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Review Article

The Process of Water Seeping into the Soil and Sustainable Use of Soil Water Resources

Zhongsheng Guo[1,2*]

[1]Northwestern A & F University, yangling, China

[2]Institute of Soil and Water Conservation. Chinese Academy of Science and Ministry of Water Resource, yangling, China 26 Xinong Road, Yangling, Shaanxi Province 712100, PR China

Corresponding author: Zhongsheng Guo, Northwestern A & F University, yangling, China and Institute of Soil and Water Conservation. Chinese Academy of Science and Ministry of Water Resource, yangling, China 26 Xinong Road, Yangling, Shaanxi Province 712100, PR China

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Abstract

The process of water seeping into the soil and Sustainable use of soil water resources is the foundation of Agriculture high-quality development in most of water-limited Regions because Soil water resources can only be used by plants and then converted into plant products and services for people to use. As population increases and economy develops in water-limited regions, there is an increasing demand for the quantity and variety of plant products and services. To meet the demands of this situation, most of the original forest has become farmland, plantation or non-native forest, grass land and farmland. As a result, as plant grow, the plant water relationship changed from equilibrium relation to non-equilibrium relationship, which led to severe soil and water loss, led to soil drought, soil and vegetation degradation, crop failure in dry years or waste of soil water in rainy years in most of water-limited regions. In order to solve these questions and improve environment and realize the sustainable utilization of soil water resources and the high-quality sustainable development of social economy, it is necessary to apply the limit theory of plant utilization of soil water resources by plants, the vegetation carrying capacity theory and critical period of plant resources relationship regulation to adjust the plant water relationship to obtain the maximum yield and benefit of vegetation and carry out Sustainable use of soil water resources and agriculture high-quality sustainable development.

Keywords: Goods and Services; Water-Limited Area; Plant Water Relationship; Soil Water Resource Use Limit by Plants; Soil Water Vegetation Carrying Capacity; Sustainable Utilization of Soil Water Resources; High-Quality Development

Introduction

To meet people's needs of the goods and services, most of old forest had changed into non-native vegetation, such as plantation, grass and crop, which changed the relationship between plant growth and soil moisture supply and consumer, leading to soil dry, soil and vegetation degradation or waste soil water resources in rainy yeas because along with plant growth, soil drought occurred, resulting in soil degradation and vegetation decline in most of soil and water conservation forest in water limited regions [1-5] because the soil water supply mainly from precipitation [6-8] and cannot meet the water needs of plants in dry year or wastes because the soil water supply from precipitation surpasses the water needs of plants, such as Chinese loess plateau.

To keep plant grow well and get its maximum produce and ecological benefits under this conditions, water-plant relationship must be regulated by reducing plant density or lop a fruit tree in order to increase soil moisture supply, to reduce transportation and maintain soil moisture balance and the stability of artificial vegetation ecosystem, to prevent soil drying and soil degradation or soil water waste. The rationale for regulation water-plant relation is that theory of Soil water resource use limit by plants and the theory of Soil Water Vegetation Carrying Capacity, especially Soil Water Vegetation Carrying Capacity in the key period of plant water relation regulation. The purpose of the paper is to introduce the theories of Soil water resource use limit by plants, the theory of Soil Water Carrying Capacity for Vegetation and the critical period of plant resources relationship regulation to carry out Sustainable utilization of soil water resources and high-quality development in water-limited Regions.

Soil Water Resource

To carry out Sustainable utilization of soil water resources and high-quality development of agriculture in water-limited Regions, first we have to master the soil water resources because Soil water resource is the basis of understanding the theory of soil water resource use limit by plants, the theory of Soil Water Vegetation Carrying Capacity, Sustainable utilization of soil water resources and high-quality development of agriculture in water-limited Regions. Soil water resources is the sum of water stored in the soil body, which are renewable water resources and components of water resources. The concept of Soil Water Resources first put forward by Budagovski in 1985 [9] after Lvovich proposed the concept of overall soil moistening in 1980 [10]. There are generalized soil water resources and narrow sense soil water resources. Generalized soil water resources can be defined as the water stored in the soil from the surface soil to the water table, commonly used in geology or architecture, and narrow soil water resources is the water stored in the root zone, commonly used in forestry, grassland and agriculture. In addition, there is a dynamic soil water resources, which is the antecedent soil water resources plus the soil water supply from precipitation in the growing season for deciduous plants, or over a year for evergreen plants. Soil Water Resources change with rainfall, soil evaporation, plant transpiration and soil water moving in the soil in most of the water-limited regions because underwater is deep and without irrigation [11].

Plant root vertical distribution

Root lives in soil body and is the most important organ for terrestrial life plant to suck soil water and nutrient even though stoma in a leaf and a stem can suck a little water when air humidity is high, such as raining. Root vertical distribution depth is an important index to estimate soil water deficit criteria because plant absorbs soil water in the root zone. Soil water resources are good indicator to express the effect of soil moisture on plant growth because plant roots are vertically distributed in soil and suck soil water in certain soil body. Sometime the root depth is more than tree height, see photo 1. The plant growth and root vertically distribution of Robinia (*Robinia pseudoacacia L.*) forest in the semiarid loss hilly region (Guyuan, China).

Photo 1: Robinia plant growth and root development and Maximal infiltration depth (Hm)in the semiarid loss hilly region of loess Plateau (Guyuan, China).

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Variation of soil water content with soil water suction

Before estimating soil water suction at different soil depth, we must take undisturbed soil sample and measure the soil water suction of undisturbed soil where plant live and wilting. Generally, the sampling pits (soil profile) was dug in the experimental site for investigating soil profile and sampling purposes, whose dimensions were 1m2 × 4 m depth. The undisturbed soil samples were collected for 3 times at different soil depth with cutting rings (a 5 cm in high, 5 cm in inner diameter and 100 cm3 in cubage). Soil water contents at different soil suctions were measured by centrifuge method, generally using a HITACHI centrifuge, made by Instrument Co., Japan, or Pressure Chamber method made in USA. Because Gardner empirical formula can better describe the relationship between soil water content w and soil water suction S, the wilting coefficient can be estimated by the Gardner empirical formula w=a · S–b (Guo and Shao, 2009). Generally, the wilting coefficient is assumed to be the soil water content when the soil water suction is 1.5 mPa because soil water potential at wilting ranged from -1.0×105 to -2.0×105 m pa, with an average of approximately -1.5×105 m pa (15 bar) (Richards and Weaver,1943). For example, the change of soil water content with soil water suction at different soil depth in caragana (Caragana korshenskii) shrubland of semiarid loess hilly region, see Figure 1, and wilting coefficient varies with soil depth, see table 1. the wilting coefficient varies with soil depth, see the Figure 1 and Table 1.

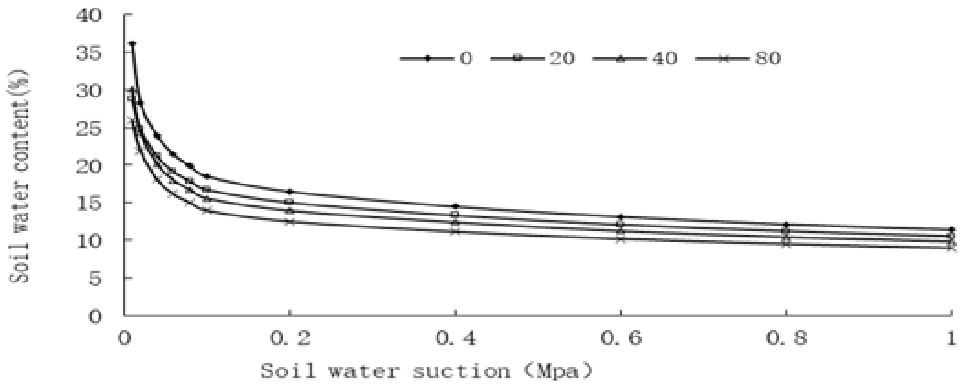

Figure 1: The changes of soil water content with soil water suction at different soil depth in caragana shrubland of semiarid loess hilly region, Guyuan, China. 0, 20, 40, 80 expresses soil depth of 0 cm, 20 cm, 40 cm and 80 cm respectively.

Infiltration depth

Infiltration is the process of water entering the soil in a certain time. After the infiltration process, there are two most important results. One is the increase of soil water content in the unit soil layer cube, which can be used to estimate the soil water supply. Another is the infiltration depth. There are two vertical soil water characteristics cures left on the soil profile. We can use the two vertical soil water characteristics cures to estimate infiltration depth. If we estimate infiltration depth before a rain event, a neutron probe (CNC503A (DR), Beijing Nuclear Instrument Co., China) was used to monitor the changes of field volumetric soil water content (VSWC) with soil depth before a rain and after the rain event because of its high precision [6,12]. If we estimate the changes of soil water content with soil depth at starting time and then the ending time of infiltration process in the soil profile, there is a starting vertical distribution curve of soil water before an infiltration process and an ending vertical distribution curve of soil water after the infiltration process, which are two curves method for estimating soil water infiltration depth. The two curves method was found by Guo in 2004, and used to estimate the depth of infiltration of Caragana shrubland by Guo and Shao in 2009 and Guo in 2014, and named by Guo in 2020 [6,13,14]. There are two vertical distribution curve of soil water after one. The two vertical distribution curve of soil water before and after the infiltration process can be used to determine infiltration depth and soil water supply. The infiltration depth for one rain event or a given time was equal to the distance from the surface to the crossover point between the two soil water distribution curves with soil depth before a rain event and after the rain event, and MID could be estimated by a series of two-curve methods, a set of two-curve methods [6].

Table 1: The changes of wilting coefficient varies with soil depth in caragana shrubland of semiarid loess hilly region of Loess Plateau, China.

Soil depth(cm)	Saturated water content (%)	Field capacity (%)	Wilting coefficient (%)	Available water content (%)
0-5	50.64	25.31	10.32	15
20-25	53.19	21.94	9.79	12.15
40-45	54.16	21.36	8.88	12.48

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80-85	52.38	18.95	8.13	10.82
120-125	54.09	19.55	8.08	11.47
160-165	52.47	20.35	7.67	12.68
200-205	54.6	23.45	8.74	14.71
240-245	56.38	24.99	9.54	15.45
280-285	54.88	24.79	9.22	15.57
320-325	53.88	25.49	9.75	15.74
360-365	55.63	26.67	10.45	16.21
400-405	56.12	26.65	10.07	16.58

Soil water resource use limit by plants (SWRULP)

Natural resources are limited, and so are plants' use of them. The limit is the limit of a plant's use of resources. The resource use limit by plants includes space resource use limit by plants in soil water and nutrient rich regions; soil water resource use limit by plants in water-limited regions and soil nutrient resource use limit by plants in soil nutrient limited regions [7,8]. The soil water resources resource use limit by plants is the water storage in given soil depth. The amount of soil water resources changes with soil depth, weather condition, plant growth and soil water movement in the soil. To understand the sustainable use of soil water resources, there should be a sustainable use indicator of soil water resources, that is the soil water resources use limit by plant (SWRULP) [7,8] and soil water carrying capacity and the kay period of plant water relationship regulation.

Plant root cannot suck soil water unlimitedly in water-limited regions. There is a limit plant use soil water. There are some soil water deficit indices, such as crop water index [15], soil water deficit index, evapotranspiration deficit index, plant moisture deficit index (Shi et al. 2015). Because most of the drought indices are based on meteorological variables [16] or on a moisture balance equation, they do not indicates water deficit accumulation or soil water storage (soil water resource) in root zone [17], they cannot act as a suitable index for distinguishing severe drying of soil in the water-limited regions because soil drought is a nature phenomenon, a water deficit accumulation or a decrease in soil water storage in the root zone soil plant root distribute.

The SWRULP can be defined as the soil water resources in the MID when the soil water content within the MID equals the wilting coefficient. The wilting coefficient is expressed by the wilting coefficient of an indicator plant, which change with soil depth [6-8,11,14]. Because the soil water content changes with soil water suction at different soil depth, and the variation of soil water content with soil water suction accords with the Garden equation, so we can use the Garden equation to fit soil water content and soil water suction data and establish the soil water characteristics curve and then estimate the wilting coefficient at different soil depth (Guo and Shao, 2009, 2013, 2021,2023) [5,13].

Soil Water Vegetation Carrying Capacity

The concept of carrying capacity come from Malthus's paper on the principle of population, which is the cores of sustainable development. Vegetation carrying capacity include space vegetation carrying capacity in soil water and nutrient rich regions; Soil Water vegetation carrying capacity in water limited regions and soil nutrient vegetation carrying capacity in soil nutrient limited regions [7,8]. In the early summer of 2000, the author studied the ability of soil water resources to carry vegetation to solve the problems of soil drought, led to soil degradation, vegetation decay and agriculture failure in water limited region, which determine the reasonable limits of soil water resources and vegetation restoration. The author put forward the concept of soil water vegetation carrying capacity. The concept first appeared in a paper submitted by the author to the 7th Soil Physics Symposium on soil physics and ecological environment construction held by the Soil Physics Committee of Soil Society of China in Yang Ling, Shaanxi, China in December 2000 [3] and then defined soil water vegetation carrying capacity as the ability of soil water resources to carry vegetation [7,8,18,19].

The soil water vegetation carrying capacity (SWVCC) is the capacity of soil water resources to support vegetation, which is the maximum amount of density expressed by indicator plants in a plant population or plant community that soil water resources of a unit area can sustain and allow to grow healthily at a given period and place [5-8,11,14,18, 20]. The SWVCC in a plant community is expressed by indicator plant because vegetation is made up of different plants and includes different communities in a nation or a district or watershed and change with plant species, time scale and location [14]. An indicator plant is the constructive species for natural vegetation or main tree species for afforestation for non-native vegetation. The SWVCC can be estimated by classical carrying capacity equation and plant density - soil water model. According to the classical soil water carrying capacity equation, soil water carrying capacity for vegetation is equal to available soil water resources dividing by individual plant water requirement [7,8,14,21,22]. Because plant water requirement changes with weather condition, plant growth stage and soil water condition and there is not a unified definition of plant water requirement, these factors influence the application of classical soil water carrying capacity equation. According to plant density-soil water model, soil water supply reduces with plant density, at the same time, the relationship between soil water consumption and soil density is a quadratic parabola under All other factors being equal. Simultaneous solution of soil water supply and soil water consumption - plant density relation, the positive solution of the equations is the soil water vegetation carrying capacity [7,8,14].

Key Period of Plant Water Relationship Regulation

After a seed germinates or buds, as the plant grows, it blooms, bears, matures, and eventually leaves fall off and enter a dormant period. After finishing all these stages, plant finished a growth cycle in a growth season or about a year [23,24]. The plant-water relationship in a growth season can be divided into two stages: the sufficient period of soil moisture, in which the soil water resources within the maximum infiltration depth (MID) is more than the soil water resource use limit by plants (SWRULP) and the soil moisture is sufficient for plant growth and plant grow in healthy way, which ensure the sustainable use of soil water resources, and the period of insufficient soil moisture in which the soil water resources within the maximum infiltration depth (MID) is smaller than the soil water resource use limit by plants, which influence the plant growth, cause vegetation decline and did not ensures sustainable use of soil water resources. Drought affects plant growth at all stages of the plant growth cycle, especially at the critical period of plant water relationship regulation because this stage decides the maximum yield and benefits of forest vegetation [25,26]. The plant water relationship changes with soil water supply and soil water condition. The plant water relationship is good relation when the soil water resources in the MID is more than SWRULP and the plant grow well. When the soil water resources in the MID is less than SWRULP, drought affects plant growth severe [27-29]. The plant–water relationship in the soil can be improved by reducing the degree of closed canopy, leaf area index and productivity by cutting or thinning trees or lopping a fruit tree based on the soil water-carrying capacity for vegetation (SWCCV) when the soil water resources within the maximum infiltration depth (MID) equal the soil water resource use limit by plants (SWRULP) in most of water limited region because of the weak self-regulation ability of exotic plants, the relationship between their growth and soil moisture supply and consumption cannot be regulated by self-thinning to adapt to severe soil drought and have to regulate the relationship , so it is necessary to use external force to adapt to severe soil drought.

Based on a three-year study of red plum apricot forest in the 2018 to 2020, the volumetric water content in the 0 to 290cm soil profile is more than the wilting point, and the soil water resources in the MID is more than the soil water resources use limit by plant. The 23- to 25years-old red plum apricot tree grow well and red plum apricot mature, see photo 2. Because Low Spring Temperature, frost and heart-eating harm affect the number of flowering fruit and fruit quality in the Spring, when plant density is equal to the soil water vegetation carrying capacity, the number of leaves and flowers or young fruit is less than the number of leaves and flowers or young fruit when planting density is equal to carrying capacity, so we have to control impact of low temperature and frost on the amount leaf and flowers and peach fruit moth (Carposina sasakii Matsumura) harm on apricot fruit using low-toxicity and high-efficiency cypermethrin and then keep the amount leaf and flowers is equal to or more than the suitable amount flowers or young fruit when plant density equals soil water carrying capacity for vegetation. as for corn or wheat and other crop, we can increase sowing amount to ensure the plant density equals soil water carrying capacity for vegetation. When the plant density is equal to the soil water vegetation carrying capacity, the amounts of leaves and flowers or young fruit is the appropriate amounts of leaves and flowers because the water-plant relationship of the fruit trees generally is regulated by lopping fruit trees, therefore, it is necessary to estimate the right amount of fruit and flowers before regulating. The peach fruit moth (*Carposina sasakii* Matsumura) harm on apricot fruit can be controlled by using low-toxicity and high-efficiency cypermethrin.

Photo 2: Flowers and fruits of red plum apricot in the semiarid loess hilly region, Guyuan, China

Critical Period of Plant Water Relationship Regulation

Although we can estimate soil water vegetation carrying capacity at different time in theory, but soil water vegetation carrying capacity at different time have different meaning for high-quality production because plant water relationship changes with plant grow. The most important soil water vegetation carrying capacity is the soil water vegetation carrying capacity in the critical period of plant-water relationship regulation because which is the most important period and decide the maximum yield and effect in the growing season [6-8,14,22]. The starting time of the critical period of plant-water relationship regulation is the time at which the soil water resources within the MID is equal to the SWRULP. The ending time of the critical period of plant water relationship regulation is the ineffective time of plant water relationship regulation, which is the last day on which we can regulate the plant water relationship based on soil water carrying capacity for vegetation and get maximum yield and benefits. The last day of the critical period of plant-water relationship regulation can be determined by thinning method. Soil and vegetation degradation can be controlled by reducing plant density or branches after a critical period of regulation of plant water relationship.

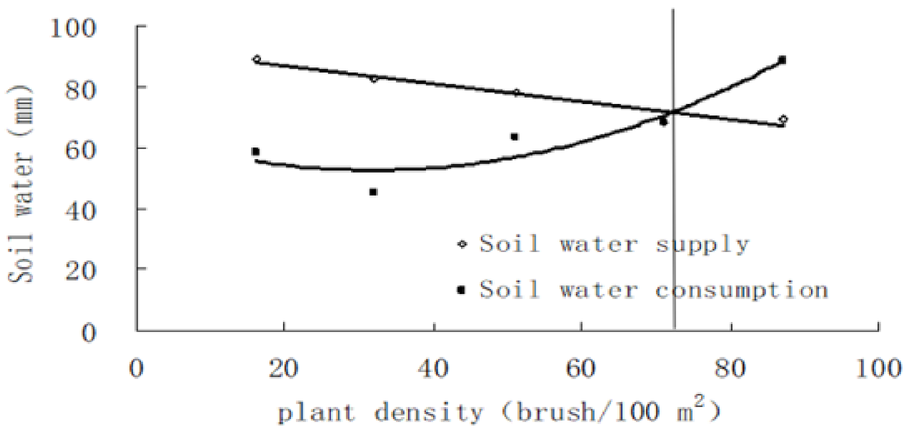

Figure 2: The plant density and soil water supply or consumption relationship and SWVCC in the critical period of plant-water relationship regulation in Caragana shrub (Guyuan, China).

Sustainable Use of Soil Water Resources in Water-Limited Region

Drought-tolerant plants generally have some ability of self-regulation. If the drought lasts less than critical period of plant-water relationship regulation, the water-plant relationship does not need to be regulated. Otherwise, to get the maximum yield and benefit in water limited region, we must estimate the soil water resources use limit by plants, soil water vegetation carrying capacity in the critical period of plant-water relationship regulation to regulate the water-plant relationship based on SWVCC in the critical period of plant-water relationship regulation. As for fruit and crop, Vegetative growth and reproductive growth should be regulated according to the suitable leaf when plant density in the critical period of plant-water relationship regulation is equal to SWVCC and the leaf and fine fruit relation to get high-quality production [7,8,22].

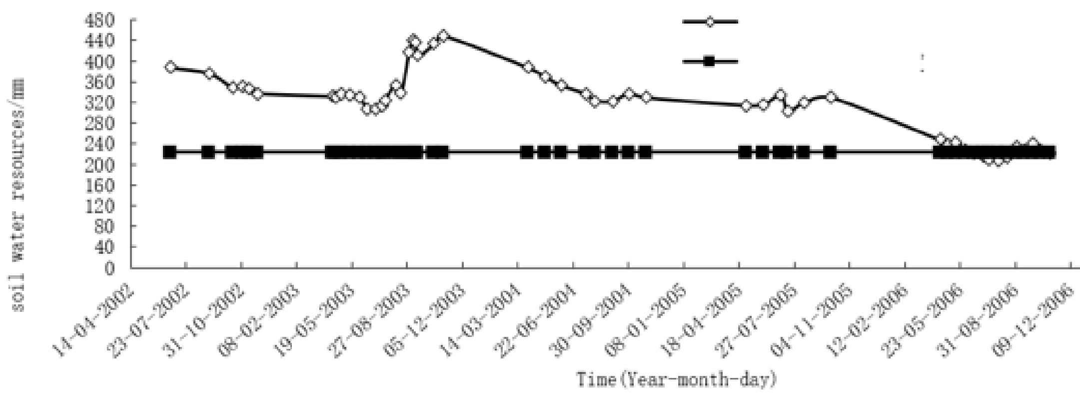

Figure 3: Critical period of plant-water relationship regulation in water-limited region.
The Symbol express available soil water resources
and Symbol express soil water resources use limit by plants in the figure.

Conclusion

When water from precipitation or irrigation, there are two most important results. One is to increase the soil water content in the same soil layer. Another is to estimate the maximum infiltration depth. Soil water resources in maximum infiltration depth of forest, grass or crops land reduce to soil water resources use limit by plants, the plant water relationship enters the critical period of plant-water relationship regulation and the ending time of the critical period of plant water relationship regulation is the ineffective time of plant water relationship regulation, soil dry in the critical period of plant-water relationship regulation severely influences plant growth, maximum yield and benefit. At this time, the plant-water relationship should be regulated on SWVCC in critical period of plant-water relationship regulation to realize the sustainable use of soil water resources, high-quality and sustainable development of grassland and forest, and Agriculture high-quality production. It is necessary to master the change of plant water relation and regulate the plant water relation relationship using the SWVCC in critical period of plant-water relationship regulation of water-limited regions to ensure plant grow well, sustainable use of soil water resources and get the maximum yield and benefit to carry out crops high-quality production and high-quality development of agriculture.

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Additional Information

Competing Financial Interests statement

There are not Competing Financial and non-financial interests.

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