Optimum Management of Water and Fertilizer for Potato in Soft Rock and Sand Compound Soil Based on WHCNS Model: Model Calibration and Validation

Huanyuan Wang*, Jie Cheng, Haiou Zhao, Zhao Wang

Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Land and Resources, Shaanxi Provincial Land Consolidation Engineering Technology Research Center, Xi'an 710075, China

*Corresponding author e-mail: 181073033@qq.com

Abstract. Soil Water Heat Carbon and Nitrogen Simulator (WHCNS) model was used to simulate the soil water and fertilizer coupling effect of potato in soft rock and sand compound soil, with a view to establishing a scheme to optimize soil water and fertilizer in local climate and soil properties. In this study, three ratios (soft rock: sand =1: 1, 1: 2 and 1: 5) of soft rock and sand compound soil were conducted. The model was validated by field experiments. The results show that the model did good in simulating water and fertilizer dynamic. With decreasing soft rock content in compound soil, the evapotranspiration was no significant change, and water drainage was increased significantly. Water use efficiency, N use efficiency and fertilizer use efficiency could reach 4.38 kg m-3, 136.80 and 96.90 kg kg-1 N-1, respectively.

1. Introduction

The Mu Us sandy land located at the junction of Shaanxi, Mongolia and Ningxia provinces has a vast area, providing a great reserve of resources for replenishing cultivated land. How to manage the sand at a low cost and effectively is a major technical problem. Han Yuchang [1-2] proposed the innovative ideas of compounding two kinds of materials into soil and further developing arable land through further research on the properties of soft rock and sand abundantly distributed in sandy land. With the support of the major project of land remediation in Shaanxi Province, a standardized and large scale project of soil and land reclamation has been innovatively implemented in Mu Us Sandland, greatly reducing the cost of land reclamation. Change soft rock and sand "two pests" as "a treasure", successfully achieved soft rock and sand scale, resource utilization [3-5]. Up to now, the use of the technology has accumulated a total of more than 100,000 acres of arable land in the region, mainly for potato and corn farming.

However, the development of arable land in sandy land is also facing the problem of water shortage and agricultural environmental pollution. Therefore, the rational development of water and fertilizer management measures to achieve high crop yield, efficient use of resources and reduce the risk of agricultural environmental pollution purposes, to protect the national food and Resources and environmental safety has important practical significance. The traditional management measures of
water and fertilizer through field experiments usually have the disadvantages of time-consuming and labor-intensive, high cost and so on. Due to the influence of meteorological, soil and field management measures in the study area, the results obtained have some limitations and one-sidedness, which greatly limits the popularization and application of the research results. The soil-crop system model based on field experiments can solve this problem well and has been widely used in crop production decision [6], water and fertilizer optimization management [7] and environmental impact assessment [8] application. Therefore, based on the planting experiment of potato, the main crop in the world, the paper used WHCNS model to quantitatively evaluate the nitrogen leaching, water-nitrogen balance and utilization efficiency of farmland with different sand and sand mixed with sand, To provide a scientific basis for water and fertilizer management measures of potato on newly added cultivated land in sandy land.

2. Materials and methods

2.1. Test Area Overview

The test sites are located in Daji Khan Village, Yuyang District (E109° 28'58"-109° 30'10", N38° 27'53"-38° 28'23"), Xianjihan County, Yuyang District, Located in northern Shaanxi, elevation 1206-1215 m, the southern edge of the Mu Us desert. The area is a typical mid-temperate semi-arid continental monsoon climate zone, uneven temporal and spatial distribution of precipitation, adequate sunshine. The annual average temperature is 8.1 °C, the annual average rainfall is 413.9 mm, 60.9% of the rainfall is concentrated in 7-9 months, and the rain and heat are in the same period. The average annual sunshine hours is 2879 h, sunshine percentage of 65%. The total annual radiation is 145.2kcal/cm². The main types of soil in the test site are mainly sandy soil, which nitrogen content of 0.75 g kg⁻¹, total phosphorus content of 0.63 g kg⁻¹, total potassium content of 26.51 g kg⁻¹, and organic matter content of 0.3 g kg⁻¹.

2.2. Experimental Design

Experimental design of the size of 15 × 12m of the district, set up two repeats, the district is divided equally into three 5 × 12m sub-district, respectively, consider the soft rock: sand 1: 1, 1: 2 and 1 : 5 and other three mixed ratio, each plot is only covered in the surface layer of 30 cm different mixed composite soil (soft rock crushed as much as possible to 4 cm in diameter to ensure that the surface of the sand and sand evenly mixed cover) The local sandy soil below 30 cm is generally homogeneous in the 30-160 cm soil profile due to the leveling of the land during land remediation. The main physical and chemical properties of three kinds of mixed soil and original sand are shown in Table 1.

| The mixing ratio | Soft rock: Sand depth (cm) | Particle size composition (%) | Texture (American made) | Bulk density (g cm⁻³) | total nitrogen (g kg⁻¹) | total phosphorus (g kg⁻¹) | total potassium (g kg⁻¹) | organic matter (g kg⁻¹) |
|------------------|---------------------------|-------------------------------|-------------------------|----------------------|------------------------|--------------------------|-------------------------|-------------------------|
| Grit Powder Cosmid | 0-30 | 53.82 38.12 8.06 sandy loam 1.37 0.44 0.50 22.26 2.26 | | | | | | | |
| 1:1 | 0-30 | 53.82 38.12 8.06 sandy loam 1.37 0.44 0.50 22.26 2.26 | | | | | | | |
| 1:2 | 0-30 | 68.86 26.01 5.13 sandy loam 1.52 0.54 0.55 23.67 2.61 | | | | | | | |
| 1:5 | 0-30 | 79.03 17.35 3.62 sandy soil 1.56 0.65 0.59 25.09 2.97 | | | | | | | |
| Original sand 30-160 | 70.37 | 4.10 0.53 | Sand 1.61 0.75 0.63 26.51 3.32 | | | | | |

The crop was planted as potato, which was planted on April 22, 2013. All the communities adopted the practices of irrigation and fertilization managed by local farmers. Before planting, the base fertilizer was applied in an amount of 120 kg N ha⁻¹, and then rotary tillage machine was used to
trowel 20 cm compound soil and fertilizer to the surface uniformly. A total of 5 irrigation times throughout the crop growing season, each time 55.6 mm. Topdressing twice with 69 kg N ha⁻¹ applied.

2.3. measurement items and methods
In the key growing period of several potatoes, soil samples of depth of 10, 20, 40, 60, 80, 100 and 120 cm were taken by soil drilling in test plots with different ratio of soft rock and sand, and the samples were fertilized and irrigated after a week. Soil samples taken immediately after the field into the refrigerator back to the laboratory for analysis, before the experiment with 2 mol / L KCl solution extraction (water to soil ratio of 5:1), with an automatic intermittent chemical analyzer (cleverchem200) Determination of ammonium Nitrogen and nitrate nitrogen content, while drying method to measure soil moisture content. Soil moisture with neutron moisture meter (CNC100) determination, which once every two weeks to determine the depth and sampling depth. The dry weight and leaf area index of the crop were measured and the yield was measured at harvest. The basic meteorological elements (maximum temperature, minimum temperature, average temperature, rainfall, solar radiation, relative humidity, sunshine hours, wind speed, etc.) are provided by the Bureau of Meteorology in Yuyang District.

2.4. Introduction to the model
In this study, Soil Water Heat Carbon and Nitrogen Simulator (WHCNS) [9] was used to simulate the study. Based on the kinetic model of the combined transport of soil hydrothermal solutes, this model introduced the crop growth and development process, soil organic matter turnover, organic nitrogen mineralization and retention, urea hydrolysis, ammonia volatilization, nitrogen nitrification and denitrification and other processes, including meteorological modules, soil water, heat and nitrogen joint transport module, crop growth module, organic matter module, root absorption nitrogen, inorganic nitrogen module and field management module 7. It can be used to quantify most of the key processes in the soil-crop system.

The WHCNS model cites FAO's meteorological module and the Dutch PS123 crop model, drawing on the theory of water solute transport associated with the Daisy, Hydrus-1D, RZWQM and Leach M models and modifying and refining it. This model, in days-steps, can be used to analyze soil hydrothermal dynamics, nitrogen anomalies, turnover of organic matter, crop growth and greenhouse gas emissions. The parameters are automatically optimized using the PEST (Model-Independent Parameter Estimation) automatic optimization tool. The WHCNS model is a systematic model for the quantitative analysis of the impact of field fertilizer and water management measures on crop production and the environment.

2.5. model input
The parameters that the model needs to input include: (1) Basic information: latitude and altitude. (2) Soil information: thickness of soil layer, texture of each layer, pH, bulk density, organic matter, total nitrogen, hydraulic properties, solute transport parameters, C / N conversion parameters. (3) Field management information: irrigation time and quantity are non-time, method and quantity. (4) Soil initial conditions: water content, inorganic nitrogen. (5) Meteorological data: daily solar radiation, the lowest temperature, the highest temperature, wind speed, humidity, rainfall, etc. (6) Crop parameters: crop growth optimum, maximum and minimum temperature, initial, middle and late crop coefficients, maximum and minimum graduation area, maximum assimilation rate, maximum rooting depth and so on.

3. Results and discussion

3.1. Model parameter calibration and validation
In the process of model verification, the model was calibrated by the test data with the ratio of soft rock and sand compounded 1:1, and the model was validated by the test data with the ratio of soft
rock and sand compounded 1:2 and 1:5. The simulated soil moisture and nitrogen simulated results are compared with the simulated values. Figure 1-4. According to the results, it can be seen that the simulation error of groundwater is small and the simulation error of surface is high when the soil moisture is simulated and corrected. The reason is that the surface soil moisture is sensitive to precipitation and evaporation and has a large simulation error [10]. In the soil nitrate-nitrogen simulation correction, the error after 40cm soil layer is small, this may be due to nitrate-based nitrogen mainly accumulated in the surface of 0-30 cm, and soil below 30 cm are all local sandy soil, the same texture, consistent irrigation, leaching loss characteristics quite. And nitrate-crop growth early simulation error is small, late simulation error. When the yield is corrected by simulation, the error of 1:1 and 1:2 compounded soil is small, and the error of 1:5 compound soil is obviously increased. The correlation coefficients of soil moisture, nitrogen measured values and simulated values reached 0.1864 and 0.184, respectively, and all reached significant correlation levels (P< 0.01). Overall, the simulation results are credible.

Fig 1. Comparison of simulated (solid line) and measured (circle) soil water content for 1:1 compound soil
Fig 2. Comparison of simulated (solid line) and measured (circle) soil nitrogen content for 1:1 compound soil

Fig 3. Comparison of simulated and measured yield for different ratio compound soil
When the yield is corrected by simulation, the error of 1: 1 and 1: 2 compounded soil is small, and the error of 1: 5 compound soil is obviously increased. Correlation coefficients between soil moisture and simulated values reached 0.1864 and 0.184, respectively, and reached significant correlations (P < 0.01). Overall, the simulation results are credible.

3.2. Water balance and utilization efficiency analysis

The water balance of 1.6 m soil with different soft rock and sand complex ratio is shown in Table 2. It can be seen that, since the same irrigation treatment was applied to different proportions of sandstone and sand compounding soil in the experiment, and because different compounding proportions of soil have different water-holding properties, their evaporation and leakage and water use efficiency showed different results. The evapotranspiration of the three kinds of compound soil is 369, 381 and 571 mm respectively, and the leakage amounts are 326, 396 and 230 mm respectively. Judging from the changes of water reserves, the water reserves of the three kinds of composite soil are 122.8, 40.8 and 16.8 mm respectively. The water reserves of the three types of compounded soils are all positive, indicating that the water is surplus, and as the content of silt sand increases, the surplus also increases. This also shows the water holding capacity of the soft rock. In terms of yield, the actual yields of the three types of compounding soil are 14000, 16000 and 25000 kg hm^{-2}, respectively, and the highest yield is obtained for siltstone sand and sand with a ratio of 1: 5, with a significant yield at a 1: 1 ratio Low. In terms of water use efficiency, the water use efficiencies under the three compounding ratios were 3.74, 4.20 and 4.38 kg m^{-3}, respectively. Based on the water use efficiency at the 1: 1 compounding ratio, 1: 2 and 1: 5 the water use efficiency of compound soil increased by 12.3% and 17.1%, respectively. The water use efficiency increased with the increase of the proportion of soft rock in compound soil, which indicated that soft rock played an important role in improving water use efficiency of sandy land significant effect.

From the above analysis, we can see that under the same conditions of rainfall and irrigation, with the decrease of the ratio of soft rock in compound soil, the yield increases, the evapotranspiration increases, the water demand increases, and the leakage decreases obviously. 1: 5 compound with the highest yield, highest water use efficiency. The above results show that when the mixing ratio is 1: 5, the compound soil is more suitable for the growth of potato, and the mixed proportion of the compound soil can be popularized and applied in the study area.
### Table 2. Water balance in 1.6 m soil profile for different ratios of compound soil

| Soft rock: sand | Rainfall (mm) | Irrigation (mm) | Evapotranspiration (mm) | Leakage (mm) | Water reserves change (mm) | Measured output (kg hm⁻²) | Simulated production (kg hm⁻²) | Water use efficiency (kg m⁻³) |
|----------------|---------------|-----------------|-------------------------|--------------|---------------------------|--------------------------|-----------------------------|-----------------------------|
| 1:1            | 484.2         | 333.6           | 369                     | 326          | 122.8                     | 14000±3740               | 14939                       | 3.74                        |
| 1:2            | 484.2         | 333.6           | 381                     | 396          | 40.8                      | 16000±4850               | 16195                       | 4.20                        |
| 1:5            | 484.2         | 333.6           | 571                     | 230          | 16.8                      | 25000±6560               | 22730                       | 4.38                        |

Note: Changes in water storage = Rainfall + Irrigation - Evapotranspiration - Leakage; Water use efficiency = Measured production / Evapotranspiration.

### 3.3. Nitrogen balance and utilization efficiency analysis

The results of nitrogen balance of 1.6 m soil with different soft rock and sand complex ratios are shown in Table 3. Different soft rock and sand compound proportion of soil fertilization are the same, and their nitrogen is not the same direction. For the 1: 1, 1: 2 and 1: 5 compound soil, ammonia volatilization reached 13.27, 5.56 and 5.05 kg N hm⁻² respectively, accounting for 5.14%, 2.16% and 1.96% Respectively, reached 3.64, 1.88 and 1.43 kg N hm⁻² respectively, accounting for 1.41%, 0.73% and 0.55% of the amount of fertilization respectively. Because of the soil temperature and humidity in sandy land, the proportion of denitrification to the amount of fertilizer was slightly higher than The average denitrification rate in dryland soil in China [11]; N leaching loss reached 71.2, 64.9 and 56.6 kg N hm⁻² respectively, accounting for 27.6%, 25.2% and 21.9% of the fertilization amount respectively, while ammonia volatilization, denitrification and N Losses are reduced as the content of soft rock in the compound soil decreases. While the crop uptake reached 93.77, 108.93 and 119.67 kg N hm⁻², respectively, which were the main ways of nitrogen export, and increased with the decrease of the content of soft rock in compound soil. Ammonia volatilization and nitrogen leaching have become the main ways of nitrogen loss. The nitrogen use efficiencies of soft rock and sand with different proportions reached 76.97, 88.27 and 136.80 kg kg⁻¹ N⁻¹, 1: 2 and 1: 5, respectively, Increased by 14.68% and 77.73% respectively; the fertiliser use efficiencies of 54.26, 62.02 and 96.90 kg kg⁻¹ N⁻¹, 1: 2 and 1: 5 fertilizers were increased by 1: 1 14.3% and 78.58%, respectively. The above results show that the compounding ratio of 1: 5, the compounding soil has the best nitrogen utilization efficiency and maintaining performance. The mixed proportion of compounding soil can be popularized and applied in the study area.

| Soft rock: sand | Fertilization | Ammonia volatilizes | Denitrification | Absorption of crops | Nitrogen rinse | NUE | FNUE |
|----------------|---------------|---------------------|-----------------|---------------------|---------------|-----|------|
|                | (kg N hm⁻²)   | (kg kg⁻¹ N⁻¹)      |                 |                     |               |     |      |
| 1:1            | 258           | 13.27               | 3.64            | 93.77               | 71.2(27.6%)   | 76.97 | 54.26 |
| 1:2            | 258           | 5.56                | 1.88            | 108.93              | 64.9(25.2%)   | 88.27 | 62.02 |
| 1:5            | 258           | 5.05                | 1.43            | 119.67              | 56.6(21.9%)   | 136.80 | 96.90 |

Note: Nitrogen use efficiency = measured yield / (ammonia volatilization + denitrification + crop uptake + nitrogen leaching). Fertilizer nitrogen utilization efficiency = measured yield / amount of fertilizer. Nitrogen leaching item the percentages in parentheses indicate nitrogen leaching factor, nitrogen leaching factor = nitrogen leaching loss / fertilizer.

### 4. Conclusion

The WHCNS model can be used to simulate and analyze the process of soil water and fertilizer transport between soft rock and sand complex soil. It can be used as a tool for water and fertilizer optimization management on soft rock and sand compound soil. The simulation results show that the evapotranspiration decreases gradually with the decrease of the soft rock content in the compound soil.
for the three types of compound ores, ie, sand, 1: 1, 1: 2 and 1: 5. The water use efficiency can reach as high as 4.38 kg m⁻³. The coupling of limited irrigation water and fertilizer is an important way to save water in arid and semi-arid regions, increase water use efficiency, and strive for high crop yields. Under the condition of limited water resources, the key to agricultural production in dry land is the reasonable cooperation of water and fertilizer.

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