Study on the effect of different grazing strategies on soil moisture and vegetation biomass

Zhenyao Zhang*

Logistics Research Center, Shanghai Maritime University, Shanghai, China, 201306

*Corresponding author: yaozz0306@163.com

Abstract. A reasonable grazing policy of "returning grazing to grass" is the key to boosting the regional economy, preventing desertification of grasslands and safeguarding people's livelihoods. In this paper, the Woodward model is used to establish the quantitative relationship between grazing and plant growth from the perspective of mechanistic analysis. To analyse the effects of different grazing strategies on the physical properties of Xilinguole grassland, this paper establishes a water balance equation for the soil-vegetation-atmosphere system and obtains a mathematical model for the effects of the physical properties of soil and vegetation biomass in Xilinguole grassland. Finally, on the basis of keeping the current grazing strategy unchanged, a model is developed to predict the future soil moisture.

Keywords: ARIMA model; water balance equation. Woodward model.

1. Introduction

As one of the most widely distributed and important types of terrestrial vegetation in the world[1-2], grasslands have important ecological functions in maintaining biodiversity, water and soil conservation, air purification, carbon sequestration, and regulating soil erosion and dust storms[3-4]. "The study of grazing optimization also provides a scientific basis for the state and government to formulate grazing policies and grassland management decisions[5].

The types of grassland in China are: temperate grassland, alpine grassland and desert grassland[6-7]. The Xilinguole Great Plain in Inner Mongolia is one of the four typical grasslands in China, located at longitude 110° 50' to 119° 58' west and latitude 41° 30' to 46° 45' north, with an average annual rainfall of 340 mm[8-9]. Xilinguole in Inner Mongolia is a major livestock production base in China and the world's leading green ecological barrier, playing an exemplary role in reducing wind and sand disasters, harsh weather and other disasters[10].

2. Effects of different grazing strategies on soil physical properties and vegetation biomass in Xilingole grassland

2.1. Woodward Models

First, let the grazing pattern be $Mi, \in$ (1, 2, 3, 4, 5), and the grazing pattern be a time-dependent function. Let the grazing intensity (density of livestock per unit area) be $Si, \in$ (1, 2, 3, 4), and grazing intensity be a function of the number of animals grazed, with the standard unit

The standard unit is the number of livestock. For the relationship between grazing and plant growth, Woodward et al. developed a simple model

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

Calculated from Bryant (1980), assuming that cows eat 0.47% of available forage per hectare, w is a function of tw is a function of the mass of grassland vegetation, w is the derivative of t, and dw/dt is the net daily accumulation. At a forage mass of 2000 kgDM/ha, the maximum yield is 4000 kgDM/ha and the maximum net forage growth rate is 49 kgDM/ha/d.

2.2. Calculation of vegetation interception flow

Vegetation retention is closely related to precipitation, vegetation cover and leaf area index (*L AI*). Vegetation coverage is a comprehensive quantitative indicator of plant community cover on the ground, which can visually reflect the abundance of vegetation on the ground. Vegetation interception is high when precipitation is low, vegetation cover is high, and *L AI* is high. Thus, the index model proposed by Merriam is developed in this paper:

$$IC_{store}(t) = c_\rho \cdot IC_{max} \cdot \left[1 - exp\left(-k \cdot \frac{R_{cum}}{IC_{max}}\right)\right] \quad (2)$$

In its equation, $ICstor\ e$ is the vegetation intercept (mm); cp is the vegetation cover; k is the is the vegetation correction factor, related to *L AI*; $Rcum$ is the cumulative rainfall (mm). $ICmax$ is the maximum interception of a given vegetation (mm) and the leaf area index (*L AI*) is a distributed, time-varying parameter related to vegetation type and growth period. In natural environments, grassland vegetation is often under water stress and *L AI* is generally below 2, which can be calculated by using the equation for *L AI*

$$IC_{max}(t) = 0.935 + 0.498 \cdot LAI - 0.00575 \cdot LAI^2 \quad (3)$$

2.3. Plant cover model

In the soil water content-precipitation-surface evapotranspiration model, P is the water supply rate (mainly precipitation) for the pasture area; E is the surface evapotranspiration rate; β is the soil water content; a is the soil vegetation cover can be expressed as $\alpha * G(w)$, w is the number of adult grasses, $G(w)$ = (1 - e-$\varepsilon g\ w/w*$) is the grassland cover, which ranges from 0.25 to 0.8 in Inner Mongolia, and $\alpha*$ is the maximum growth rate, which depends on environmental conditions (e.g. light, temperature, soil nutrients, etc.) other than the amount of grass produced in the rangeland; $D = \beta*(e\varepsilon gw/w*- 1)$ is the wilting rate.

$$\frac{d\beta}{dt} = P - E(a) \quad (4)$$

From this, the paper develops the soil moisture content-precipitation-surface evaporation model equation to establish the plant cover model equation.

$$c_p(t) = \left[a^* - W\left(e^{-\varepsilon_g w/w^*} - 1\right)\right]\left(e^{-\varepsilon_z w/w^*} - 1\right) \quad (5)$$

2.4. Basic equation for grassland water balance

Under natural conditions, the main factors affecting the water balance include natural and socio-economic factors such as precipitation, temperature, light, humidity and other meteorological factors. Water is cycled through the soil-vegetation-atmosphere continuum in the form of precipitation, infiltration and evaporation, and the process is very complex and difficult to analyse.

$$\Delta W = W_{t+1} - W_t = P + G_u + R_{in} - (Et_a + G_d + R_{out} + IC_{store}) \quad (6)$$

Where ΔW is the change in soil water storage, Wt+1 and Wi are the beginning and end soil water content in the time period, respectively, P is the precipitation, Gu and $G\ d$ are subsurface capillary rise and soil water infiltration, respectively, Eta is actual evapotranspiration, Rin and $Rout$ are inflow and outflow runoff, respectively. $ICstor\ e$ is the vegetation interception flow. Even if local runoff occurs during heavy rainfall, the incoming and outgoing runoff can be considered equal throughout the grassland area, so the amount of runoff generated by precipitation is not considered. The runoff from precipitation is not considered. A review of the literature shows that capillary rise has little effect on the 2m soil water cycle when the depth of groundwater is greater than 4m. In the Inner Mongolian plateau, the depth of groundwater burial is mostly 30 to 40 m. The effect of capillary rise can be ignored, so the water balance equation is simplified to

$$\Delta W = P + G_u - (Et_a + G_d + IC_{store}) \quad (7)$$

2.5. Grazing strategy model

This paper is based on the Woodward model, the vegetation interception formula, the plant cover model and the basic equation of grassland water balance.
The following grazing strategy model is developed based on the Woodward model, the vegetation interception flow calculation formula, the vegetation cover model and the grassland water balance equation

$$\begin{cases} \frac{dw(t)}{dt} = 0.049w(t)\left(1-\frac{w(t)}{4000}\right) - 0.0047S(t)w(t) \\ \Delta W = P(t) + G_u - \left(E(t) + G_d + IC_{store}(t)\right) \\ IC_{store}(t) = c_\rho \cdot IC_{max} \cdot [1 - exp(-k \cdot R_{cum}/IC_{max})] \\ c_p(t) = \left[a^* - W\left(e^{-\varepsilon_g w/w^*} - 1\right)\right]\left(e^{-\varepsilon_z w/w^*} - 1\right) \\ IC_{max}(t) = 0.935 + 0.498 \cdot LAI - 0.00575 \cdot LAI^2 \end{cases} \tag{8}$$

Based on this model association, it is possible to combine grazing strategy S(t), soil water content ΔW, and vegetation biomass

The grazing strategy-soil moisture content-vegetation biomass effect model was constructed by organically combining.

3. Predicting future soil moisture

3.1. Optimisation of the model and mechanistic analysis

Based on the soil moisture data, soil evaporation data and medium precipitation data, a model was developed to predict soil moisture at different depths in 2022 and 2023, keeping the current grazing strategy unchanged, and the predicted results were entered into the table. The essence of the problem is the prediction of soil moisture at different depths in 2022 and 2023, which is in essence an application of the model of problem 1.

$$\begin{cases} \frac{dw(t)}{dt} = 0.049w(t)\left(1-\frac{w(t)}{4000}\right) - 0.0047S(t)w(t) \\ \Delta W = P(t) + G_u - \left(E(t) + G_d + IC_{store}(t)\right) \\ IC_{max}(t) = 0.935 + 0.498 \cdot LAI - 0.00575 \cdot LAI^2 \end{cases} \tag{9}$$

The model is shown above. The key to solving the model is to determine the relationship between the independent and dependent variables. The analysis of the question shows that the solution to the soil water storage content β required in this paper is equivalent to the solution to ΔW. Therefore, solving for soil water storage is equivalent to investigating for moisture β. Therefore, in this paper, the images of soil moisture β10cm, 40cm, 100cm and 200cm were first plotted using matlab software, as shown in Figure 4.1 below. After that, the relationship of greenery coverage was fitted. According to Annex 5, there is no complete data on greenery coverage for the period 2012-2022, and the pattern of observation data nodes is once a month on the 10th, 20th and 30th of the month. Therefore, this paper averages the data to calculate

$$d'_{ata} = \frac{\Sigma_{i=1}^{n} \text{data}(i)}{n} \tag{10}$$

In this paper, we try to predict the vegetation cover by combining the vegetation cover index model with the vegetation cover. Firstly, we plot the line graph of vegetation cover index and vegetation cover, and fit the relationship according to the ctftool toolbox in matlab. It is a fluctuating cycle. Therefore, the first-order relationship does not apply to the vegetation cover graph. Similarly, the second-order relational fit is not applicable to the vegetation cover, as most of the data are still not on the fitted curve, so the third-order fit is used. The fourth order is more accurate, but the accuracy of

the fit is not high, and there may be high instability in the fit. Therefore, in this paper, the third-order relation is chosen as the fitting relation for the vegetation cover function, as follows:

$$\text{fugailv} = -5.778 * nvdi^3 + 5.827 * nvdi^2 - 0.8941 * nvdi + 0.007545 \quad (11)$$

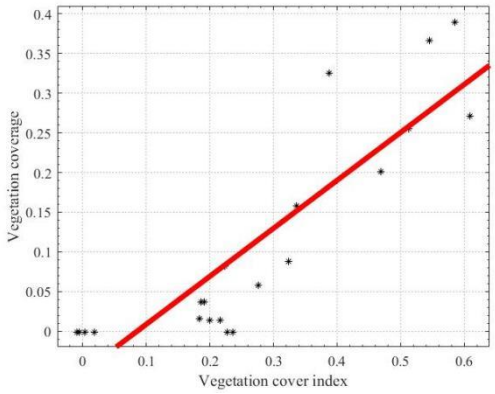


Figure 1. Primary fitted curve

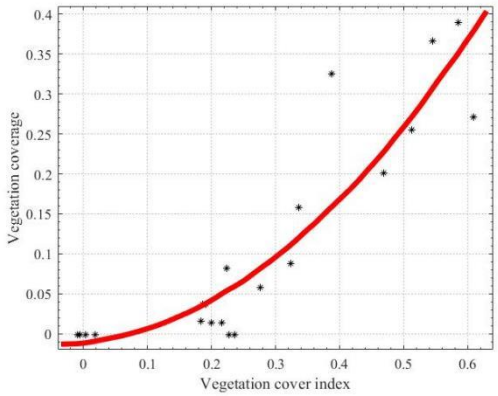


Figure 2. Secondary fitted curve

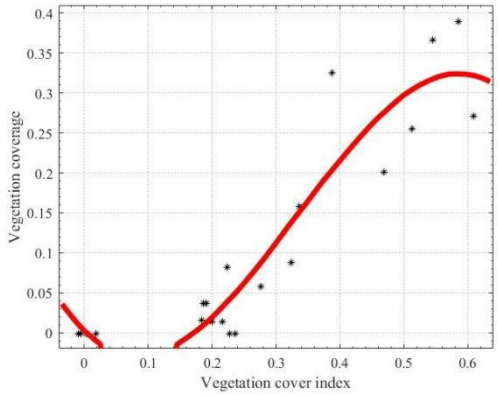


Figure 3. Triple-fit curve

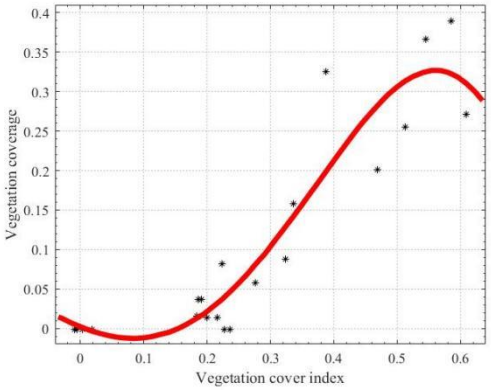


Figure 4. Quadruple-fit curve

The figure 1 to 4 shows that the four-fit equation works better than the rest of the fitted curve, while the negative values in the above graph are replaced with a minimal value of 0.01 to make the fitted curve more consistent with the actual value. Further, the remaining indicators are plotted in this paper and the results are shown below

Establishing a water balance equation for the soil-vegetation-atmosphere system

$$\Delta W = P(t) + G_u - \left(E(t) + G_d + IC_{store}(t)\right) \quad (12)$$

This paper uses the water balance equation to calculate the vegetation interception flow

$$IC_{store}(t) = P(t) + R_{in} - E(t) - G_d - R_{out} - \Delta W(t) \quad (13)$$

The Xilinguole grassland in Inner Mongolia is a representative and typical grassland in the temperate zone, one of the four major grasslands in China, located on the Xilin River in the Inner Mongolia Plateau, with geographical coordinates between 110°50 119°58 E and 41°30 46°45 N. The average annual precipitation is 340 mm. The incoming and outgoing runoff can be considered equal throughout the grassland area. The monthly precipitation can be obtained from the climatic data and calculated as if there were 31 days in a month, giving the daily precipitation as figure 5.

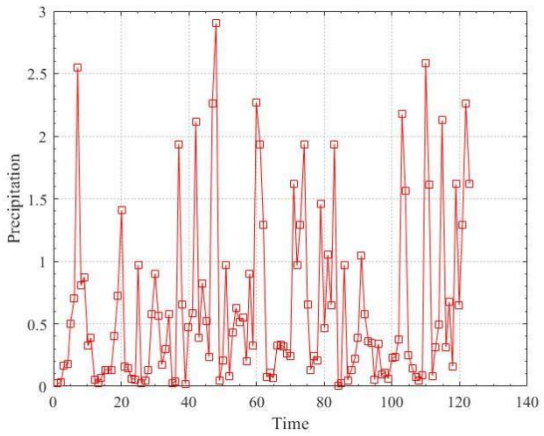


Figure 5. Daily precipitation

According to the above graph, the daily precipitation of Xilinguole grassland in Inner Mongolia is less than 10mm, so the inlet and outlet runoff can be ignored. Therefore, the above formula is optimised and the following formula is obtained

$$IC_{store}(t) = P(t) - E(t) - G_d - \Delta W(t) \tag{14}$$

For the above transformed equation, precipitation and soil storage are brought into the equation and the leaf area index k is solved by inverse substitution according to the equation, and the real and imaginary parts of the k data are processed. The images of the real and imaginary parts are plotted as figure 6.

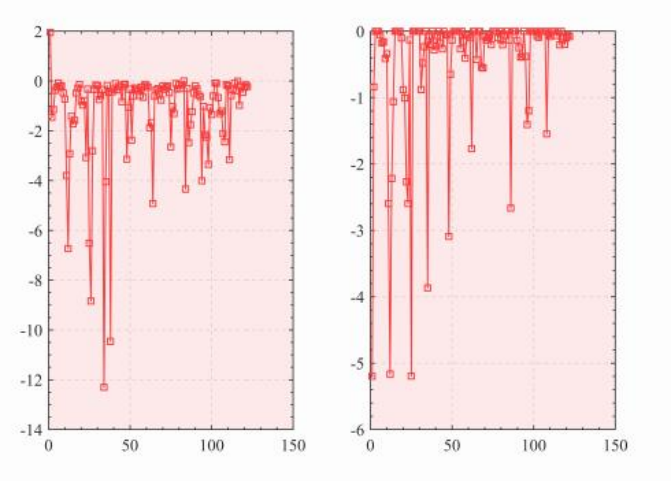


Figure 6. Real and imaginary parts of the leaf area index correction factor k values

Analysis of the above graph shows that there is a significant periodicity between the real and imaginary parts. Therefore, the forecasting model can be used to predict the future trend. Before making a time-series forecast of the data, the data is first tested for smoothness.

ADF test

The ADF test (Augmented Dickey-Fuller Testing) is one of the most commonly used unit root tests.

The ADF test (Augmented Dickey-Fuller Testing) is one of the most commonly used unit root tests to determine whether a series is stationary by testing whether there is a unit root in the series. Hypothesis: Original hypothesis $H0$: $\rho = 1$ (unit root exists, time series is non-stationary); alternative hypothesis $H1$: $\rho < 1$ no unit root exists, time series is stationary, smooth without the carrier and trend terms, smooth with the carrier term, smooth with the carrier term and (trend smooth).

ADF test steps: (1) Autoregressive equation without drift term.

$$Y_t = pY_{t-1} + \sum_{i=1}^{k} C_i \Delta Y_{t-i} + \varepsilon_t, (t = 1,2, \dots, n), Y_0 = 0 \tag{15}$$

(2) Autoregressive equation with drift term:

$$Y_t = \mu + pY_{t-1} + \sum_{i=1}^{k} C_i \Delta Y_{t-i} + \varepsilon_t, (t = 1,2, \dots, n), Y_0 = 0 \quad (16)$$

(3) Autoregressive equation with drift and trend terms:

$$Y_t = \mu + \beta t + pY_{t-1} + \sum_{i=1}^{k} C_i \Delta Y_{t-i} + \varepsilon_t, (t = 1,2, \dots, n), Y_0 = 0 \quad (17)$$

Where μ is the constant term, β is the time trend term and ε is the random disturbance term.

KPSS test

The KPSS test (proposed by Kwiatkowski, Phillips, and Shin 1992), compared to the three ADF tests above, is the most different from the KPSS test.

The main difference between the KPSS test and the above three ADF tests is that its original assumption is a smooth or trending smooth series, while the alternative assumption is the existence of a unit root.

Assumptions.

The original hypothesis: the original hypothesis does not exist unit root (the time series is smooth or trending smooth); the alternative hypothesis: the series exists unit root (the time series is non-smooth or trending smooth).

The alternative hypothesis is that there is a unit root (the time series is non-stationary).

Further, this paper uses the two smoothness detection functions in matlab to test the data. The data passed the test.

The data passed all the tests, and the arima and sarima models are used for the next step of prediction.

ARIMA model

The ARIMA model (proposed by Box and Jenkins in the 1970s) is also known as the autoregressive moving average (ARIMA) model.

Model, also known as the autoregressive intergrated moving average model, treats the time series of the predictor over time as a random process.

The ARIMA model, also known as the autoregressive intergrated moving average model, treats the time series of a predictor over time as a stochastic process and describes it as a mathematical model that can be used to predict future time values.

This model can be used to predict future values. ARIMA (p,d,q) has become a more mature time series forecasting model and is used in a wide range of applications.

(The general expression for the (p,d,q) model is

$$u_t = C + \varphi_1 \mu_{t-1} + \cdots\cdots + \varphi_P \mu_{t-\rho} + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \cdots\cdots + \theta_q \varepsilon_{t-p} \quad (18)$$

Where c is a constant, φ is the autoregressive model coefficient, θ is the moving average term, and d is the number of differences made when the time series is stationary.

is the number of differences made when the time series is stationary.

The basic steps in modelling an ARIMA model are: (1) smoothness test; (2) smoothing of non-stationary series; (3) identification and ranking of the model; (4) estimation level test of the model parameters; (5) model prediction

SARIMA model

In this paper, a seasonal time series model, namely SARIMA (p,d,q) P, D, Qs, is used, where p and P

Represent the order of the autoregressive and seasonal regressions, respectively; d and D represent the different differences and different quarterly differences according to

Of the permutations; q and Q represent the order of the moving averages and seasonal moving averages, respectively. The formulas are as follows.

$$\varphi(B)\phi(B^s)\nabla^d \nabla_s^D y(t) = \theta(B)\vartheta(B^s)\varepsilon(t) \quad (19)$$

Among them

$$\begin{gathered}\varphi(B)\phi(B^s)\nabla^d\nabla_s^D y(t)=\theta(B)\vartheta(B^s)\varepsilon(t)\\ \phi(B^S)=1-\phi_1B^S-\cdots-\phi_pB^S\\ \vartheta(B^S)=1+\vartheta_1B^S+\cdots+\vartheta_qB^S\\ \nabla_s^D=(1-B^S)^D\end{gathered}\tag{20}$$

B, ∇, (t), $\varphi(B)$, $\phi(B)$ and $\varepsilon(t)$ form the ARIMA model with seasonal indices. (BS) represents the seasonal regression parameters; $\vartheta(BS)$ as the seasonal moving average polynomial, $\vartheta 1$, $\vartheta 2$,$\vartheta 3$... .ϑQ as the seasonal moving average parameter; ∇Ds denotes the seasonal variance value of the D series

Time series model predicted indicator data

After observing the graphs of each indicator, it can be concluded that leaf area index and vegetation maximum interception have significant

The ARIMA model mentioned above was used to predict precipitation, SARIMA model to predict evapotranspiration and vegetation cover index.

The ARIMA model is used to predict precipitation, SARIMA model to predict evapotranspiration and vegetation cover index.

In addition, due to the influence of natural environmental factors, this paper uses the SARIMA model to predict the leaf area index by predicting the leaf area index correction factor.

The SARIMA model was used to predict evapotranspiration and vegetation cover index.

When looking at the soil moisture profiles at different depths, it was found that there was an inevitable bottom-up infiltration relationship between the various moisture layers.

This leads to the subjective conclusion that there is a quantitative relationship between the different soil layers at different depths. After this, the paper

The relationship between the moisture levels of the soil was then further fitted.

Stepwise regression model

The idea of the stepwise regression model is to introduce the independent variables one by one, test the significance of each variable in the regression equation, eliminate the non-significant independent variables, and repeatedly introduce the independent variables.

The model is based on the idea of introducing the independent variables one by one, testing the significance of each variable in the regression equation, and eliminating those that are not significant. Finally, a multiple regression equation is created.

Step by step regression procedure:

(1) Build the correlation coefficient matrix ($x1k$, $x2k$, - - - , xmk, xm+1k) (k = 1, 2, - - - - ,),, the correlation coefficient $ri\ j$ can be calculated from

and to build the augmentation matrix of correlation coefficients R

$$\begin{cases}\gamma_{ij}=\frac{S_{jk}}{\sqrt{S_{Ii}S_{ij}}}\\ (i,j=1,2,\ldots,m)\\ Sij=\sum_m^{k=1}(x_{ik}-\overline{x_\iota})\left(x_{ik}-\overline{x_J}\right)\end{cases}\tag{21}$$

(2) Select a variable in the equation and calculate the contribution of variance

$$v_i^{(0)}=\frac{r_{m+1i}^{(0)}r_{im+1}^{(0)}}{r_{ii}^{(0)}}\tag{22}$$

Select the largest one for the F-test, and if $Fk1 > F1$, introduce the variable into the regression equation and transform it to obtain the Zeng-Guan matrix, otherwise do not introduce the equation until $Fkn <= Fkn$-1; (3) continue to select a variable into the regression equation and test whether new variables are introduced in the same way as in the second step; (4) test whether the variables that have been introduced into the regression equation need to be removed, and perform an F-test as above to verify whether the introduced variables need to be removed. This paper uses the stepwise regression

model described above to obtain the fitted relationship between 100 cm and 200 cm, setting the soil moisture at 200 cm as y and at 100 cm as x:

$$y = 170.089 - 0.052 * x \tag{22}$$

After that, this paper further conducts a combined regression using 200cm and 10cm and 40cm, setting the soil moisture at 10cm as z and at 40cm as w, and the regression equation is as follows

$$y = 169.692 - 0.08 * w + 0.064 * z \tag{23}$$

The predictions were obtained by establishing regression equations for soil water content at different depths.

4. Conclusions

This paper establishes mathematical models of the effects of different strategies on the physical properties of soil and vegetation biomass in Xilinguole grassland from the perspective of mechanistic analysis. For the relationship between grazing and vegetation growth, this paper uses the Woodward model to establish the quantitative relationship between the two, i.e. to establish a mathematical model of the effect of grazing intensity and vegetation biomass; for the analysis of the effect of different grazing strategies on the physical properties of Xilinguole grassland, this paper establishes the water balance equation of the soil-vegetation-atmosphere system by studying the law of water circulation, so as to establish a model of the effect of different grazing methods and grazing intensity on soil physical properties. In this paper, we study the water cycle and establish the water balance equation for the soil-vegetation-atmosphere system, so as to model the effects of different grazing practices and grazing intensities on soil physical properties.

This paper first makes graphs of soil moisture, precipitation and vegetation cover to observe their trends and periodicity, and then predicts the vegetation cover index by fitting equations to the vegetation cover and vegetation cover index. In this paper, we establish ARIMA model and SARIMA model to predict precipitation, vegetation cover index and leaf area correction factor, and finally solve the model established in the previous paper, and also observe and analyse that there is a quantitative relationship between soil moisture at different depths, and use stepwise regression to get the regression equation of soil moisture at different depths, and finally predict soil moisture by regression equation.

References

[1] Randall K.J.,Ellison M.J.,Yelich J.V.,Price W.J.,Johnson T.N.. Managing Forbs Preferred by Greater Sage-Grouse and Soil Moisture in Mesic Meadows with Short-Duration Grazing[J]. Rangeland Ecology & Management,2022,82(1).

[2] Soares Pedro R.,Pato Rosinda L.,Dias Susana,Santos Daniela. Effects of Grazing Indigenous Laying Hens on Soil Properties: Benefits and Challenges to Achieving Soil Fertility[J]. Sustainability,2022,14(6).

[3] Fenger F,Casey I A,Holden N M,Humphreys J. Access time to pasture under wet soil conditions: Effects on productivity and profitability of pasture-based dairying.[J]. Journal of dairy science,2022,105(5).

[4] Wang Le,Xu Hengkang,Zhang Hao,Zhang Yingjun. Grazing and Mowing Affect the Carbon-to-Nitrogen Ratio of Plants by Changing the Soil Available Nitrogen Content and Soil Moisture on the Meadow Steppe, China[J]. Plants,2022,11(3).

[5] Lin Xi,Zhao Hongbin,Zhang Shengwei,Li Xiaoyuan,Gao Wenlong,Ren Zhaoyi,Luo Meng. Effects of animal grazing on vegetation biomass and soil moisture on a typical steppe in Inner Mongolia, China[J]. Ecohydrology,2021,15(1).

[6] Yan Ruirui,Zhang Yu,Wang Miao,Li Ruiqiang,Jin Dongyan,Xin Xiaoping,Li Linghao. Interannual variation in ecosystem respiration in an Inner Mongolian meadow steppe in response to livestock grazing [J]. Ecological Indicators,2021,131.

[7] Yu Lingfei,Sun Wenjuan,Huang Yao. Grazing exclusion enhances plant and topsoil carbon stocks in arid and semiarid grasslands[J]. Agriculture, Ecosystems and Environment,2021,320.

[8] Wang Xixi,Gao Ruizhong,Yang Xiaomin. Responses of soil moisture to climate variability and livestock grazing in a semiarid Eurasian steppe[J]. Science of the Total Environment,2021,781.

[9] Döbert Timm F.,Bork Edward W.,Apfelbaum Steven,Carlyle Cameron N.,Chang Scott X.,Khatri-Chhetri Upama,Silva Sobrinho Laio,Thompson Ry,Boyce Mark S.. Adaptive multi-paddock grazing improves water infiltration in Canadian grassland soils[J]. Geoderma,2021,401.

[10] Ashworth Amanda J.,Adams Taylor,Kharel Tulsi,Philipp Dirk,Owens Phillip,Sauer Thomas. Root decomposition in silvopastures is influenced by grazing, fertility, and grass species[J]. Agrosystems, Geosciences & Environment,2021,4(3).