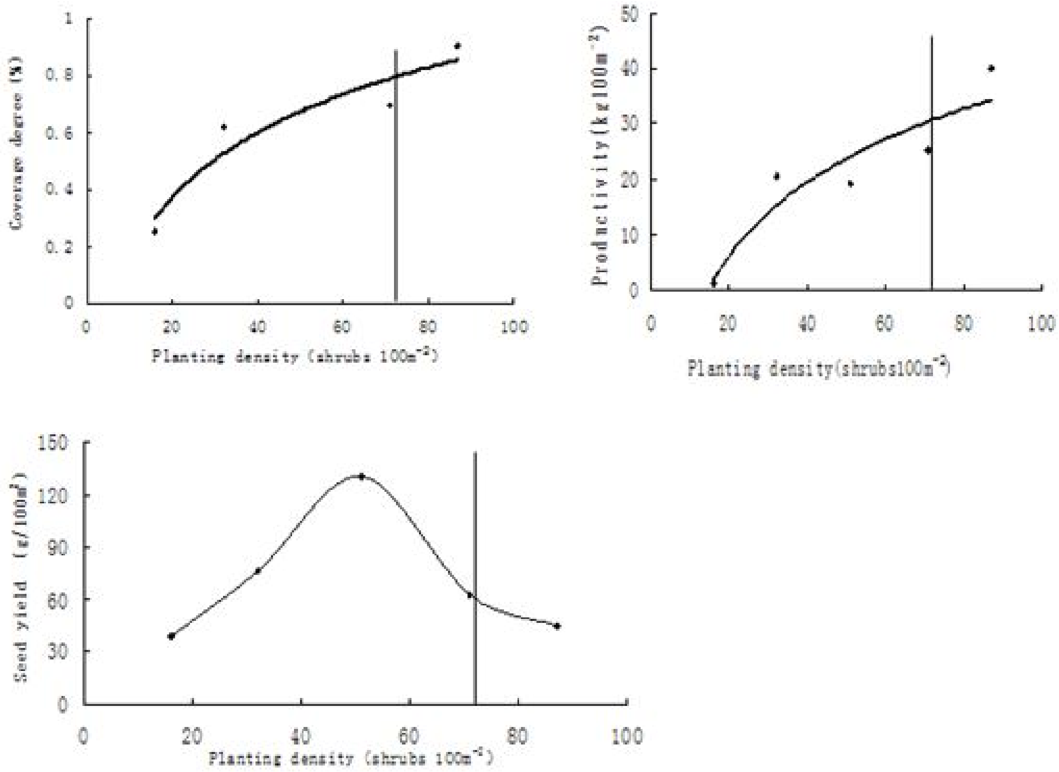

Figure 5: The change of coverage degree, productivity and seed yield with planting density and SWVCC in Caragana shrubland of the semiarid loess hilly region, China. a, The change in coverage degree with planting density and SWVCC. b, The change in Productivity with planting density and SWVCC. c, The change in seed yield with planting density and SWVCC

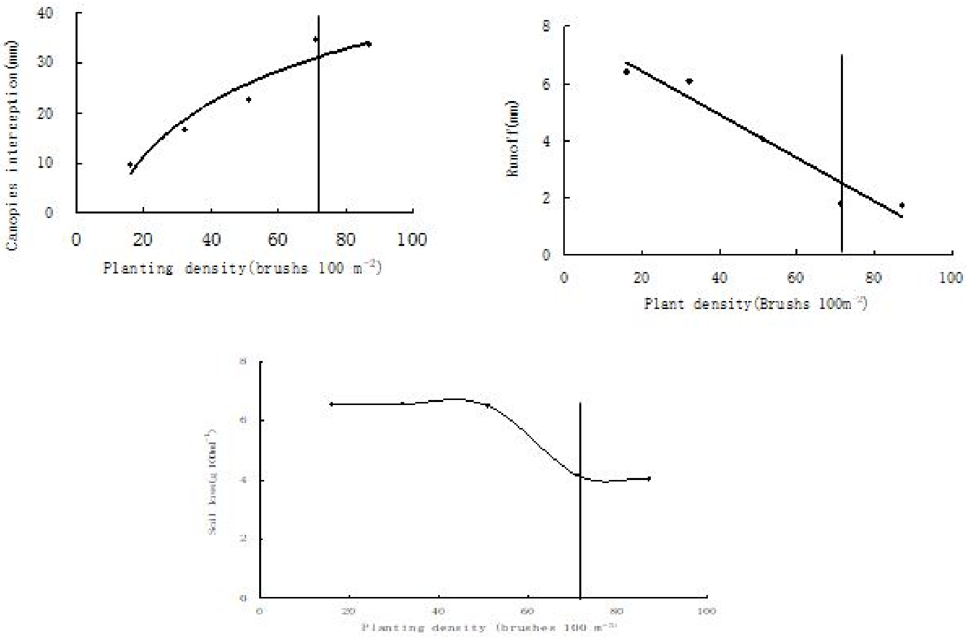

Figure 6: The Changes of canopy interception, runoff, and soil loss with planting density and SWVCC in the Caragana shrubland in the semiarid loess hilly region of China. a, The change in canopy interception with planting density and SWVCC; b, The change in runoff with planting density and SWVCC; c, The change in soil loss with planting density and SWVCC

In order to carry out agriculture high-quality development, we have to carry out Agriculture high-quality production. When the density of indicator species in a plant community equals the SWVCC value, the plant community makes the most of the soil water resources, and conditions of the community such as the appearance, crown coverage, productivity, constituents and carbon-fixing capacity should be indexes or the theoretical basis for high-quality sustainable management of the vegetation and high-quality production of crop. The cover degree, productivity, biomass and its components and carbon-fixing capacity when the density of indicator species in the plant community equals the SWVCC value and the requirement of stakeholders should be combined to determine the method of Agriculture high-quality development. After regulating the plant water relationship in the critical period, according to the quality fruit and leaf quantity relationship and the appropriate leaf quantity, that is, the leaf quantity when the density is equal to SWVCC, the vegetative growth and reproductive growth relationship of the plant can be adjusted to obtain the maximum yield and benefits and realize the high-quality production of fruits and crops.

Conclusion

Fast global economic development and increase in population in the past century has led to unprecedented consumption of natural resources to satisfy the growing demands for food, fibre, energy and water in water-limited regions. These natural assets were perceived as free and limitless for many decades. Nowadays, with scientific, technological and economic development, increasing public awareness of the value of soil, water and forest resources and the growing need for environment quality has gradually led governments to adapt their policies and strategies to match sustainability goals. This has meant dealing with the overuse of soil water resources, soil degradation and vegetation decline in the process of soil and water conservation and vegetation restoration in water-limited regions. Sustainable use of natural resources and keeping the environment sustainable in water-limited regions is the basis for high-quality sustainable development of social economy and human consensus because the area of water-limited regions accounts for the most of global land and supports a numerous and ever-growing population.

Soil water resources is the water storing in the soil and only used by plants. Soil water resources are a kind of precious natural resources and should be used only by plant and then changed into special products, such as fruit, food, fuel and. In water-limited regions, soil water resources are reduced with growth of forest even with a sudden increases of soil water resources after rain events. When the soil water resources equal the SWRULP, plant water relation enters the critical period of plant water relation regulation. If the present density is more than SWVCC, soil water severely constrains plant growth and get maximal yield and service of a plant community. When this occurs, SWVCC should be considered and estimated – on which the plant water relationship should be regulated.

Carrying capacity is the measure of sustainable use of natural resources by living creatures and the core issue of sustainable development in regions where natural resources are lacking. SWVCC is the core issue for forest vegetation restoration, SUSWR, SFM and restoration of a harmonious relationship between humans and nature in water-limited regions such as the Loess Plateau. We should plant trees and manage forests in the way of high quality and sustainable in soil and water loss regions to conserve soil and water and improve the environment.

SWVCC is the ability of soil water resources to support vegetation and can be defined as the maximum plant population quantity (absolute index) or plant density (relative index) of indicator (plant) species in a plant community when soil water consumption is equal to soil water supply in the root zone on an annual basis in a water-limited region. The value of the SWVCC change with kinds of plant community (indicated by indicator species), time period and location. When the density of indicator species in a plant community is more than the SWVCC value, the plant water relationship should be regulated. When the density of indicator species at the key period of plant water relationship regulation in a plant community equals the SWVCC value, the conditions of the community such as the appearance, crown coverage, productivity and its constituents and carbon-fixing capacity should be indexes or the theoretical basis to determine C&I for SFM. The SWRULP, SWVCC in the critical period of plant water relation regulation provide a scientific basis for SUSWR in the process of vegetation restoration.

Agriculture high-quality development is to take some measure and method to make land produce maximum yield and service and meet people's increasing needs for better life and agriculture production and services. So, we have to select best plant species or variaties, take suitable initial planting density and effective measures or methods to ensure plant normal grow and get the cultivate goal [24]. If the existing plant density is more than SWVCC in the critical period of plant water relationship regulation, it is time to regulated the plant water relationship based on SWVCC to get the maximal yield and service of a plant community to realize forest and grass land high quality management and fruit and crops high quality production in water-limited regions.

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