Potential Impact of Climate Change on Subsurface Drainage in Iowa's Subsurface Drained Landscapes

R. Singh[1]; M. J. Helmers[2]; Amy L. Kaleita[3]; and Eugene S. Takle[4]

Abstract: The study presents hydrologic simulations assessing the potential impact of climate change on subsurface drainage and its pattern in Iowa's subsurface drained landscapes. The contemporary (representing the decade of 1990s) and future (representing the decade of 2040s) climatic scenarios were generated by downscaling the projections of global climatic model HadCM through two regional climatic models RegCM2 and HIRHAM to a regional grid box of $52-55\ \text{km}^2$, which contains Perry, IA. These climatic scenarios were used to drive the field scale deterministic hydrologic model DRAINMOD to simulate subsurface drainage from one of Iowa's predominant hydric soils, WEBSter, cultivated with Continuous Corn (WEBS_CC), and equipped with a conventional drainage system (30-m drain spacing at 1.2-m drain depth). The simulation results consistently indicate an increase in subsurface drainage from WEBS_CC under future climatic scenario as compared to contemporary climatic scenario. This increase in subsurface drainage would be more in the winter months (from December to March) and early spring months (from April to May) than summer and fall months. Since subsurface drainage is a primary carrier of nitrate-nitrogen (NO_3-N) from the agricultural lands, the extrapolation of this study simulations suggest that there would be a potential for increased NO_3-N loss from Iowa's subsurface drained landscapes under future (in the decade of 2040s) climatic conditions.

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Introduction

Subsurface drainage systems, predominately installed at the end of the 19th and during the first half of the 20th century, have been a necessary component in the conversion of the prairie-wetlands landscape into agricultural production areas in humid zones with poorly or somewhat poorly drained soils. Excess precipitation in the agricultural areas of Iowa and other Mississippi/Ohio River watersheds is removed artificially via subsurface drainage systems that intercept and divert it to surface waters. Subsurface drainage systems allow for timely seedbed preparation, planting and harvesting, and protect crops from extended periods of flooded soil and/or high water table conditions. In Iowa alone, about 3.6×10^6 ha of row crop area (about 39% of the total crop area in the state) benefits from subsurface drainage during the crop growing season from April to October (Baker et al. 2004). In general subsurface drainage also results in less surface runoff and thereby decreases the transport of pollutants such as sediment, phosphorus, ammonium-nitrogen (NH_4-N), bacteria, and pesticides to the receiving surface water bodies. However, the tradeoff for improved subsurface drainage is a significant increase in nitrate-nitrogen (NO_3-N) leaching loss ($8-20\ \text{mg l}^{-1}$) from agricultural fields (Gilliam et al. 1999). This movement of NO_3-N from agricultural fields via subsurface drainage waters is a major factor in nonpoint source pollution of surface waters and ultimately the Gulf of Mexico, where it has been implicated as a contributor to the hypoxic zone (Rabalais et al. 1996; Goolsby et al. 1999; Mitsch et al. 2001).

The existing subsurface drainage systems in Iowa are designed to remove excess precipitation and are commonly designed with a drainage coefficient of $0.95-1.27\ \text{cm day}^{-1}$ (Cooperative Extension Service, Iowa State University, 1987). Singh et al. (2006) found that a drainage intensity of $0.46\ \text{cm day}^{-1}$ was adequate to maximize crop production over a fourteen year (from 1990 to 2003) period in north-central Iowa. These drainage designs relative to drainage coefficient and drainage intensity are based on present and historic climatic conditions. However, since many of the drainage systems in Iowa were installed during the early and middle of the 20th century there will be significant replacement or rehabilitation of these systems in the future. Traditionally single lines of tile were installed at different spacings and angles to drain only "wet spots" in a field. With improved drainage technology farmers are tending to install tiles in a grid pattern throughout the field to improve drainage conditions and maximize crop production.

Climatic variables such as precipitation and temperature affect the hydrology and crop production in a certain region and thus play an important role in the design of subsurface drainage systems. In the coming decades, the climatic conditions are likely to

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change due to the anticipated increase in atmospheric concentrations of greenhouse gases (IPCC 2007). There is a large body of literature indicating that climate change is occurring; among the changes are differences in average temperature and precipitation distribution. By the end of 21st century there may be 20–40% increase in annual precipitation over much of the upper Midwestern United States including Iowa (Easterling and Karl 2001). The future climatic patterns may impact subsurface drainage, in particular, *the amount and timing of drainage water* and the corresponding crop production which may have both environmental and economic implications. There is a need to evaluate whether future climatic patterns may impact drainage design, subsurface drainage, and crop production in subsurface drained landscapes.

The objective of this study, therefore, was to assess the potential impact of climatic change on subsurface drainage in Iowa's subsurface drained landscapes. Hydrologic models are cost effective tools to estimate the potential impact of climate change on subsurface drainage hydrology and crop production in a region. Though hydrologic models are based on simplified mathematical representations of complex processes in the natural system, they are reasonably capable of integrating any changes to the system and offer a wide range of applications for drainage water management. In this study, the hydrologic model DRAINMOD (Skaggs 1978) was used to investigate the hydrology and corresponding impacts on crop production for one of the most common subsurface drained landscapes in Iowa: Webster soil cultivated with Continuous Corn. Generally, the potential impact of future climatic patterns on hydrology of a region is simulated by driving the model with predicted future climatic variables for that region. In recent decades researchers have been developing and actively using global and regional climatic models to construct scenarios of contemporary and future climatic conditions for certain regions (Giorgi et al. 1994; Rosenzweig et al. 2002). In this study, the contemporary (representing the decade of 1990s) and future (representing the decade of 2040s) climatic scenarios simulated by the global climatic model of Hadley Centre HadCM (Murphy 1995; Murphy and Mitchell 1995) were downscaled using two regional climatic models RegCM2 (Giorgi et al. 1993) and HIRHAM (Christensen et al. 1996) to a regional grid box of 52–55 km^2, respectively, which contains Perry, Iowa. The simulated climate data sets were first compared with the observed climate data set for Perry (IA), and then used to drive DRAINMOD to simulate the potential impact of predicted future climatic conditions on subsurface drainage in Iowa's subsurface drained landscapes.

Methods

Hydrologic Modeling

The field scale deterministic hydrologic model DRAINMOD (Skaggs 1978) simulates a soil-water regime of surface and subsurface drainage systems and predicts surface runoff, infiltration, evapotranspiration, subsurface drainage, and seepage (vertical and lateral) from subsurface drained landscapes. A basic relationship of the model is a water balance for a vertical soil column of unit surface area, which extends from the impermeable layer up to the soil surface, and located midway between adjacent drains (Skaggs 1978). The average depth of surface depression storage characterizes surface runoff, which begins when surface depressions are filled. The rates of infiltration, evapotranspiration, drainage, and distribution of soil water in the profile are computed by approximate methods, which have been tested and validated for a range of soil and boundary conditions (Skaggs 1980). The Green-Ampt equation (Green and Ampt 1911) characterizes the infiltration rates through a soil profile. The potential evapotranspiration is calculated by the method of Thornthwaite (1948) and then reduced to actual evapotranspiration depending on the weather and soil water conditions (Skaggs 1980).

Following the Dupuit-Forchheimer (DF) assumptions and considering flow in the saturated zone only, the subsurface drainage flux into the subsurface drains is calculated with the Hooghoudt steady-state equation with a correction for convergence near the drains (Van Schilfgaarde 1974)

$$q = 4K_e m(2d_e + m)/L^2 \qquad (1)$$

where q=lateral drainage flux (L T^{-1}), K_e=effective lateral hydraulic conductivity (L T^{-1}) below the water table, m=midpoint water table height above the drains (L), d_e=equivalent depth from drain to the impermeable (restrictive) layer (L), and L=drain spacing (L). The equivalent depth d_e is determined as a function of the depth from drain to the impermeable layer and drain spacing (Moody 1967). The Hooghoudt equation assumes an elliptical water table. Sometimes excess precipitation may raise the water table to the soil surface and cause water to remain on the surface for relatively long periods. In case of surface ponding, the application of Hooghoudt's equation based on the DF assumptions has limitations to calculate the subsurface drainage flux into the subsurface drains since the streamlines will be concentrated near the drains with most of the water entering the soil surface in that vicinity (Kirkham 1957). DRAINMOD calculates the subsurface drainage flux from a ponded surface using the equation derived by Kirkham (1957) for surface ponding conditions.

Seepage rates from the soil profile are calculated with a straightforward application of Darcy's law for vertical seepage, and the DF discharge formula for lateral seepage. DRAINMOD also has been modified to include soil temperature processes simulating soil freezing/thawing in cold conditions (Luo et al. 2000; 2001). Crop production is expressed as relative yield (actual yield/potential yield) accounting for excess water, drought, and delayed planting stress on crop production. A detailed description of crop stress simulations incorporated in DRAINMOD are given in Hardjoamidjojo et al. (1982), Evans et al. (1991), and Kanwar et al. (1994).

Subsurface Drainage System

Predominant hydric soils, which need subsurface drainage in Iowa's agricultural lands, are Webster (fine loamy, mixed, superactive, mesic) and Canisteo (fine loamy, mixed, superactive, calcareous, mesic) accounting for 23% of 3.6×10^6 ha of total hydric soils in Iowa (ISPAID 2004). These soils are predominantly cultivated with continuous corn or corn-soybean in rotation. In this study, we simulated the Webster soil cultivated with Continuous Corn, referred to as WEBS_CC hereafter. The Iowa Drainage Guide (Cooperative Extension Service, Iowa State University 1987) recommends for Webster soil a drain spacing of 18–24 m at drain depth of 0.90 m or a drain spacing of 24–30 m at drain depth of 1.20 m. These systems are generally operated with an approach of free drainage at the drain outlet. In this study, the recommended drainage system was simulated with a drain spacing of 30 m at drain depth of 1.20 m operated with free drainage at the drain outlet, referred to as Conventional Drainage System.

In addition to daily weather input parameters (precipitation and temperature), DRAINMOD requires soil, drainage system, crop, and trafficability input parameters to simulate WEBS_CC in Iowa's subsurface drained landscapes. These parameters were the same as summarized by Singh et al. (2006). They calibrated and validated DRAINMOD for WEBS_CC using the observed subsurface drainage from Webster soil experimental plots, located near Gilmore City (SW 1/4, Section 27, T92N, and R31W) in Pocahontas County, IA. The system being simulated was sufficiently represented with a correlation coefficient of 0.89 between the observed and simulated annual subsurface drainage (Singh et al. 2006). The cumulative subsurface drainage over the calibration and validation years from 1990 to 2003 was simulated only 2% higher (coefficient of mass residual=0.02) than the observed subsurface drainage from the Webster soil plots. The overall values of index of agreement (Willmott 1982) and model efficiency (Nash and Sutchliffe 1970) were higher than 0.85. These numbers provided confidence in DRAINMOD to simulate and predict subsurface drainage in Iowa's subsurface drained landscapes.

Contemporary and Future Climatic Scenarios

The weather input parameters were used to drive the model under contemporary and future climatic scenarios to estimate the potential impact of climate change on subsurface drainage in Iowa's subsurface drained landscapes. The required DRAINMOD weather input parameters, precipitation and daily maximum and minimum temperatures, were taken from regional climate models that were driven by a global model. We used two sets of climate data: a contemporary scenario (representing the decade of 1990s) and a future scenario (representing the decade of 2040s). These two scenarios were based on the results of global climate model HadCM of the Hadley Centre. HadCM is a coupled atmosphere-ocean model that uses a finite difference grid of 2.5° latitude by 3.75° longitude (about 300 km in midlatitudes) (Murphy 1995, Murphy and Mitchell 1995).

HadCM's resolution does not provide enough spatial climate detail to represent realistic subregional climates. Giorgi et al. (1994) showed that a nested regional model produces a more realistic simulation of precipitation over the United States than the driving global model alone, and also that the estimated changes in climate were different: precipitation changes differed locally in magnitude, sign, and seasonal details. Therefore, two fine grid resolution regional climate models, RegCM2 and HIRAM, were nested into the coarse grid global model HadCM to dynamically downscale global information to a sub-regional scale. The regional climatic model RegCM2 (Giorgi et al. 1993) simulations have a horizontal grid spacing of 52 km (Pan et al. 2001), while HIRHAM simulations have a horizontal grid spacing of 0.5° latitude by 0.5° longitude, approximately 55 km in our study region (Christensen et al. 1996). For this study, the model simulations were selected for the single grid box containing the Perry, IA study site. Both contemporary and future climatic data sets contain 9 years of climate realizations. The contemporary climate scenario corresponds roughly to the 1990s and is based on the HadCM simulations without enhanced greenhouse gas forcing and has a CO_2 level of 360 ppm. The future climate scenario corresponds roughly to the 2040s and is based on the transient HadCM simulations that assumed a 1%/year increase in effective greenhouse gases after 1990 and has a CO_2 level of about 500 ppm.

The RegCM2 and HIRHAM simulated contemporary data sets were compared with the observed weather (from 1981 to 1989) for a weather station located at Perry (41°50′N/94°07′W) in Dallas County, IA. The DRAINMOD simulations carried out using the climatic data sets simulated by RegCM2 and HIRHAM are referred to as RCMDM and HHMDM, respectively, hereafter (Fig. 1). These simulations provide a physically consistent set of results with which to analyze if future climate patterns might have an impact on subsurface drainage in Iowa's subsurface drained landscapes. Two different regional climatic model data sets were used with the aim of identifying the common pattern in the potential impact of climate change on subsurface drainage in the region.

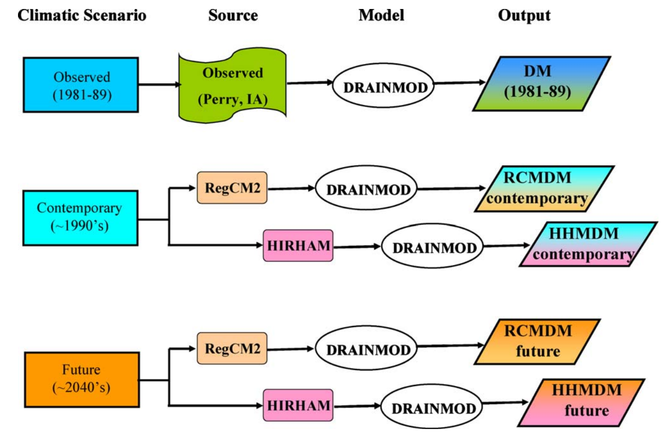

Fig. 1. Schematic representation of potential climatic change simulations in Iowa's subsurface drained landscapes

Results and Discussion

Climatic Change Projections

Precipitation is the key climatic variable for the hydrology of subsurface drainage systems in a given region. Table 1 summarizes the observed and simulated annual precipitation for the study site Perry, IA. The average annual contemporary precipitation simulated by RegCM2 was approximately 3.9% higher than the observed, while that simulated by HIRHAM was 9.2% lower than the observed. Both simulated contemporary climatic data sets showed precipitation in more regular occurrences of small events, where the observed data set included more days with no precipitation and more days with high precipitation. The tendency of simulating more light rain events and less intense events is common to both global and regional climate models at grid spacing of 50 km or larger, although regional climatic models are somewhat better than global climatic models (Mearns et al. 1995; Bell et al. 2004). Nonetheless, both contemporary climatic data sets simulated by RegCM2 and HIRHAM were reasonable repre-

Table 1. Observed and Simulated Precipitation for Perry, IA; Contemporary Refers to the Decade of 1990s and Future Refers to the Decade of 2040s

Weather data set	Mean daily (mm)	Median daily (mm)	Average annual [mm (in.)]
Observed (contemporary)	2.18	0	796 (31.3)
RegCM2 contemporary	2.26	0.3	827 (32.6)
HIRHAHM contemporary	1.98	0.3	722 (28.4)
RegCM2 future	2.81	0.5	1,027 (40.4)
HIRHAM future	2.60	0.4	951 (37.4)

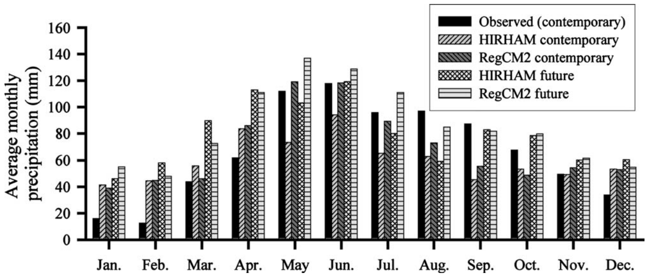

Fig. 2. Monthly distribution of observed and simulated precipitation for Perry, IA

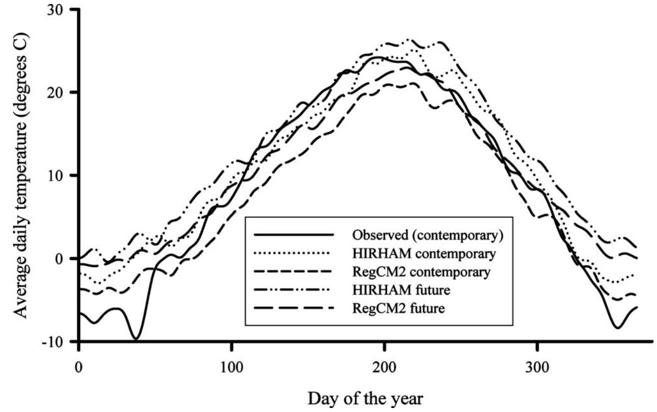

Fig. 3. Daily average observed and simulated temperature for Perry, IA. The lines represent 10-day *k*-smoothing averages to eliminate noise in the data and allow for easier visualization for data trends

sentations of realistic climate data for the study site especially since the simulated precipitation would not be expected to exactly reproduce the observed data; the simulated data represents *a plausible sequence of weather* for a location under contemporary greenhouse gas concentrations *rather than an expected sequence of actual weather* events.

In addition to total precipitation, the distribution of precipitation is also equally influential to subsurface drainage from Iowa's subsurface drained landscapes. Fig. 2 presents the monthly distribution of observed and simulated precipitation for Perry, IA. While the simulated precipitation had a more uniform distribution than the observed, the simulated contemporary scenarios still had greatest precipitation during the months from April to July, which is the predominant drainage season in Iowa (Helmers et al. 2005).

Most relevant to this study is how the simulated future climate data compare to the simulated contemporary climate data. As shown in Table 1, both RegCM2 and HIRHAM simulated an increase in the average annual precipitation (24% by RegCM2 and 32% by HIRHAM). The simulated precipitation for the future climate data showed an increased monthly precipitation compared to the simulated contemporary precipitation for most months with noticeable increases in the early spring period from March to May and then early fall period in September and October. Also of interest for this study are changes in temperature patterns, as this may influence evapotranspiration and thus affect the hydrology of subsurface drained landscapes. The simulated contemporary average temperatures were warmer than observed during the coldest periods of the year (Fig. 3). The HIRHAM contemporary temperatures were similar to the observed temperature during the major growing season but RegCM2 was slightly lower than the observed temperature. Comparing the simulated contemporary to future scenarios, the temporal distribution of temperatures were similar, but the magnitudes were changed: RegCM2 gave annual average future temperatures that were 2.7°C warmer than contemporary temperatures, and HIRHAM showed an average warming of 2.3°C. These projections of rising temperature and increase in precipitation correspond to the climate change projections over the upper Midwestern portion of United States in general (Easterling and Karl 2001).

Subsurface Drainage under Contemporary Climatic Conditions

Climatic variables such as precipitation and temperature govern the evapotranspiration and subsurface drainage and determine the hydrology of subsurface drained landscapes in a certain region. Fig. 4 with a strong correlation (R^2=0.83) shows that simulated subsurface drainage is highly sensitive to the interannual variability of weather conditions, in particular, precipitation in Iowa's subsurface drained landscapes. Helmers et al. (2005) also found a similar correlation between the observed precipitation and subsurface drainage during the crop season (from April to November) at experimental plots in north-central Iowa. Using the observed climatic data set (from 1981 to 1989) at Perry, IA (Fig. 1) the hydrologic model DRAINMOD simulated for WEBS_CC an average annual subsurface drainage of 181 mm, i.e., 23% of the average annual precipitation of 796 mm (Table 1). This was in a good agreement with the observed about 25% of precipitation (823 mm) as subsurface drainage (205 mm) at a field of 44.5 ha (dominated by Webster soil) located in the Walnut Creek watershed of the Des Moines Lobe landform region in Iowa (Bakhsh et al. 2001). This provides confidence that the hydrologic model DRAINMOD can be used to simulate the potential impact of climate change in terms of precipitation and temperature on subsurface drainage in Iowa's subsurface drained landscapes.

Since some differences were noted between the simulated and observed contemporary climatic data sets it would be expected that there would be some differences in subsurface drainage hydrology when comparing the DRAINMOD results using observed versus simulated contemporary climatic data sets. Despite this, it is useful to compare the results to evaluate if the results are consistent with expectations based on the climatic data sets. Since RegCM2 consistently had cooler temperatures and slightly more precipitation than the observed data set, as expected the RCMDM (RegCM2+DRAINMOD) gave more subsurface drainage and less evapotranspiration than the results from the DM (1981–1989)

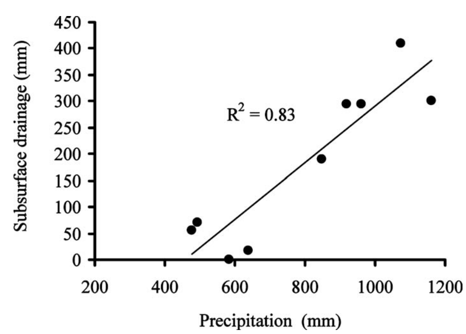

Fig. 4. Correlation between precipitation and simulated subsurface drainage of WEBS_CC under observed (1981–1989) climatic conditions for Perry, IA

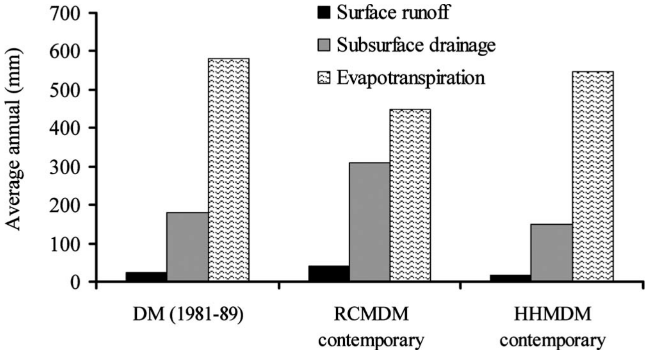

Fig. 5. Hydrological variables of WEBS_CC simulated using observed (1981–1989) climatic conditions and simulated contemporary climatic scenario for Perry, IA

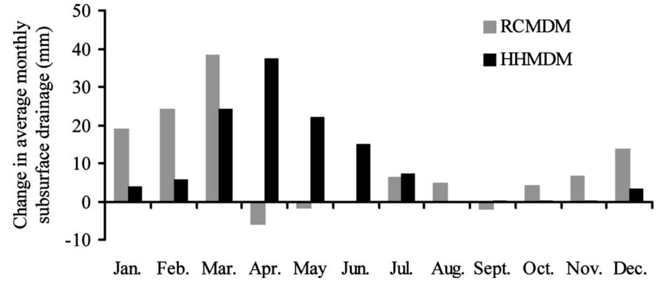

Fig. 7. Relative change in monthly subsurface drainage of WEBS_CC simulated using contemporary and future climatic scenario for Perry, IA

(observed+DRAINMOD) (Fig. 5). However, since HIRHAM had relatively similar temperature but slightly less precipitation than the observed data set, there was slightly less subsurface drainage but similar evapotranspiration in the HHMDM (HIRHAM +DRAINMOD) simulations when compared to the simulations with the DM (1981–1989) (Fig. 5). Overall, the DRAINMOD results follow the expected pattern based on the differences in climatic data sets.

Subsurface Drainage under Future Climatic Conditions

Of primary interest in this study is how the projected future climate change may impact subsurface drainage from Iowa's subsurface drained landscapes. Working on the basis that DRAINMOD accurately simulates subsurface drainage response to weather inputs in the study region, we can assess the type, direction, and scale of changes in subsurface drainage occurring with climate change by comparing model outputs simulated using the contemporary and future climatic data sets. In particular, we compared total average annual drainage volumes, monthly distribution of subsurface drainage, and crop productivity. We also analyzed whether current drainage system design recommendations would be sufficient under future climate conditions.

Both model combinations RCMDM (RegCM2+DRAINMOD) and HHMDM (HIRHAM+DRAINMOD) (Fig. 1) consistently simulated higher subsurface drainage in the future climatic scenario as compared to the contemporary climatic scenario (Fig. 6). According to RCMDM simulations there would be an increase of 35% in the average annual subsurface drainage from a 24% increase in the average annual precipitation. Similarly HHMDM simulated an increase of 80% in the average annual subsurface drainage from a 32% increase in the average annual precipitation.

The future climate patterns would not only increase the annual subsurface drainage amounts but also change the distribution of subsurface drainage over the year. Fig. 7 reproduces the simulated change (increase or decrease) in average monthly subsurface drainage under future climatic scenario as compared to contemporary climatic scenario. The RCMDM simulations showed that subsurface drainage under future climatic scenario would mainly increase in months from December to March, while HHMDM simulated the increase in months from March to June. However, both RCMDM and HHMDM simulations consistently suggested that there would be higher subsurface drainage in winter months from December to March under the future climatic scenario (Fig. 7). This might be attributed to the increased precipitation in winter months in the future climatic data set as compared to contemporary climatic data set (Fig. 2). There would also be more opportunity for infiltration, thereby increase in subsurface drainage due to less frozen soil as temperature is increased during winter months (Fig. 3).

The increased infiltration, however, could have a positive impact by decreasing the surface runoff. This was indicated by both RCMDM and HHMDM models simulating about 10 and 21% decrease in the average annual surface runoff, respectively, under the future climatic scenario as compared to the contemporary climatic scenario. The increased temperature in the future climatic scenario (Fig. 3) would also increase evapotranspiration from Iowa's subsurface drained landscapes as reflected by RCMDM and HHMDM models simulating about 21 and 19% increase in the average annual evapotranspiration, respectively, under future climatic scenario as compared to contemporary climatic scenario.

Changes in future climatic conditions are expected not only to impact the subsurface drainage hydrology but also crop production in Iowa's subsurface drained landscapes. As a result, the optimal drainage design for maintaining crop productivity could also change; thus we investigated this question. Crop production in DRAINMOD is expressed as relative yield (actual yield/potential yield) accounting for excess water, drought and delayed planting stress impacts on crop production. As expected, the simulations resulted in different relative yield responses for WEBS_CC simulated with different climate data sets simulated by RegCM2 and HIRHAM models. However, both RCMDM and

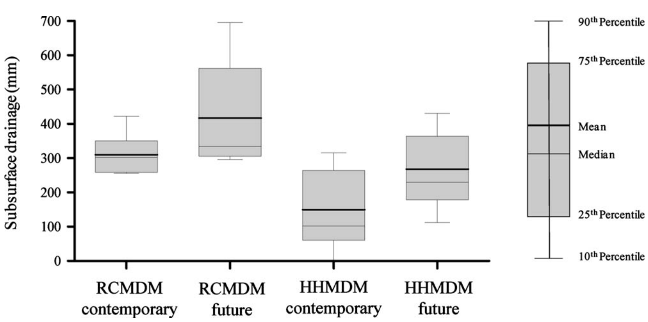

Fig. 6. Subsurface drainage of WEBS_CC simulated using contemporary and future climatic scenario for Perry, IA

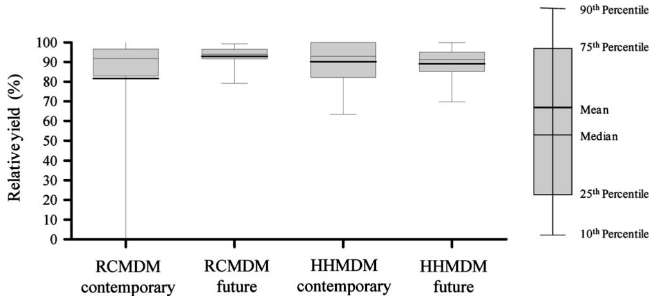

Fig. 8. Relative yield response of WEBS CC simulated using contemporary and future climatic scenario for Perry, IA

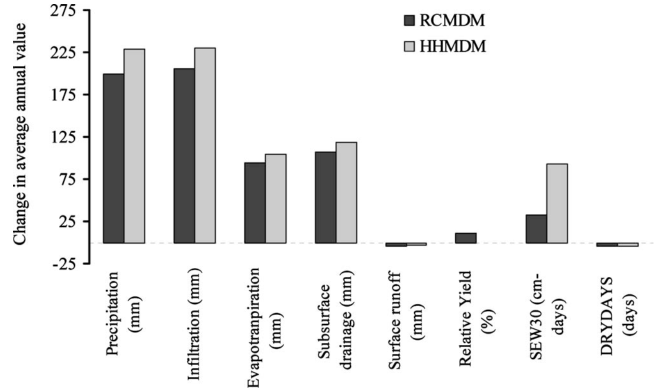

Fig. 10. Relative change in average annual values of different variables of WEBS_CC simulated using contemporary and future climatic scenario for Perry, IA

HHMDM simulations indicated that the recommended conventional drainage design with a drain spacing of 30 m at drain depth of 1.20 m (Cooperative Extension Service, Iowa State University 1987) would be able to maintain the average crop production level (>80% relative yields) of WEBS_CC under future climatic conditions (Fig. 8).

Subsurface drainage systems are installed to remove excess amount of water from the soil profile to protect crops from the extended periods of flooded soil and/or high water table conditions. The occurrence of high water tables in DRAINMOD could be expressed by SEW30 (cm days) defined as the sum of excess water in the upper 30 cm of soil profile (Skaggs 1978). Generally, crop production deceases for SEW30 values greater than 100 cm days. In this study, both RCMDM and HHMDM simulations indicated that the SEW30 values for conventional drainage design may increase under future climatic conditions (Fig. 9). This increased waterlogging may put excess water stress on crop production thereby reduce crop yields. Rosenzweig et al. (2002) also simulated that there would be increased crop damage, nearly double by 2030, due to excess soil moisture under climatic change scenarios as compared to present day conditions in U.S. Corn belt including Iowa. However, Fig. 8 shows that mean relative yields were equal or even higher under future climatic conditions. This is due to the fact that future climatic patterns also reduced drought stress on crop production, as indicated by the decreased number of dry days (Fig. 9). Future climatic precipitation patterns, therefore, may have both positive impact by reducing the drought stress (DRYDAYS) in the later part of growing season (from August to October), and negative impact by increasing waterlogging (SEW30) in the early part of growing season (from April to May). To reduce the negative impact of waterlogging in early growing season, farmers may tend to increase drainage intensity by installing tile drains narrower than the recommended conventional drainage design (24–30 m spacing at 1.2 m depth). Decreasing the drain spacing would result in a further increase in subsurface drainage since subsurface drainage increases with decreased drain spacing (Singh et al. 2006).

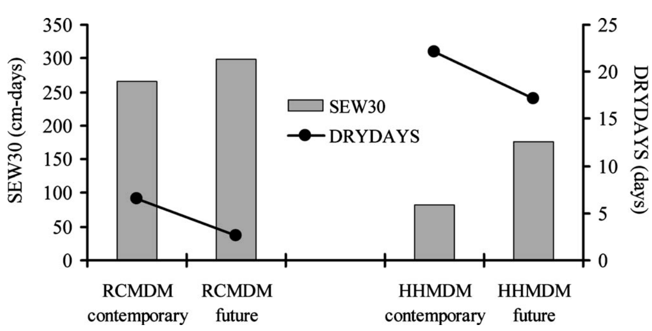

Fig. 9. Average sum of excess water in upper 30 cm soil profile (SEW30) and DRYDAYS of WEBS_CC simulated using contemporary and future climatic scenario for Perry, IA

Concluding Remarks

The benefits of subsurface drainage in terms of increased crop production are evident in Iowa and other Mississippi/Ohio River watersheds, but it has been identified as a major source of pollution transporting nutrient (nitrate) from agricultural lands to surface water bodies. Climatic conditions play a significant role in determining the hydrology and crop production benefits of subsurface drainage in a region. With the anticipated increase in CO_2 levels there are projections of an increase in temperature and annual precipitation over much of the upper Midwestern United States. These future climatic patterns may impact subsurface drainage, in particular, the amount and timing of drainage water and the corresponding crop production which may have both environmental and economic implications. Addressing this research need the present study was designed to simulate the potential impact of climate change on subsurface drainage in Iowa's subsurface drained landscapes.

The regional climatic models, RegCM2 and HIRAM, nested into the coarse grid HadCM global climatic model predicted that there could be an increase of 24 to 32% in the average annual precipitation, and days would be 2.3–2.7°C warmer in Perry, IA in the decade of the 2040s. With the contemporary (representing the decade of 1990s) and future (representing the decade of 2040s) climate variables as input the hydrologic model DRAINMOD consistently simulated an increase in subsurface drainage, an increase in evapotranspiration, and a slight decrease in surface runoff under the future climatic scenario as compared to the contemporary climatic scenario (Fig. 10). The future climatic patterns would not only increase the annual subsurface drainage amounts but also the distribution of subsurface drainage over the year. There would be more subsurface drainage during the winter months, from December to March, in the region.

In addition to predicting increased subsurface drainage, future climatic patterns also indicated an increase in excess water stress on crop production by increasing waterlogging intensity (SEW30) in the early part of growing season (from April to May), but the future climate patterns indicated a benefit to crop production by decreasing drought (DRYDAYS) in the later part of growing season (from August to October). As a result, to remove excess water stress in early season farmers may tend to increase drainage intensity by installing tile drains at reduced spacing, which would further increase subsurface drainage from Iowa's subsurface drained landscapes. If in-field drainage systems are designed with reduced drain spacing, this would require increased capacity of the entire drainage network system and this factor would need to be considered in future drainage network design.

Since subsurface drainage is a primary carrier of nutrients (nitrate-nitrogen) from the agricultural lands (Gilliam et al. 1999), the extrapolation of the presented simulations suggests that if crop practices remain consistent there would be the potential for increased NO_3-N loss from Iowa's subsurface drained landscapes under future climatic conditions. This would place increased emphasis on efforts and implementation of best management practices to reduce nutrient loss from agricultural lands.

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