Vegetation Carrying Capacity of Soil Water

Guo Zhong-sheng

Institute of Soil and Water Conservation. CAS
Content

1. Background
2. Definition of vegetation carrying capacity of soil water, VCCSW
3. Method of Determining the VCCSW
4. Use of the VCCSW in Practice
Background

Sustainable forestry

The kinds and increment of forest vegetation is the bases of using forest resources. Because increment or growth of forest, $G(t, x)$, is the functions of time, $t$, single weight or volume, $Z(v)$ and the density of plantation, $x$, written in the form: 

$$G(t, x) = R(t) \times Z(v) \times F(x)$$

We should first consider the density of trees and make sure whether the density of plantation is within the limits of land resources to bear in order to realize the sustainable forestry, especially in the area where the natural resources such as water resources is in shortage.
1. Because of reclamation, civil war and overgrazing, the native forest vegetation is seriously destructed. The quality of forest is reduced, and forest land change into grassland and grassland change into farmland. Forest coverage become lower, the original environments is gradually degraded, soil and water loss become worse and worse.

2. Forest vegetation can effectively conserve soil and water, and improve the degraded environment, so large-scale plantation has been afforested since 1950.

3. About 10 years later, soil degradation appeared in the form of soil desiccation in grassland and forest land, which are widespread in the Loess Plateau.
4, Soil degradation is the consequence of soil desiccation. Soil desiccation influences not only plant growth and development, but also the stabilization, ecological, economic and social benefits of artificial forest.

5, In fact, soil desiccation is the misadjusted relation of forest to water resources. Water balance should be kept in order to realize sustainable development.
There are two ways to solve the question:

1. To use the method - artificial rainfall or irrigation to meet the need for forest vegetation take and use. Theoretic base is the ecological water demand.

2. To reduce the size of plant population or community and control productivity, based on the soil water condition, soil water’s ability to support vegetation.
Background

Water resources per capita in China is a quarter of average world level and water resources per capita on the Loess Plateau is a quarter of water resources per capita in China. Because of water resources shortage and low productivity and economical benefit of forest vegetation on the Loess Plateau, the best measure to control soil desiccation is to reduce the size of plant population or community on the vegetation carrying capacity of soil water.
Carrying Capacity

History of the Study

The study of the carry capacity can be traced to Tomas Robert Malthus.

Society has the ability to increase agricultural production only at an arithmetic rate while the number of mouths to be fed increases at a geometric rate. Hence, at some point, population is likely to outstrip food supplies with calamitous results.
Carrying Capacity

Expression

In ecological terms, the carrying capacity of an ecosystem is the size of the population or community that can be supported definitely upon the available resources.

In the context of sustainability, carrying capacity is the size of the population that can be supported definitely upon the available resources.

Vegetation carrying capacity is the finite size of the population or community that can be supported by land resources without degrading the natural environment.
Carrying Capacity

Two conditions

**Energy:** plant root can take and use soil water at the scope of energy from about 0 bar (field capacity soil water) to 15 bar (permanent wilting point)

**Soil depth** plant root only take and use soil water in the range of soil depth (the root zone soil layers, which is the function of plant species and age)
Water cycle in Forest vegetation ecosystem

- Precipitation
- Plant transpiration
- Canopy evaporation
- Soil evaporation
  - Prohibited by canopies
- Runoff along the slope
- Neighbouring soil interflow in
- Neighbouring soil interflow out
- Canopy interception
- Infiltrating into soil
- Soil vaporation
  - SW resources
    - SW resources
    - Per area unit
    - Deep Leakage
    - underground water
    - Per area unit
Water cycle

Soil water supply and Soil water consumption

Precipitation, P(mm)

Throughfall + Stemflow + Interception

Per unit area

Plant transpiration, TR(mm)

Canopies vaporation

Soil evaporation, SE(mm)

runoff along the slope
Or changing into soil

interflow in

Soil water storage
Per unit area

runoff along the slope

interflow out

Leakage

Move up

underground water
Definition

Vegetation Carrying Capacity of Soil Water

Vegetation carrying capacity of soil water is soil water-driven or soil water-limited vegetation carrying capacity. It is defined as the ability of soil water to carry vegetation. The limit is the largest density of the plant population under the condition that soil water consumption is equal to soil water supply in the root zone soil layers.

The factors influence VCCSW includes geography location, landform, climate, soil and the like,
Plant growth

Growth is the process by which a plant increases in the number and size of leaves and stems. Plants get their energy from the sun through photosynthesis which is the process where the green pigment in the plant's leaf absorbs energy from sunlight and, using this energy, water, and carbon dioxide, produces O₂ and simple sugars. The plant then uses these sugars to make more complex sugars and starches, to make cellulose and hemicellulose for cell walls or with N, to make proteins.

How the plant uses its energy depends on the developmental stage of the plant and on environmental conditions.
Determining the VCCSW limiting factors

The carrying capacity of an area is usually constrained by limiting factors - such as water, nutrients, etc.

On the Loess Plateau and N China, excluding irrigation area and wetland where the groundwater level is high, Soil water, mainly derived from seasonal rains which shows a high temporal and spatial variability within a year and among years, is the most important limiting factor.

Although there are many factors which influence vegetation carrying capacity of soil water, there is a factor (available soil water resources) which can be used to determine the VCCSW.
Determining the VCCSW

Three steps

Hypothesize that soil water supply is the function of density, written in the form: \( SWS = F(x) \), and soil water consumption is also the function of density: \( SWC = g(x) \)

Establish the simultaneous equation set

\[ SWS = F(x) \quad \text{............... (1)} \]
\[ SWC = g(x) \quad \text{............... (2)} \]

Under the condition that soil water consumption is equal to soil water supply, find the solution of the equation set, the root is the VCCSW.
Use of VCCSW in practice

Three possibility results

If the density of trees is bigger than the VCCSW, forest plants overuse the soil water resources, the soil desiccation become worse; the water relation of forest vegetation need to be regulated;

If the density of trees is equal to the VCCSW, forest rationally use the soil water resources, It is good for sustainable forestry;

If the density of trees is smaller than the VCCSW, the soil water resources can not be rationally used, we should change the type of forest vegetation or increase the density of plantation.
Case Study

Shanghuang Eco-experimental Station

Latitude: 35’ 59” - 36’ 03” N, longitude: 106’ 26” -106’ 30” E in the semi-arid regions of the Loess Plateau.

g geomorphology: loess hilly

Soil is Huangmian soil

Soil depth $\geq 60$ m
Study Site

Monthly and Yearly Distribution of Air Temperature

$y = 0.1506x - 292.61$

$R^2 = 0.6696$
Study site

Monthly and Yearly Distribution of Precipitation

![Graph showing the monthly and yearly distribution of precipitation.](image)
Research Object

Artificial Caragana (*Caragana microphylla*) forest

- forest is consisted of one dominant species
- Age of stand\(_1\), even-aged pure stands (16-year-old forest)
- Age of stand\(_2\), even-aged young-growth stands
- Photo taken in 2006

16-year-old in 2002
Photo taken in 2006

sowing in 2002
Photo taken in 2006
Measuring canopies interception

Throughfall

Rain gauge
Runoff measuring
Standard runoff plot (1)

aluminum access tube

20 m

5 m
Runoff measuring

Standard runoff plot (2)
Calculating Depth of wetting soil and infiltration

when measuring the vertical distribution of soil water content before and after a rain event:

Infiltration depth of a rain even is the distance from the surface (0 cm) to the joint of two curves (vertical distribution of soil water content)

\[
F_t = \int_0^l \left[ \theta(x, t) - \theta(x, 0) \right] dx
\]
The rainfall in 2003 (623.3 mm) is close to the biggest value of 634.7 mm in 1984.
Deepest Infiltrating Depth

Infiltration Depth change with precipitation and time

Biggest Infiltration depth is 2.7 m
Some Important Equation

Case study

Canopy interception, \( I = P_2 - P_1 - \text{Stemflow} \)

where \( P_2, P_1 \), rainfall outside or inside of forest

The evapotranspiration is small and approach to 0 when it is raining and infiltrating depth is smaller than measuring depth, the amount of leakage gives 0, so

Soil water supply, \( \text{SWS}(\text{mm}) = \sum P_2 - \sum \text{ET}_1 - \sum I - \sum \text{Runoff} - \sum \text{leakage}; \)

\( \text{ET}_1 \), evapotranspiration when it is raining
Some Important Equation

Case Study

The distance soil water through the soil from one side to another side in the same direction is smaller and the rainfall uniformly distribute in the study plot, although soil water flow in soil to the plot is different from soil water flow out from the plot, but the flow_{in} approaches to flow_{out}.

Soil water consumption, \( SWC \text{ (mm)} = \sum \text{ initial soil water storage} - \sum \text{ final soil water storage} + \sum SWS - \sum \text{ leakage} \)
SWS is a linear relation to density:
SWS = 0.0021x + 63.562

SWC and density relation is parabola and can be written in the form:
SWC = 0.000001x^2 − 0.0023x + 66.81

Find the solution of the simultaneous equation set, the root is 8115 clumps per hectare.

SWS and SWC in root soil layer change with density (2002)
Use of VCCSW in practice

Foundation

The plant species to be selected is the dominant species because the dominant plant not only influences growth of the other plants but also determines the functions of the plant community.

If the VCCSW is too small to accept, which means that the type of forest vegetation is not suitable to this kind of conditions, all of the dominant plants need to be fell. There is an exception in desert or in arid region where the main task is to conserve the biology diversity and the ecological environments because of the limits of natural resources.
Use of VCCSW in practice

Standard Foundation

If the value of VCCSW is considerable big and can be accepted, then determine the thinning trees, optimal use direction and the use intensity by comparing the possible results of different uses according to the vegetation form, ecological function and productivity of forest vegetation when the density is equal to VCCSW.
Use of VCCSW in practice

Case Study

1. Thinning trees: the density of trees \(VCCSW=\frac{8700-8115}{585}=585\), that means 585 clumps Caragana per hectare need to be thinned in order to avoid soil from degrading in root soil layers.

2. Determine the optimal use direction and use intensity

   Caragana is a shrub with about 2 meters high, it does not produce timber.

   The increment of aboveground biomass (dry) per hectare per year is 1.43 ton, which approaches to the standard of Fuel forest produce (1.5 ton), it is a better fuel forest
Use of VCCSW in practice

Case Study

Leaf and forage produce (fresh output) is 3.02 ton, which is approach to the output of high-yield grassland, and belongs to a better grassland.

Seed produce (dry) is 51 kg, and the income is 612 yuan/hectare, which is smaller than other economic forests in the same region. It is a bad economic forest.

Caragana forest is a good soil and water conservation forest.