Research Article *Open Access*

Journal of Geoscience and Eco Agricultural Studies

Sustainable use of Soil Water Resources and Agriculture High-quality Development in Water-limited Regions

Zhongsheng Guo

Northwestern A & F University, yangling, China, Institute of Soil and Water Conservation, Chinese Academy of Science and Ministry of Water Resources, yangling, 26 Xinong Road, Yangling, Shaanxi Province 712100, PR China.

Citation: Zhongsheng Guo (2024) Sustainable use of Soil Water Resources and Agriculture High-quality Development in Water-limited Regions. J.of Geo Eco Agr Studies 1(1), 01-08. WMJ/JGEAS-101

Abstract

As population increases and economy develops, there is an increasing demand for quantity agriculture products and services. To meet these kinds of demands, most of the original vegetation had become farmland, plantation or grass land. As plant grows, the plant water relationship had changed to non-equilibrium relationship, led to soil drought, soil degradation, vegetation degradation and crop failure or waste of soil water, which is not good for Sustainable utilization of soil water resources and agriculture high-quality development. After a couple of yeas research, the result showed that plant water relationship must be regulated based on Soil Water Vegetation Carrying Capacity in the critical period of plant water relationship regulation to get the quality and maximum yield and benefit to carry out Sustainable utilization of soil water resources and agriculture high-quality development.

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

Submitted: 01.11.2024 Accepted: 06.11.2024 Published: 13.11.2024

Keywords: Soil water, Goods and Services, Water-limited Area1, Plant Water Relationship, Soil Water Resource use limit by Plants, Soil Water Vegetation Carrying Capacity, Critical Period of Plant Water Relationship Regulation, Sustainable use, High-quality Development

Introduction

M Most of the goods and services that people in the world enjoy are produced by forests, grass and crop. To meet people's increasing needs, most of old forest changed into non-native vegetation and changed the relationship between plant growth and soil moisture, leading to soil dry, soil and vegetation degradation in dry years or soil water resources waste in rainy years For example, along with plant growth, soil drought occurred, resulting in soil degradation and vegetation decline in most areas of the region because the soil water supply mainly from precipitation 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 in a rainy year Chinese loess plateau [1-6]. As plant grows, vegetation decline and eventually desertification in most of the Loess Plateau or soil water resources wastes. This, in turn, affects so il quality, plant growth and its quality and maximum economic and ecological benefits. This is not desirable for the sustainable use of soil water resources and high quality development of vegetation [2-4].

To keep plant healthy growth and get its maximum produce and ecological benefits, water plant relationship must be regulated by reducing plant density or cut some branches at right time to increase soil water supply, reduce evapotranspiration and maintain soil water 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, theory of Soil Water Vegetation Carrying Capacity and Key period of Regulation of plant water relationship. The purpose of the paper is to introduce these theories to realize sustainable utilization of soil water resources and high-quality development in water-limited Regions.

Research Method

When I first thought of the limit of soil water resources to support vegetation in water-limited Regions, I proposed the conception of Soil Water Vegetation Carrying Capacity in 2000 [3]. Because Soil water resource use limit by plants, the theory of Soil Water Vegetation Carrying Capacity and Key period of Regulation of plant water relationship are the most important issue for vegetation restoration, Sustainable use of soil water resources and agriculture high-quality development in water-limited Regions, I had established different plant density of adult and young caragana shrub in semiarid loess hilly region and investigate the precipitation inside and outside of caragana shrub, runoff, soil water content and plant growth, and then analyzed the relationships between plant density and soil water supply and consumption and finish the theory of Soil Water Vegetation Carrying Capacity, Soil water resource use limit by plants and Key period of Regulation of plant water relationship [7,8].

The main estimation equation.

Canopy interception

$CI=P_2- P_1-Sf$

Here, CI is the canopy interception in mm. P_2 is the precipitation outside forest in mm, P_1 is the precipitation inside forest in mm. Sf is Stemflow in mm.

Soil water supply (SWS)

$SWS= P_2\text{-runoff-soil evaporation}$

Here, SWS is Soil water supply in mm. Ci is the canopy interception in mm.

Soil water consumption (SWC)

$SWC=W_2-W_1+ SWS$

Here, SWC is Soil water consumption in mm in given period or the key period of plant water relation regulation in mm. W_2 is the soil water resources at the ending time of given period or the key period of plant water relation regulation in mm. W_1 is the soil water resources at the starting time of given period or the key period of plant water relation regulation'

Soil water resources

Soil water resources is the total of Soil water resources in given soil depth.

$SWR= \int_0^H SWCdh$

Here, SWR is Soil water resources in mm. H is soil depth in cm.

Soil water resource use limit by plants

$SWRULP= 10 * \int_0^{hm} WcDh$

Here, SWRULP is Soil water resource use limit by plants in mm. Wc is wilting coefficient in mm. H is soil depth in cm.

Results

Soil Water Resources

Soil water resources is the total water in the soil body, which are renewable water resources and components of water resources. The term Soil Water Resources first put forward by Budagovski in 1985 after Lvovich proposed the concept of overall soil moistening in 1980 [9,10]. 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].

Root Vertical Distribution

Plant root fix itself in soil body and suck soil water and nutrient for plant lives. Root is the most important organ for terrestrial 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 distributed 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

Soil Water Resource use Limit by Plants (SWRULP)

Soil water resources are limited, and so are plants' use of them. The limit is the limit 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 [12,13]. The soil water resources resource use limit by plants is the soil water storage (resources) in given soil depth.

Plant root cannot suck soil water unlimitedly in water-limited regions because there is a limit plant use soil water. There are some soil water deficit indices, such as crop water index soil water deficit index, evapotranspiration deficit index, plant moisture deficit index. Because most of the drought indices are based on meteorological variables or on a water balance equation, they do not indicate water deficit accumulation or soil water storage (resources) in root zone, 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 resources in given depth soil plant root distributes [14-16].

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) and soil water carrying capacity and the kay period of plant water relationship regulation.

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. 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 equation to fit soil water content and soil water suction data and then establish the soil water characteristics curve and then estimate the wilting coefficient at different soil depth [17].

Variation of Soil Water Content with Soil Water Suction

Before estimate 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. 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., Jappan, or Pressure Chamber method made in USA.

Because Gardner empirical formula can better express the relationship between soil water content w and soil water suction S, the wilting coefficient can be estimated by the Gardner empirical formula $w=a \cdot S^{-b}$ [17].

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 -1.0×10^5 to -2.0×10^5 mPa, with an average of approximately -1.5×10^5 mPa (15 bar) (Richards and Weaver,1943). For example, the change of soil water content with soil water suction in semiarid loess hilly region, and wilting coefficient varies with soil depth. The wilting coefficient varies with soil depth.

Infiltration and Infiltration Depth

Infiltration is the process of water entering the soil in a certain time. After the infiltration process, there are two cures expressing vertical distribution of soil water left on the soil profile. We can use the two cures to estimate infiltration depth. Before estimating infiltration depth, 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 according to weather report and after the rain event because of its high precision [18,19,6].

If we estimate the changes of soil water content with soil depth at starting time and 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. Two curves method was found by Guo in 2004, and used to estimate the infiltration depth of Caragana shrubland, and named by Guo in 2020 [17,8].

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 for one rain event or a period. 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 the MID could be estimated by a series of two-curve methods, a set of two-curve methods.

Photo 1 Flowers and fruits of red plum apricot in the semiarid loess hilly region (Guyuan, China)

Soil Water Vegetation Carrying Capacity

The idea of carrying capacity came from Malthus's paper on the principle of population, which is the core of sustainable use of natural resources and high-quality development [12,13].

In the early summer of 2000, the author studied the the ability of soil water resources to carry vegetation to solve the problems of soil drought, soil degradation, vegetation decay and agriculture failure in water limited region and put forward the concept of soil water vegetation carrying capacity. The concept first occurred in a paper submitted to the 7th Soil Physics Symposium on soil physics and ecological environment construction held by the Soil Physics Committee of Soil Society of China and then defined soil water vegetation carrying capacity as the ability of soil water resources to carry vegetation [3,7,20,12,13].

The SWVCC is the capacity of soil water resources a unit area to support vegetation, which can be expressed by the maximum amount or density expressed of indicator plants in a plant population or plant community. The soil water vegetation carrying capacity is the soil water resources of a unit area can sustain and allow to grow healthily at a given period and place [7,21,11-13].

Because vegetation is made up of different plant population or communities in a nation or a district, so vegetation includes different plant population or communities, and change with plant species, time scale and location [8]. An indicator plant is the con structive 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 watermodel. 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 [22,8]. 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 set is the soil water vegetation carrying capacity [8]. see figure 1

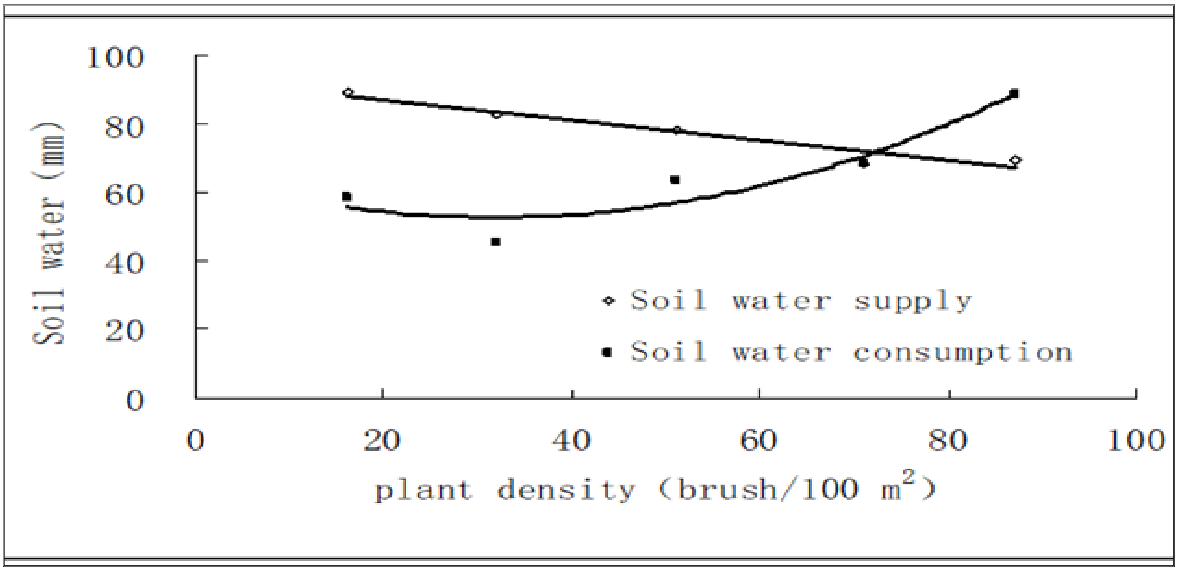

Fig.1 The change of soil water supply or consumption with plant density in the critical period of plant-water relationship regulation in Caragana shrubland (Guyuan, China)

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 vegetation and high-qualility production. 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 the soil water vegetation carrying capacity decide the maximum yield and effect in the growing season [8].

Critical Period of Plant Water Relationship Regulation

Plant water relationship changes with time. 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. The plant water relationship can be divided into two stages: the period of sufficient soil moisture, in which the soil water resources within the MID is more than the 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. The period of insufficient soil moisture in which the soil water resources within the MID is smaller than the soil water resource use limit by plants, which influence the plant growth, cause vegetation degradation and did not ensure sustainable use of soil water resources.

Drought affects plant growth, especially at the critical period of plant water relationship regulation because at this stage, soil water vegetation carrying capacity decides the maximum yield and benefits of vegetation. 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. 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 SWCCV when the soil water resources within the MID equal the 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 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 carrying capacity of vegetation, 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 heart-eating (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 carrying capacity for vegetation, the amoumts 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 heart-eating (Carposina sasakii Matsumura) harm on apricot fruit can be controlled by using low-toxicity and high-efficiency cypermethrin.

As plant growth, the soil water resources reduce. When the soil water resources reduce to the soil water resource use limit by plants (SWRULP), 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 plant water relationship regulation. For fruit and crop, the ending time of the critical period of plant water relationship regulation can be decided by the stop time of fruit expanding. the critical period of plant water relationship regulation is the foundation of vegetation and location. For example, in semiarid loss hilly region of China, the ending time of the critical period of plant water relationship regulation for red plum apricot is 15 July because on which red plum apricotfruit stop expansion. The ending time of the critical period of plant water relationship regulation in cara gana shrub is the end of September because caragana shrub in the semiarid region mainly used for soil and water conservation in and the rainy season finished in the end of September. The Soil degradation and vegetation degradation cannot be controlled by reducing plant density or branches after a critical period of regulation of plant water relationship.

Sustainable use of Soil Water Resources Agriculture High-quality Development

Drought-tolerant plants generally have enough ability of self-regulation to deal with soil drought. If the soil 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 and soil water vegetation carrying capacity after estimating maximum infiltration depth and soil water supply and regulate the water-plant relationship based on SWVCC in the critical period of plant-water relationship regulation. As for fruit tree 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 realize agriculture high-quality development [12,13].

Conclusion

Soil water resources is an important part of water resources in water-limited regions. Management of Soil water resources is the most important part of high-quality development. When 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 critical period of plant-water relationship regulation, the ending time is the ineffective time of plant-water relationship regulation, such as 15 July in red plum apricot and end of September in Caragana shrub. Soil water in the critical period of plant water relationship regulation severely influences plant growth and decide the quality and maximum yield and benefit. At this time, the plant water relationship should be regulated based on SWVCC in critical period of plant-water relationship regulation to realize the sustainable use of soil water resources and Agriculture high-quality development

high-quality development.

Because the farming land is large and there are many kinds of crops, It is necessary to master the change of plant water relation and regulate the plant water relation relationship and get the qulity and maximum yield and benefit using SWVCC in critical period of plant-water relationship regulation of water-limited regions and to ensure sustainable use of soil water resources and Agriculture high-quality development.

Acknowledgements

This project is supported by National key Research & Development plan (Project No.2016YFC0501702) and the National Science Foundation of China (Project No: National Science Foundation of China,42077079,41071193).

Additional Information

Competing Financial Interests statement:
There are not Competing Financial and non-financial interests

References

1. Yang WZ, Yu CZ (1992) Regional control and evaluation in Loess Plateau. Science Press, Beijing 190-297.
2. Li YS (2001) Effects of forest on water cycle on the Loess Plateau. Chin. Chin. J. Natural RESOUR 6: 427-432.
3. Guo ZS, Shao MA, Zhang YP, Wu QX (2002) An Layer-dividing method to soil water in forest land, Proceedings of soil physics and ecological environment construction, edited by Shao MA, Shaanxi Science and technology press 75-79.
4. Chen HS, Shao MA, Li Y (2008) Soil desiccation in the Loess Plateau of China, Geoderma 143: 91-100.
5. Guo ZS, Shao MA (2013) Impact of afforestation density on soil and water conservation of the semiarid Loess Plateau. J. Soil water conserv 68: 401-410.
6. Guo ZS (2020) Estimating Method of Maximum Infiltration Depth and Soil Water Supply. Scientific Reports 10: 9726.
7. Guo ZS, Shao MA (2003) Carrying capacity of soil water for Vegetation in the Loess Plateau, In:

Water-saving agriculture and sustainable use of water and land resources. Shaanxi Science and Technology Press 704-11.

8. Guo ZS (2014) Theory and Practice on Soil Water Carrying Capacity for Vegetation. Chinese Science Press: website at www.geobooks.com.cn.
9. Budagovski AI (1985) Soil water resources and water supplies of plant cover, Vodnye. Resursy 4: 3-13.
10. Lvovich MI (1980) Soil trend in hydrology. Hydrological Sciences Bulletin. 25: 33-45.
11. 11. Guo ZS (2011) A review of soil water carrying capacity for vegetation in Water-limited regions. Chinese Journal of Forestry Sciences 47: 140-144.
12. Guo Z (2021a) Soil water carrying capacity for vegetation. Land degradation development https:// DOI: 10.1002/LDR.3950.
13. Guo Z (2021b) Soil hydrology process and Sustainable Use of Soil Water Resources in Desert Regions. Water 13: 2377.
14. Palmer WC (1968) Keeping track of crop moisture conditions, nationwide: the new crop moisture index. Weatherwise 21: 156-161.
15. McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales. In: Eighth Conference on Applied Climatology. American Meteorological Society, Anaheim, CA 179-184.
16. Martínez-Fernández J, González-Zamor A, Sánchez N, Gumuzzio A (2015) A soil water-based index as a suitable agricultural drought indicator. J. Hydrol 522: 265-273.
17. Guo ZS, Shao MA (2009) Soil water infiltrating process in afforested land on slopes of semiarid region of loess plateau. ACTA pedologica Sinica 46: 953-958.
18. Wang GY, Shi XP, Zhang JH, Liang WL (2000) A study on the comparison of measuring soil water content with TDR, neutron probe and oven dry. Chin. J. Agr. University of Hebei 23: 23-26.
19. Evett SR, Schwartz RC, Casanova JJ, Heng LK (2012) Soil water sensing for water balance, ET and WUE. Agr Water Manage 104: 1-9.
20. Wang Y, Yu P, Xiong W, Shen Z (2008) Water-yield Reduction after Afforestation and related Proicesses in the semiarid Liupan Mountains, Northwest China. Journal of the American Water Resources Association 44: 1086-1097. west China. Journal of the American Water Resources Association 44: 1086-1097.
21. Xia YQ, Shao MA (2008) Soil water carrying capacity for vegetation: A hydrologic and biogeochemical process model solution. Ecological Modelling 214: 112-124.
22. Cohen JE (1995) Population Growth and Earth's human carrying capacity. Science 54: 213-229.
23. Guo Z (2023) Forest restoration, resources sustainable use and high-quality sustainable management. Glob J Ecol 8: 007-010.
24. Mishra AK, Singh VP (2010) A review of drought concepts. J. Hydro 391: 202-216.
25. Ning T, Guo ZS, Guo MC, Han B (2013) Soil water resources use limit in the loess plateau of China. Agri Sci 4: 100-1005.
26. Price D (1999) Carrying capacity reconsidered. Popul Enviro 21: 5-26.
27. Richards LR, Weaver (1943) Fifteen atmosphere percentage as related to the permanent wilting percentage. Soil Science 56: 331-339.
28. Steiguer JED (1995) Three theories from economics about the environment. Bioscience. 45: 552-557.
29. Young CC (1998) Defining the range. The development of carrying capacity in management. J Hist Biol 31: 61-83.

.