Optimizing water and nitrogen management for irrigated maize in desert oases in Northwestern China

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Abstract

Understanding water and nitrogen transport through the soil profile is important for efficient irrigation and nutrient management, and to minimize nitrate leaching to the groundwater. In this study a process-based water and nitrogen management model (WNMM) was used to simulate soil water movement, nitrate transport, and maize growth under desert oasis conditions in Northwestern China. The model was calibrated and validated with a field experiment. The model simulation results showed that about 35% of total water input and 58% of the total nitrogen input was leached to below 1.8 m depth under the traditional management practice. Over 1700 scenarios combining various irrigation and fertilizer practices were simulated. We analyzed the results to derive best management practices (BMPs) that simultaneously consider crop yield, water use efficiency, fertilizer N use efficiency and nitrate leaching. The results indicated that the BMPs under the specific desert oasis conditions are to irrigate maize with 600 mm water over eight irrigation events with a single fertilizer application at a rate of 75 kg N/ha.

Key Words

Desert oasis, WNMM model, water drainage, nitrate leaching, best management practices.

Introduction

Rapid economic and population growth requires agriculture to produce sufficient food to sustain China's development. Large irrigation and N fertilizer inputs are being used to maintain and increase crop production but there is generally low water and N use efficiency. Increasing incidences of nitrate pollution and dramatic increases of groundwater nitrate concentrations in intensively farmed regions have been reported by many researchers (Hu *et al.* 2005). This issue has become very serious in desert oases of western China. The cropping of light-textured soils, excessive irrigation (typically as flood irrigation) and heavy fertilizer applications have resulted in NO_3^--N concentrations as high as 130 mg N/L in groundwater accessed in community wells in the Left Banner, Alxa league (Inner Mongolia). There are number of models such as GLEAMS, EPIC, NLEAP, LEACHM, APSIM, DAISY, RZWQM, and DSSAT that can be used to evaluate the integrated effects of soil, climate, and management on crop growth and nitrate leaching. Recently, Li *et al.* (2007) developed a process-based water and N management model (WNMM). This model can simulate water, carbon and N dynamics, as well as plant growth under various agricultural management practices, specifically for the intensive cropping (wheat-maize) systems of the North China Plain. The model has been well calibrated and validated for Chinese agroecosystems (Li *et al.* 2005; Li *et al.* 2007). The objectives of this study are to (i) validate and apply the WNMM model to simulate water movement and the fate of the nitrogen, and (ii) to optimize water and nitrogen management for maize cropping, in a desert oasis as a basis for devising best management practices (BMPs).

Materials and methods

Study area and field experiment

The study area is located in Left Banner, western Inner Mongolia, China (37°24'-41°52' N and 103°21'-106°51' E). The average annual precipitation is 116 mm of which 70-80% is concentrated during the summer season. The annual average temperature is 8.3 °C. The groundwater depth is about 40-70 m and is the only source of irrigation water. The oasis cropping system is a single crop produced annually from the middle of April to early October. The experimental site was located in the mid-south of the Chahantan oasis. A soil profile pit was excavated to 2.0 m and samples of soil textural layers were collected for analysis of basic physicochemical properties. Maize (*Zea mays L*) was planted on April 15 and harvested on Sep. 26, 2005. There were two irrigation and fertilizer treatments: traditional management practice (T1) and improved management practice (T2). The plot size was 20 m×20 m, with five replicates. For the traditional practice, the plots received 165 mm/d water for each of five irrigation events. For T2, the plots received 105, 135, 135, 135 and 120 mm/d water for the five irrigation events, respectively, based on the suggestions from local farm experts. The irrigations occurred on day 55, 73, 93, 118 and 142 after the planting. Diammonium phosphate at 225 kg/ha was applied as a basal fertilizer on April 15. Urea was surface-applied just before the first irrigation for both treatments at a rate of 138 kg N/ha. Since the nitrogen input from irrigation under treatment T2 was less than that under treatment T1 (the average NO_3-N concentration of the irrigation water was 28.5 mg N/L), additional urea (138 kg N/ha) was applied at the third irrigation for treatment T2. In each plot for all 5 replicates, the soil volumetric water content was measured every 7 days using TDR probes at 10 cm intervals to a depth of 180 cm. Soil samples from depths of 0-35, 35-47, 47-63, 63-70, 70-80, 80-85, 85-97, 97-140, and 140-180 cm were collected at four times: before sowing, on day 82 and 117 after planting, and at harvest. Each fresh soil sample was extracted with 1 mol/L KCl and the concentrations of NH_4-N and NO_3-N were determined using a Continuous Flow Analyzer. Crop height, leaf area index, root depth and density, dry matter weights and nitrogen contents of all plant parts (root, stem, leaf, tassel and cob) at the key plant development stages were determined. Grain yield was measured at harvest.

Simulation scenarios

Crop yield, nitrate leaching, water drainage, and water use efficiency (WUE) under various agricultural management practices were simulated by the WNMM model (Li *et al.* 2007). To optimize irrigation and N fertilizer management practices 1700 numerical simulations were conducted for the following scenarios: 1) varying the total irrigation inputs from between 300 and 900 mm with increments of 60 mm; 2) varying irrigation events from 3 to 11; 3) varying total fertilizer application inputs from 75 to 300 kg N/ha with increments of 15 kg N/ha; and 4) varying the fertilizer application events from 1 to 4. The maximal irrigation rate was set to 160 mm/d and the minimal rate was set to 60 mm/d, with the same intervals between sowing and harvest. The fertilizer application dates were 0, 55, 93 and 126 days after planting which corresponded with the key stages of maize growth: sowing, jointing, heading, and grain-filling, respectively. The numbers of scenarios for water and fertilizer inputs were 68 and 25 respectively, so the total number of scenarios combining variable amounts and times of water and fertilizer practices was 1700. The modelling of the scenarios described above was conducted by varying each parameter one at a time whilst holding the values of the other parameters at their default levels.

Results

The model input parameters, including soil hydraulic properties, dispersivity and diffusion coefficients, crop development, C and N transformation parameters, were presented previously (Hu *et al.* 2009). Data from treatment T1 were used to calibrate the model. Soil nitrogen transformation parameters were adjusted by comparing the simulated and measured data. Data from treatment T2 were then used to validate the model. The preliminary results showed that the WNMM model was suitable for simulating water movement, the N cycle, and maize growth under various agricultural management practices in the study area (Hu *et al.* 2009). The simulation results indicated that nitrogen losses by ammonia volatilization and denitrification were very small from these sandy soils of the desert oasis. However, loss by nitrate leaching was very large. Under the traditional management practices about 35% of total water input and 58% of total nitrogen input were lost from the 1.8-m soil profile. The water and nitrate inputs under treatments T1 and T2 far exceeded crop requirements. To reduce the nitrate leaching risk and to conserve water and fertilizer resources it is imperative to optimize the water and fertilizer application to match crop requirements.

The results for 1700 numerical simulation showed that irrigation and fertilizer practices had significant effects on the crop yield, WUE, water drainage and nitrate leaching. Quantitative analyses of the simulation outputs were conducted to derive BMPs for water and N applications by using evaluation indices that included crop yield, WUE, fertilizer N use efficiency (FNUE) and nitrate leaching. Their weights were set as +5, +3, +2 and -5 respectively. Results of the four evaluation indices from all the proposed scenarios were then normalized over a range of 0 to 1. An integrated index was then calculated by summing the product of the normalized indices and their corresponding weights. Table 1 summarizes the evaluation results for some selected scenarios. The treatment with 600 mm irrigation input, four irrigation times and 300 kg N/ha fertilizer input had the lowest integrated evaluation index. Under this situation, the nitrate leaching was 150.7 kg N/ha, and the crop yield only reached 57% of the maximum. The FNUE was 20.8 kg/kg/N. When the fertilizer application was reduced to a single application at a rate of 75 kg N/ha and the number of irrigations increased to 8, the FNUE was significantly improved to 67.5 kg/kg/N whilst the WUE increased from 19.0 to 26.2 kg/ha/mm, and the crop yield reached the maximum. This scenario had the highest integral evaluation index and may be used as the BMPs for maize in this region. The total irrigation area in the Chahantan oasis