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DNDC model is able to simulate the vine biomass at different planting ages in vineyards in Ningxia, China

Yajie Zhang [a], Xudong Wu [b], Shiping Wang [c], Haishan Niu [a,*]

[a] College of Resources and Environment, University of Chinese Academy of Sciences, No. 19A Yuquan Road, Beijing, China
[b] Breeding Base of State Key Laboratory for Preventing Land Degradation and Ecological Restoration, Ningxia University, Yinchuan, China
[c] Institute of Tibetan Plateau Research, Chinese Academy of Sciences, No.16 Lincui Road, Beijing, China

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ABSTRACT

The vine total biomass of different planting ages from plants in vineyard (1–12 years) was investigated by analysing biomass in stands with various ages and also simulated using the denitrification-decomposition (DNDC) model in the east Helan Mountains, Ningxia in 2011. The results indicated that the DNDC model accurately simulated the total biomass at different planting ages in the studied vineyard; the simulated results were approximately 93.6% of the measured results, and the biomass determination coefficient R^2 between the model simulation and the in situ observations was 0.948 ($p < 0.01$), representing a significant correlation. Under the simulation, the vine biomass accumulation was found to be sensitive to the changes of fertilisation depth, soil organic carbon content, pH and other factors, and would effectively increase by appropriate increase of the fertilisation amount and decrease of the irrigation amount at the same time. Therefore, the DNDC model is applicable for simulating biomass in Ningxia vineyards and it has the potential to be widely applied to assess crop biomass variations under different climate conditions or management methods.

1. Introduction

Biomass, which represents the total accumulation of organic matter in plants, serves as an indicator of ecosystem health and is also important for many other reasons (i.e., carbon-sequestration capacity, ratio yield/biomass, etc.) [1]. Studies on biomass allocation patterns have been gradually conducted in different ecosystems, regions and biosphere scales [2]. Recently, the spatial pattern research of biomass mainly has two kinds of basic methods: field investigation and model simulation [3–5]. Some indices and models have been considered to be ideal mathematical models to describe biomass accumulation in a vine plantation [6]. When research conducts in the regional scale or with the deficiency of observation data, the denitrification-decomposition (DNDC) model, which is a process-based model that is developed to estimate soil carbon (C) and nitrogen (N) dynamics, ammonia (NH_3) and greenhouse gas emissions, and crop biomass production based on the soil environment, local climate, and on-site management practices, has been applied to estimate plant biomass with good results [7–10].

Ningxia, an autonomous region in northwest China, has unique climate and soil conditions and been widely considered to be one of the world's best grape-producing areas for wine [11]. According to the statistics of the Ministry of Agriculture of the People's Republic of China, up to 2015, the acreage of grapes in Ningxia has reached 32,400 ha, accounting for approximately 4% of the total grape growing area in China. Until recently, wine grape and vine studies have primarily focused on yield and quality but studies on the biomass distribution rule of vine, which are helpful to understand the vine growth pattern and resources allocation dynamic, are still needed. Moreover, studies using mechanistic models to simulate growth processes and total biomass of vine also have not been effectively conducted in China [12–14].

In this study, the DNDC model was used to simulate total biomass of vine based on actual biomass measurements at different planting years in Ningxia vineyard, to evaluate whether the DNDC model is suitable for the popularisation and application in vineyards, and then to predict the biomass accumulation of vines which partly presents the crop growth and final yield under different environment conditions and farmland management measures. These also provide a theoretical basis for the application of mechanism models and modern agricultural managements in vineyards.

2. Materials and methods

2.1. Study area

The experiment was conducted at the Yuquanying farm (three plot sites, i.e., Dongdatan, East of distillery and Mayue base) in Yongning,

* Corresponding author at: College of Resources and Environment, University of Chinese Academy of Sciences, No. 19A Yuquan Road, Beijing 100049, China.
E-mail address: niuhs@ucas.ac.cn (H. Niu).

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Ningxia (38°23′N, 106°47′E) with an elevation of 1130 m in September 2011 (Fig. 1). The three plot sites had the similar climatic conditions, same agricultural management measures and close geographic distance, which excluded the interferences of the environmental factors. Limited by the reconstruction of the farm since 2012, all the sampling had to finish in only one year (2011). To fill this gap, three plot sites and six plantation ages were selected to validate model using in this study and were regarding as repeated trials in spatial and temporal scales.

The soils in the study area, which are mainly derived from alluvial deposits, are classified as sierozems with a sandy loam texture and the soil granulometric composition of fine sand. In general, the shallow root system of drip irrigated vines vertically distributes to the 15–100 cm soil and mainly concentrates in 20–40 cm soil, so that the basic physicochemical properties of the 0–20 and 20–40 cm soil are as follows [15,16] (Table 1):

Based on the nutrient classification standards from the second nationwide general soil survey, the soils in the study area have the following characteristics: high pH value and degree of desertification, low field capacity, and low nutrient level. In particular, the soil organic matter content is <5 g kg^{-1}, which is characteristic of low organic carbon accumulation in semi-arid regions with barren sandy soils [16,17].

This region is indicative of a typical warm temperate continental monsoon climate, and the mean annual temperature is 8.5–9.0 °C. Additionally, the mean annual precipitation is 180–200 mm, the effective accumulated temperature (EAT, the sum of daily temperature for the period of daily mean temperature above 10 °C) is 3135–3272 °C, the annual sunshine duration is 3032 h, and the frost-free period is ~156 d in the history records. The large temperature difference between day and night promotes the synthesis and accumulation of organic matter, which is suitable for crop growth [18].

The average vine planting density is approximately 10,000 plant ha^{-1}, and the plant spacing is approximately 0.5 m × 2 m. In this research, different planting age (i.e., 1 a, 2 a, 3 a, 4 a, 8 a and 12 a) of "Merlot" (*Vitis vinifera* L.) that were grown using a single-arm trellis were studied. And the vertical dragon trunk-like shape of wine grapes was adopted as the main training and pruning system.

2.2. Experimental design

According to the planting age diversity, standard sample areas with consistent site types and farmland management measures were selected in Yuquanying farm where the planting histories are varied in different farm areas [6]. The selected area was 3 × 100 m^2 for each planting age of vine. One vine was selected for investigation from each plot.

The experience in production demonstrated that the furrow irrigation quantity was 9000–13,500 m^3 ha^{-1} during the growth period of vine and an additional of water might be needed for leaching salts and providing frost protection [19]. Therefore, drip irrigation, which increased the potential for control of vine growth, was used 21 times with the same water amount (the date of irrigation was determined by the soil moisture conditions and vine growth status) throughout the year and the total amount was 5250 m^3 ha^{-1} via a single tube dropper which was tied on the fence 0.2 m from the ground [20]. These large amounts of irrigation water were determined by the poor efficiency of irrigation mainly caused by the water leakage in sandy loam soil. The first and last irrigation events were by furrow with the water amount of 1500 m^3 ha^{-1}.

When irrigating, fertilisation measures (solid fertilisers dissolved in irrigation water) were collected during the experimental period. In general, as the average annual amount of total N of 65–85 kg ha^{-1} required for normal growth of vines, 75 kg ha^{-1} of urea was applied on April 20th after germination stage; after flowering, both 150 kg ha^{-1} of urea and diammonium phosphate were top dressed on May 25th; 300 kg ha^{-1} compound fertiliser (14% N, 16% P, 15% K) was top dressed on June 25th; and 300 kg ha^{-1} potassium sulfate was top dressed on August 20th. Additionally, 1300 kg C ha^{-1} of organic fertiliser was applied on September 20th which was used to provide necessary nutrients and create a good soil condition for the plant growth of the next year [19]. The specific amount of fertilisation was also determined by the vine ages and growth stages.

2.3. In situ observations

The aboveground biomass of the vines was determined using the full harvest method. After determining the fresh weights, the whole stems

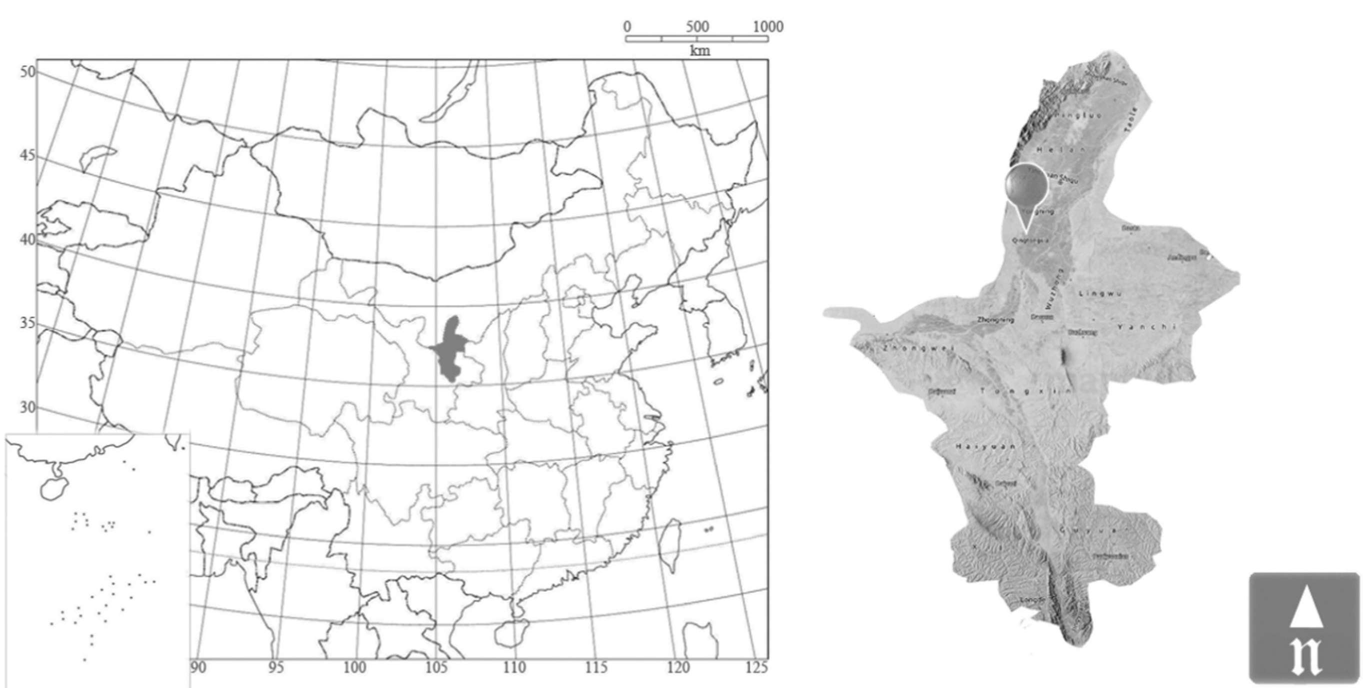

Fig. 1. The location of the study area.