Environment, Resource and Ecology Journal (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/erej.2022.060504
ISSN 2616-3756 Vol. 6 Num. 5

Effect of grazing strategy on soil moisture and vegetation biomass

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Keywords: Differential equations, grazing strategies, mathematical models

Abstract: In this paper, firstly, five grazing methods were measured in two dimensions of time and space to complete the quantification of variables. It is found that there is a chain propagation effect between grazing, vegetation biomass and soil moisture through mathematical derivation, and the single effect between grazing and vegetation biomass is described by Woodward's equation, and the effect model of grazing mode on vegetation biomass is obtained by inverse solution of differential equation; the effect model between vegetation biomass and soil moisture is reached through soil-vegetation-atmosphere equation. The relationship between vegetation biomass and soil moisture is reached through the soil-vegetation equilibrium equation, and the model of the effect of grazing on soil moisture is fitted in the software based on the aforementioned model of the effect of grazing on vegetation biomass through the chain effect. The mathematical model of the effects of different grazing strategies on soil moisture and vegetation biomass was thus obtained.

1. Introduction

Grassland accounts for about 25% of the global land area, and is the largest terrestrial ecosystem in China, with a wide distribution area and the second largest proportion of the world's grassland area. The Xilinguole Grassland in Inner Mongolia is located in the east-central part of Inner Mongolia Autonomous Region, within the Xilinguole League[1-2], and is an important part of the large temperate grassland in northwest China, with a total area of 179,600 square kilometers, and is the main natural barrier in north China, and an important place for the vast number of northern herdsmen to survive[3]. It has an important and strategic significance to guarantee national ecological security, border stability, national unity and promote sustainable socio-economic development, and increase economic income for farmers and herdsmen[4-5].

Since the 18th Party Congress[6], grassland protection and restoration work has achieved remarkable results. But the current grassland ecosystem in China as a whole is still relatively fragile. The General Office of the State Council issued on March 30, 2021 "General Office of the State Council on strengthening grassland protection and restoration of a number of opinions" pointed out that the goal of grassland restoration is to 2025[7-8], grassland protection and restoration system is basically established, grassland comprehensive vegetation cover stable at about 57%,; by 2035, grassland comprehensive vegetation cover stable at about 60%; by the middle of this century, degraded grasslands get Comprehensive treatment and restoration, the formation of a new pattern of harmonious coexistence of man and nature[9-10].

2. Model building and solving

We address two main issues: (1) quantification and preparation of grazing strategy as a variable; (2) modeling of soil moisture and vegetation biomass, respectively.

According to the requirements, this paper firstly prepares the independent variables, and splits the grazing strategy into two aspects: grazing method and grazing intensity. For grazing method, the five grazing methods given in the question (year-round continuous grazing, closed grazing, zoned grazing, light grazing and long term rest) are measured in two dimensions: time and space. In the spatial dimension, the variables were ranked from strong to weak in order of continuous grazing, light grazing, long-term resting grazing, zoned grazing, and no grazing; for grazing intensity, the variables were classified as control, light, moderate, and heavy according to the information given in the question.

The first idea of this paper is to set the grazing strategy as 0-1 variable, and get two results by controlling the presence or absence of grazing, so as to exclude the influence of precipitation and soil evaporation, and thus get the influence of grazing strategy on soil moisture, after the algorithm fitting the model effect is not good, so we turn to the second mathematical derivation idea.

There is a chain propagation effect between grazing, vegetation biomass and soil moisture, and grazing indirectly affects soil moisture by affecting vegetation biomass. Therefore, this problem inverse deduces or fits the impact model required by the topic by establishing the mathematical link between each chain link, and the single side effect between grazing and vegetation biomass is described by Woodward's formula, and the grazing effect on soil moisture is obtained by inverse solving the differential equation The model of the effect of grazing on vegetation biomass is obtained by solving the differential equation; the relationship between vegetation biomass and soil moisture is reached through the soil-vegetation-atmosphere water balance equation, and the model of the effect of grazing on soil moisture is fitted in the software based on the aforementioned model of the effect of grazing on vegetation biomass through the chain effect. The results are shown in the figure 1.

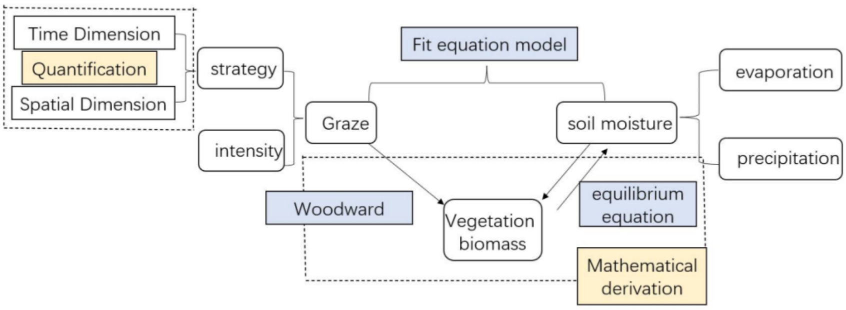

Figure 1: Solving ideas diagram

2.1 Data pre-processing and description

Soil moisture data are taken from the title annex, where the data period is from January 2012 to March 2022 and the measurement period is one month. Soil moisture, or soil water content, is generally referred to as the absolute soil water content, i.e., the number of grams of water contained in 100 g of dried soil, also known as soil water content. In this paper, indicators are extracted from the soil moisture content in Annex 3, using 10 cm of moisture data from each testing time in the solution process of the first question. The extracted index data were imported into SPSS software, and the outliers were identified using the 3σ principle, i.e., the probability in (μ-3σ, μ+3σ) is 0.9973, which can be considered as outliers beyond that range, and the outliers were identified using box plots in SPSS software, followed by descriptive statistics .The results are shown in the figure 2.

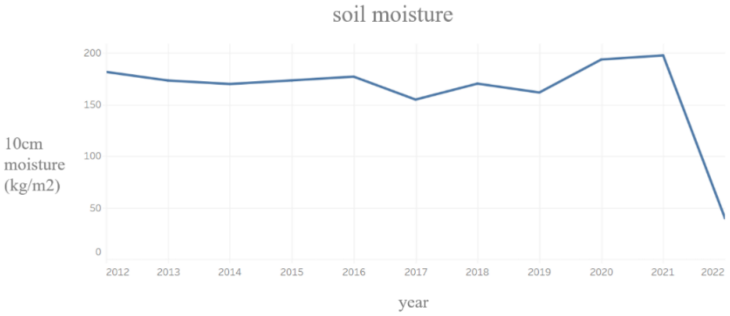

Figure 2: Time series plot of soil moisture

According to the vegetation biomass data, in order to visualize the status and changes of vegetation biomass under different grazing conditions, the data samples were initially processed in this paper, firstly, the data were grouped according to the sample data treatment groups (no grazing, light grazing, medium grazing and heavy grazing), useless indicators such as plant species name, plant community function, grazing plot and clump width were deleted, and according to the definition of vegetation biomass, it refers to the total amount of living organic matter (dry weight) per unit area at a certain time, so the dry weight indicator was selected, and the data were summed for each group on the same date to obtain the processed vegetation biomass data, and bubble plots were drawn for descriptive statistics. The results are shown in the figure 3.

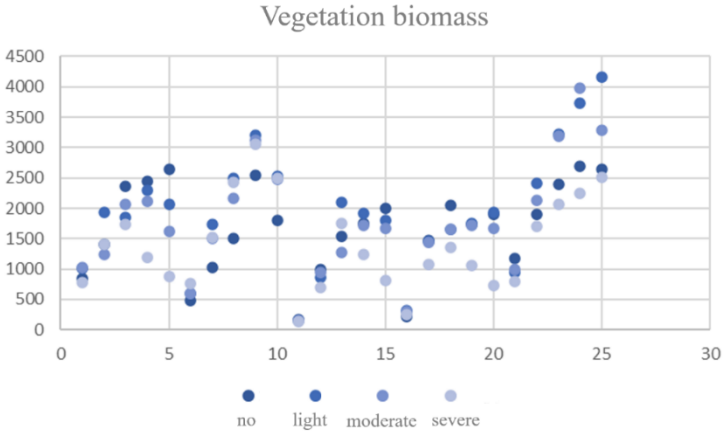

Figure 3: Vegetation biomass under different grazing practices

2.2 Model Building

The analysis from the mechanism point of view refers to the mathematical point of view to derive the results based on the formulae derived from scientific theories.

With regard to the grazing method, the data from Annex 5 "Green Vegetation Cover" for about two years can be consulted to know that there is no vegetation cover in Xilingole grassland from November to March of the following year. Only the vegetation cover from late May to early October is above 0.1. Annex 8 "Climate of Xilinguole League" shows that the average temperature of

Xilinguole grassland is above 0 ° only from May to September, and the precipitation is also concentrated in this time period. From Annex 15, "Community structure monitoring data set of typical grassland rotational grazing sample sites in Xilinguole League, Inner Mongolia Autonomous Region", it can be seen that the current grazing period also happens to be concentrated from the end of May to the beginning of September. Considering that temperature and precipitation are the fundamental factors for plant growth, and that winter is cold and not suitable for plant growth, and that there is no data on winter grazing, this paper considers that grazing is firstly excluded from year-round grazing, and only grazing and resting are considered from late May to late September. At this time, the climate is suitable for the growth of forage grass, and it is assumed that the climate conditions are ideal, and only the effect of grazing on vegetation biomass is considered.

After analysis, grazing will directly affect vegetation biomass, and vegetation biomass will affect soil moisture, but grazing will not directly affect soil moisture, but indirectly affect soil moisture through vegetation biomass. Therefore, the effect of grazing method and intensity on vegetation biomass is analyzed first.

From the extended reading given in the question, for the relationship between grazing and plant growth, Woodward et al. developed a simple model to describe the role of livestock carrying rate on vegetation biomass from one side under the condition that only the effect of grazing is considered.

$$\frac{dw}{dt}=0.049w\left(1-\frac{w}{4000}\right)-0.0047Sw \tag{1}$$

where w is the vegetation biomass and s is the livestock carrying rate per unit area.

By solving the differential equation inversely, by solving the differential equation, we obtain the following model. The results are shown in the figure 4.

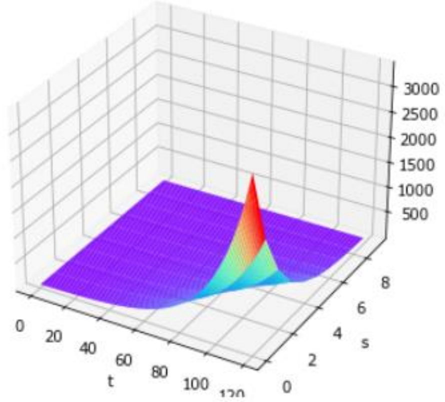

Figure 4: Schematic diagram of differential equation model

According to the grazing duration of four months and 120 days, and the grazing intensity is defined from 0 to 8 according to the definition of the topic, the model of the change of vegetation biomass with grazing intensity can be obtained, and the following figure 5-8 shows the visualization of the model:

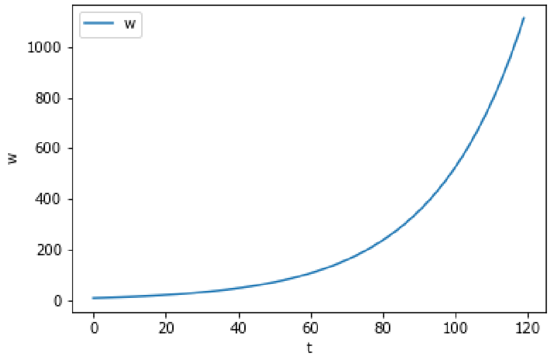

Figure 5:s=0

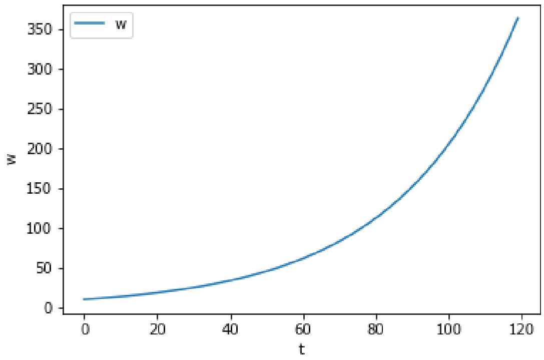

Figure 6:s=2

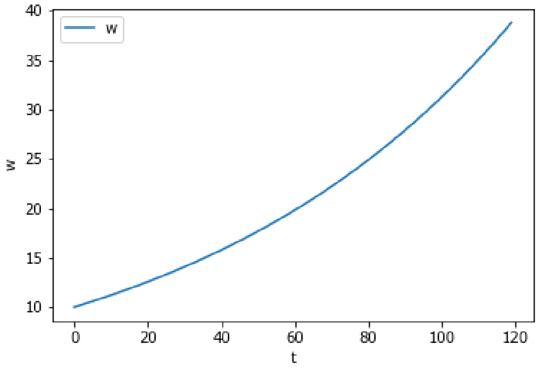

Figure 7:s=4

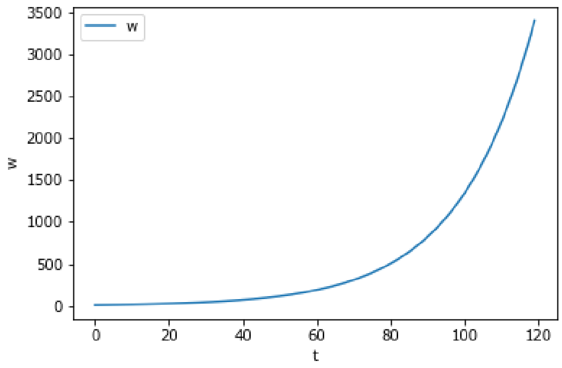

Figure 8:s=8

For the relationship between vegetation biomass and soil moisture, refer to the soil water content-precipitation-surface evaporation model in the extended reading given in the question. The variable P represents precipitation in the pasture area, β is soil water content (which can be considered as soil moisture in the analysis of this question), α is soil cover, w is the amount of grass formation, and $G(w)$ represents the cover of the grassland:

$$\frac{d\beta}{dt} = P - E(\alpha) \tag{2}$$

$$G(w) = (1 - e^{-\varepsilon_g w / w^{\wedge}}) \tag{3}$$

The mathematical derivation is based on the existing formula, and the model formula is first integrated by

$$\int d\beta = \int P dt - \int E(\alpha) dt \tag{4}$$

and known,

$$E(\alpha) : \alpha = \alpha^* G(w) = \alpha^* (1 - e^{-\varepsilon_g w / w^*}) \tag{5}$$

We integrate both sides of the equation separately for time t to obtain:

$$\beta = \int P \, dt - \int E(a) dt \tag{6}$$

We take a month of thirty days for calculation. $\int P\, dt$can be regarded as monthly precipitation and $\int E(a)dt$can be regarded as monthly evapotranspiration. Knowing that evapotranspiration is related to vegetation cover, we use nonlinear least squares to fit the relationship between evapotranspiration and vegetation cover by using the evapotranspiration and vegetation cover data for eight months from March to October 2021

$$\int E(a)dt = C_1(a^{C_2}) + C_3 + C_4 \tag{7}$$

The fit yieldsC_1 is 53.02355616 C_2 is 0.15171168 C_3 is -20.88919818. Considering the effect of temperature on evaporation, we add the temperature variable C_4against the following table 1.

Table 1: Comparison table of temperature variables

March	April	May	June	July	August	September	October
0	0	2	7	10	-5	-5	-5

When the temperature effect is not considered, i.e., C4 is set to 0, the fitting results are as follows figure 9:

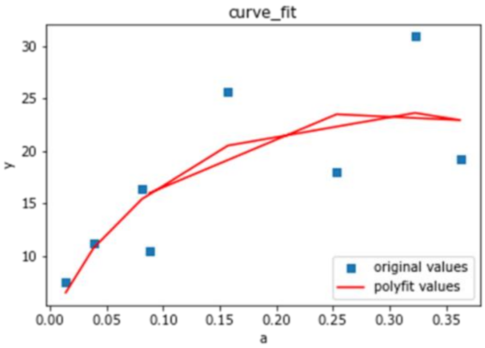

Figure 9: No temperature fitting results

We approximated the relationship between vegetation area and vegetation quantity as proportional. The equation for the relationship between vegetation cover and vegetation biomass is as follows.

$$a = kw \tag{8}$$

A is the vegetation cover, w is the vegetation biomass, and k is the correlation coefficient. Evapotranspiration is related to vegetation biomass as follows.

$$\int E(a)dt = 53.02(kw)^{0.15} - 20.89 + C_4 \tag{9}$$

We also fitted the link between the number of precipitation and evaporation for many years from March to October, excluding the case of snowfall in winter and low temperature evaporation, we found a roughly linear relationship between precipitation and evaporation in spring and summer, and the fitted equation is as follows figure 10.

$$\int P\, dt = 5.42 * \int E(a)dt - 55.84 \tag{10}$$

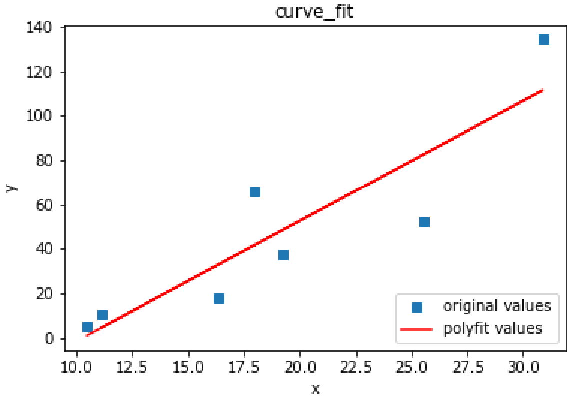

Figure 10: Fitted graph

The formula for water content yields:

$$\beta = \ 5.42(53.02(kw)^{0.15} - 20.89 + C_4) - 55.84 \qquad (11)$$

where w and s are related as:

$$\frac{dw}{dt} = 0.049w(1 - \frac{w}{4000}) - 0.0047Sw \qquad (12)$$

3. Conclusions

As the most important ecological barrier in China and North China, Xilinguole grassland in Inner Mongolia Autonomous Region has an important and strategic significance in ensuring national ecological security, border stability, national unity, promoting sustainable socio-economic development and increasing economic income for farmers and herdsmen. Therefore, the discussion on the grazing policy of grassland is in line with the development plan of "ecological priority and production development". In order to model the effects of grazing strategies on soil moisture and vegetation biomass, this paper quantifies the five grazing methods in two dimensions: time and space. Based on the aforementioned model of the effect of grazing methods on vegetation biomass, the mathematical model of the effect of grazing on soil moisture and vegetation biomass is obtained by fitting the model of the effect of grazing on soil moisture through chain effects in the software.

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