Effect of overhead irrigation on corn yield and quality under shallow water table conditions

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Abbas, H. and R. Sri Ranjan. 2016. Effect of overhead irrigation on corn yield and quality under shallow water table conditions. Canadian Biosystems Engineering/Le génie des bio systèmes au Canada 58: 1.33-1.44. Corn is a moisture sensitive crop and drought conditions during critical growth stages affect kernel yield and quality. The objective of this field research was to determine the impact of water contribution from shallow water table under overhead irrigation and no irrigation treatments on corn yield, in a fine sandy loam soil in Southern Manitoba. The study was conducted at two different sites (Canada Manitoba Crop Diversification Centre (CMCDC), and Hespler Farms). Compared to no irrigation treatment, the overhead-irrigated plots had a 16% (p = 0.021) and 9% (p = 0.025) significantly higher yield at CMCDC, and Hespler sites, respectively. The kernel quality, based on kernels passing through 14/64-mesh size, in overhead-irrigated plots was found to be significantly better in overhead-irrigated plots at CMCDC (p = 0.011) and Hespler (p = 0.003) sites compared to the non-irrigated treatment. The increased unsaturated hydraulic conductivity due to increased water content of the soil beneath the root zone in the irrigated treatment led to an increased upward migration of water from the shallow water table compared to the upward migration in the non-irrigated treatment. In the irrigated treatment, the irrigation water quality was better than the quality of the water supplied from the water table because groundwater had high concentration of nitrate (55 ppm). However, in the non-irrigated treatment, the precipitation alone was not sufficient to dilute the poor quality water from the water table leading to lower yield and poor kernel quality. Keywords: Water table level, overhead irrigation, corn root-zone, corn yield, kernel quality soil water content, upward flux.

INTRODUCTION
As a major irrigated crop, corn (Zea mays L.) is the most important staple crop after wheat and rice. It is widely used in human food items, livestock feeds, medical drugs, and fuels all over the world (World Bank 2011; MAFRI 2011). The total annual world production of corn is reported to be 600 million MT from an area of 118 million hectares (World Bank 2011). The USA is the world’s largest corn producer with an annual production of 3 x 10^8 MT, while China is the second largest producer with an annual corn production of 1.66 x 10^8 MT (FAO 2008). Canada’s corn production from an area of 1.25 x 10^6 ha yields 1.06 x 10^7 MT of which Manitoba’s share is 6.6 x 10^5 MT (Statistics Canada 2009). Corn is the fourth largest crop in Canada, following wheat, canola, and barley with respect to the production volume (Statistics Canada 2009). Ontario, Quebec and Manitoba are the three main corn producing Provinces of Canada.

Major factors affecting the corn yield include weather conditions (Morgan et al. 2003), nitrogen fertility, hybrid (Baron et al. 2006), previous crop (Anderson et al. 1997), plant population, tillage (Dinnes et al. 2002), irrigation depth, irrigation water quality, and method of application (Yazar et al. 2002). Of all these factors, irrigation management is one of the most important factors that affect the total corn yield.

The total growing season of corn could be divided into seven stages i.e. (1) vegetative growth, (2) silking, (3) blister, (4) milk, (5) dough, (6) dent, and (7) physiological maturity. Corn is sensitive to moisture stress, and the effect of water stress on corn is different at different
growth stages of corn (Otegui et al. 1995). Drought stress during the periods of peak water demand may limit the plant growth and production. Many studies showed that water stress at critical growth stages of corn led to reduced growth, delayed maturity, and reduced biomass and corn grain yield due to the reduction in number of kernels per ear or the kernel weight (El-Hendawy and Schmidhalter 2010; Ko and Piccinni 2009; Payero et al. 2009; Di Paolo and Rinaldi 2008; Karam et al. 2003). Several authors reported that corn yield increased significantly with the application of supplemental irrigation during periods of high evapotranspiration (ET) (Farre and Faci 2006; Yazar et al. 1999). Karam et al. (2003) reported reduction in total yield, and leaf area index under water stress conditions. Pandey et al. (2000) reported 26% yield reduction, and a significant decrease in kernel number, and weight under drought conditions. Shaw (1974) reported that the corn plant is tolerant to water stress during the first 30 days after planting. Moisture stress approximately two weeks before silking until two to three weeks after silking can cause significant reduction in corn yield (Frey 1981). The drought conditions before silking stage may lead to poorly developed ears, while moisture deficit conditions during the silking stage leads to a decrease in kernel number per cob (Karam et al. 2003). Doorenbos and Kassam (1979) reported that 25.4 mm (1-inch) ET deficit resulted in 7% yield reduction during vegetative growth stage, up to 22% during flowering stage, and up to 4% during the dough stage. Heiniger (2001) reported that water stress during the mid-vegetative growth stage can decrease the corn yield by 25%; water stress during the silking stage can decrease the yield by 50%, and water stress during the dough stage can cause a 21% yield reduction. Several other studies have reported reductions in kernel numbers resulting from soil moisture stress at silking and early grain fill stages (Prosser et al. 2015; Chun et al. 2011; Hundal and Takhar 2010; Joris et al. 2013; Jones et al. 2015; Khodarahmpour 2011). Nesmith and Ritchie (1992) reported 21 to 40% yield reduction due to water stress during the grain filling stage.

Overhead irrigation systems e.g. linear move irrigation system, and travelling gun systems are generally used for irrigating the corn crop in Southern Manitoba. In a linear move irrigation system, a single motorized lateral with sprinklers moves in a linear path watering the entire width of the field in one pass. The travelling gun waters the field with a large sprinkler mounted on a wheeled cart connected to a hose reel, which receives the water supply from an irrigation pipeline. Major advantages of these systems include convenience, application uniformity, relatively higher water use efficiency compared to other types of irrigation systems.

In the Canadian Prairies, in areas with a heavier soil beneath the root zone, the water table is relatively shallower during the early part of the growing season due to spring snowmelt infiltration. Ayars et al. (2006) reported that shallow water table closer to the bottom of the root zone of the crop has the potential to contribute towards crop water demand during periods of drought. The irrigation requirements may be decreased or completely eliminated by the upward migration from the shallow water table (Prathapar and Qureshi 1999; Beltrao et al. 1996). The water uptake potential of plant from the shallow water table depends on plant root depth as well as the location of the water table. Deep-rooted crops influence ground water by direct uptake from the saturated zone or the capillary fringe above it (Nosetto et al. 2007). Increased uptake of water from the water table by plant roots may lead to lowering of the water table as compared to the surrounding environment (Heuperman 1999). Therefore, deeper plant roots have the ability to draw moisture from shallow water table to replenish full or a part of the ET and has a positive impact on crop productivity. McKevin et al. (1998) reported some negative impacts of shallow water table including water logging and reduced root zone aeration. They found that water logging caused by shallow water table led to decreased root activity, nutrient availability, plant germination which led to subsequent yield losses. Ayars et al. (2006) observed a decrease in water table contribution with an increase in water table depth and/or irrigation quantity. It shows that if supplemental irrigation is decreased, the shallow water table may contribute to meet the crop water demand.

Folleti et al. (1974) have shown evidence of water table contribution on corn yield. They reported an increase in yield under shallow water table conditions (0.5 m) in sandy loam soil. Torres and Hanks (1989) reported that no irrigation is required for corn crop, if the water table remains at a depth < 1.2 m during the growing season in sandy loam soil. On the contrary, Rathore et al. (1996) reported decreased corn yield at water table depth < 0.8 m in sandy clay loam soil. Kalita and Kanwar (1992) investigated the effect of shallow water table on corn yield in loamy soil structure by keeping the water table at 0.3, 0.6, and 0.9 m depth. They found that corn yields increased significantly with increasing water table depths from shallower to deeper indicating the importance of root zone aeration.

Yield reduction caused by moisture stress and water table contribution towards crop water demand may vary with location. Metrological conditions and soil type of the location are the most important factors affecting the crop water requirement. Only a few studies have been reported about the effect of shallow water table on corn yield in the Canadian Prairies. A combination of shallow water table and overhead irrigation can play an important role in the water balance within the corn root zone provided that water quality is adequate to achieve the higher yield goals. The objective of this study was to determine the impact of water table contribution under overhead irrigation and no irrigation treatments on soil moisture availability within the corn root zone and subsequent grain yield and quality under southern Manitoba conditions.
MATERIALS AND METHODS

Study sites
The experimental site was located in the south of Winkler (49° 10'N Lat., -97° 56'W Long., 272-m elevation), Manitoba, Canada, during the 2014 growing season. The growing season in this area usually starts from May and lasts up to October. Two sites, located approximately one km apart from each other, were selected for this experiment. The first experimental location was the Canada Manitoba Crop Diversification Center (CMCDC) farm while the second location was the Hespler Farm. The soil in the area is a sandy loam texture and belongs to the Reinland Series (Podolsky 1991; Manitoba Soil Survey 1973), which is an imperfectly drained Gleyed Rego Black soil (MAFRI 2010). The textural percentages of the soil are 69, 20, and 11% for the sand, silt, and clay fractions, respectively. In sandy loam soils, corn roots could go up to 1.3 m deep. Corn growers in this area generally rely on rainfall for meeting the major water demand and use overhead irrigation to supplement crop water demand during the deficit period to ensure higher yield. The average temperature of the area ranges 12 to 22 °C during the growing season. The optimum temperature for corn growth is 16 to 24 °C (Smith et al. 2007). The growing season temperature of the area makes it very favourable for growth of corn. The 30-year average annual rainfall during the growing season was reported as 342 mm (Environment Canada 2010).

Experimental design
At CMCDC, the selected field area of 1.2 ha (2.97 ac) was divided into six equal plots of approximately 0.18 ha (0.44 ac). The dimension of each plot was 44.6 m by 40.3 m. At Hespler, an area of approximately 1.29 ha (3.19 ac) was divided into six equal plots with dimensions of 50 m by 44 m. The effect of two water management treatments: Irrigated (IR) and Non-Irrigated (NI), on corn yield and water uptake was compared. The field plots were replicated three times at each site. Corn was planted in all the plots. Supplemental irrigation was applied using overhead irrigation systems. The source of the supplemental irrigation water was a reservoir located 3 km west of the field, which was established to store the spring snowmelt runoff. The non-irrigated treatment was expected to rely only on natural precipitation to meet the crop water demand. Soil water contents were measured at the centre of each plot at 0.2 m intervals up to depth of 1.0 m from the ground surface throughout the growing season. Depth to the water table was continuously measured at the center of each experimental plot throughout the growing season.

Instrumentation and data collection
Soil water monitoring The EC-5 sensors (Decagon Devices, Pullman, WA) were installed in the center of each plot at 0.2, 0.4, 0.6, 0.8, and 1.0 m depth from the ground surface to measure the volumetric soil water contents. These probes were programmed to measure the soil water contents every 30 minutes throughout the growing season. The water content data from the EC-5 sensors were made available in real time through the Weather Innovations Network (WIN) website.

Water table monitoring Observation wells (piezometers) made of 2.5 m long and 2-inches diameter metal pipes were installed manually using a soil auger in the center of each plot. In order to monitor the local groundwater flow, observation wells were also installed in the surrounding plots of the experimental field. A water level sensor (Solinst Levelogger Junior 3001, Solinst Canada, Ltd., Georgetown, ON, Canada) was suspended inside each well to monitor the water table level below the ground surface throughout the growing season. These sensors were set to record the water table level every 30 minutes. A barometric pressure sensor (Solinst Barologger Gold, Solinst Canada, Ltd., Georgetown, ON, Canada) was installed in the manhole nearby the experimental plots to do the barometric correction of the water table sensor data. Groundwater quality analyses were done prior to the study. An average nitrate concentration of 55 ppm was found in the groundwater samples of both study sites.

Weather variables recording Manitoba Agriculture Weather Network station located on the site (Spectrum Technologies, Inc. Weather Station 2000 Series) was used to record the minimum, maximum, and average daily temperature, relative humidity, solar radiation, wind speed and direction, and precipitation on a daily basis. Daily reference evapotranspiration (ET₀) was calculated by the Penman-Montieth method (Allen et al. 1998). Daily crop evapotranspiration (ETᵣ) was calculated by:

\[
ETᵣ = Kᵣ \cdot ET₀
\]  

where, \(ETᵣ\) is the crop evapotranspiration (mm), \(Kᵣ\) is the crop coefficient for corn, and \(ET₀\) is reference evapotranspiration (mm).

Supplemental irrigation application
The whole growing season was divided into three growth periods i.e. initial, mid, and final. Initial growth period consisted of vegetative growth stage. Mid growth period consisted of silking, blister, and milk stages. Final growth stage consisted of dough, dent, and maturity stages. During the initial growth period (vegetative stage), supplemental irrigation was not applied at both sites because rainfall was sufficient to meet the crop water demand. Supplemental irrigation was applied during mid (Silking, Blister, and Milk stages), and final (Dough, Dent, and Maturity stages) growth periods at both sites. The total rainfall depth was reported as 29 mm and 15 mm at CMCDC and Hespler Farms, respectively, between the first and last irrigation events.

Overhead irrigation was applied in the irrigated plots using a linear move irrigation system (O3000 Orbitor, Nelson Irrigation Corporation, Walla Walla, WA) at the CMCDC and a travelling gun irrigation system (Ag-Rain, Kifco Inc., Havana, IL) was used at the Hespler site. Depth of irrigation (mm) was determined on the basis of growth period, rooting depth, and evapotranspiration. The irrigation rate of overhead irrigation systems was adjusted...
to meet the daily ET demand of the potato crop. In-field rain gauges were used to measure irrigation application rates. At CMCDC farm, a total of 140 mm overhead irrigation was applied to replenish the full ET using eight irrigation events with a dedicated linear move overhead irrigation system. The Hespler Farm site was part of a commercial operation managed by a local farmer who used the travelling gun system to irrigate this site and neighboring fields. Therefore, the irrigation interval and schedule was impacted by the off-site irrigation operations resulting in a 30% lower (95 mm) overhead irrigation application depth using five irrigation events.

**Agronomic Protocols**

In Manitoba, corn is commonly grown in rotation with potatoes to prevent the disease spreading, and reduces the impact of insects. In order to prepare the seed bed and to cut up the vines from the previous season potato crop, all plots were tilled up to 0.08 m depth using a super coulter (Summers Manufacturing Company, Inc., Devils Lake, ND) in early May. Fertilizer (N, P, K, and S) rates for the study area were determined by soil test results. Fertilizer was applied using the broadcast method and were incorporated into the soil using a chisel plough. Fungicides were applied on a weekly basis whereas herbicides and insecticides were applied based on the detection of pests. All plots were seeded to corn hybrid ‘Pioneer 39B94’ on May 16, 2014. Harvesting was done on October 22, 2014 at the Hespler farm, and October 23, 2014 at the CMCDC farm. Yield was measured by hand harvesting 20-m long portions of the row in the center of each plot.

**Post-harvest handling**

Corn quality analysis was done at the Agriculture and Agri-Food Canada laboratory located at Portage-La-Prairie. The harvested corn kernels from each of the 20-m row were used to obtain the total weight including oversize kernels, standard size kernels, broken corn, and dockage (any material intermixed with corn kernels). Then the corn samples were poured on the round-hole sieve of the corn grader having a top sieve size of 24/64 and bottom sieve of size 14/64. The sieves were shaken and the foreign material remaining on the top of the 24/64 was discarded and oversized corn kernels remaining on the 14/64 sieves were collected and weighed as over-sized kernel. All standard-sized corn kernels passing through the 14/64 round sieve were collected and weighed to obtain the standard size kernels. A fan blowing across the sieves removed the impurities and broken corn kernels which collected in another container along with material retained by the 24/64 sieve which were then weighed to obtain the dockage. Weight of the standard size kernels was determined as follows:

\[
\text{Wt. of standard-sized kernels} = \text{Total wt.} - (\text{Wt. of oversized-kernels} + \text{Wt. of dockage})
\]

A 250 g corn sample was used to determine the moisture content using a grain moisture meter (Labtronics, Model 919). Yields were corrected to 15% moisture content.

**Statistical analysis**

The comparison of means was done separately for the two different locations and the results are presented separately. Final yield, kernel quality, and growth period specific water table depth data were analyzed by comparing means of treatments within the same site using Student’s t-test at the 0.05 significance level (JMP software, Ver. 8, SAS Institute, Inc., Cary, N.C.). The relationship between growth period specific average water table depth and the final corn yield for the CMCDC farm and Hespler farm was determined using regression analysis (MS Excel, Ver. 2010, Microsoft Corporation).

**RESULTS AND DISCUSSION**

**Weather conditions at study sites**

The weather data from the CMCDC site is presented in Fig. 1. During the growing season, the average \(T_{\text{max}}\) and \(T_{\text{min}}\) were recorded as 23 °C and 9.5 °C, respectively. (Environment Canada 2010) has reported the average 30-years (1971-2000) rainfall for the study area as 342 mm between May and September. The 2014 growing season experienced relatively drier conditions with a lower rainfall (262 mm) compared to the 30-year (1971-2000) average. As both study sites were located approximately 1.5 km apart from each other, the meteorological history of both sites as reported was similar. Figure 1 shows the mean monthly rainfall along with the 30-year average for the growing season.

Except for the month of June and August, the experimental site received much lower precipitation compared to the 30-year average precipitation. May, July, and September were drier months with only 19, 33, and 18 mm rainfall, respectively. The month of June (vegetative period) experienced higher rainfall (101 mm) compared to the 30-year average. Lesser than normal precipitation, resulted in drought conditions during the month of July, which coincided with the period of comparatively higher ET due to the larger number of days with > 25 °C.

![Fig. 1. Comparison of precipitation between 30-year average and the 2014-year at the CMCDC Site.](image-url)
Corn yield and quality
The total growing season spanned 159 days. Compared to the no irrigation treatment, the overhead-irrigated plots had a 16% (p = 0.021) and 9% (p = 0.025) significantly higher corn yield at CMCDC and Hespler sites, respectively (Fig. 2). The average yield obtained from both treatments was considerably higher than the Manitoba’s 10-year (2000-2009) average of 4.80 Mg ha⁻¹ as reported by Manitoba Agricultural Services Corporation (2009).

The kernel quality is determined on the basis of standard sized kernels, which pass through 14/64-mesh size. Standard size kernels were obtained after removing oversize kernels, broken kernels, and dockage (any material intermixed with corn kernels) from corn yield samples of both treatments. The proportion of standard sized kernels was found to be significantly higher at both CMCDC (p = 0.011) and Hespler (p = 0.003) sites in overhead-irrigated plots compared to the non-irrigated plots (Fig. 3). Better availability of moisture within the corn root zone through the application of supplemental irrigation resulted in higher yield and better quality of kernels, as indicated by a larger proportion of standard-sized kernels, in the irrigated treatment.

Effect of water table depth on corn yield
Water levels monitored in piezometers in adjacent plots and outside the experimental area indicated no significant gradient to cause lateral flow. Drill log information from the site showed soft clay layers extending from 2.5 m to 5.5 m below the ground surface indicating restricted deep percolation (PFRA, 2007). Therefore, the decline in water table elevation was attributed to upward flux to meet the crop water demand. The final corn yields from both treatments were compared with the average water table depth associated with each growth period (Figs. 4 and 5).

Water table depth and upward flux
At both study sites, the average water table was deeper in the irrigated treatment as compared to the non-irrigated treatment at each growth period. Statistical analysis of the differences indicated that the difference was not significant during the initial growth period. However, during the mid- and final-periods, the average water table levels were significantly deeper in the irrigated treatment at CMCDC (p = 0.0001) and Hespler (p = 0.003) farms. The same trend was also observed in the irrigated treatment during the final period at CMCDC (p = 0.0006) and Hespler (p = 0.0001) farms (Fig. 6).

During the initial period, no irrigation was applied and the water table remained similar in both treatments. The main source of moisture for the plants during the initial period was precipitation. During the mid and final periods, the water table depth and total yield were positively correlated in the irrigated treatment while it was negatively correlated in the non-irrigated treatment at both sites. This suggests that the mid- and final-periods are more sensitive to lack of moisture and the moisture deficiency during these periods may have significantly impacted the total corn yield and quality. At the Hespler farms, the water table depth from the ground surface was shallower as compared to the CMCDC site. Although water table depths in the irrigated treatment were within the same range as the non-irrigated treatment several times during the mid- and final-periods, the higher soil moisture present in the irrigated treatment facilitated the upward migration of shallow groundwater. However, lower soil moisture within the root-zone of the non-irrigated treatment developed a hydraulic barrier between the groundwater table and the corn root-zone resulting in lower upward migration from the water table in the non-irrigated treatment.
Corn needs comparatively lower moisture during the initial and final periods of growth compared to the mid-period. During the initial period (vegetative stage), corn received 115 mm rainfall. Higher rainfall during this period met the crop water demand resulting in the decreased need for contribution from the shallow water table in both treatments. Therefore, the difference between water table levels in both treatments was not significantly different during the initial period during which no irrigation was carried out in both treatments. During the mid- and final-periods, higher ET and infrequent rainfall events necessitated supplemental irrigation to the irrigated treatment.
treatment via overhead irrigation systems. The overhead irrigation and rainfall events increased the unsaturated hydraulic conductivity of the soil layer between the bottom of the corn root-zone and the water table in the irrigated treatment as compared to the non-irrigated treatment. The increased unsaturated hydraulic conductivity, due to the application of the irrigation water, may have resulted in providing better hydraulic connection between the corn root-zone and the saturated zone coinciding with the water table. The upward flux of water from the water table to meet the corn water demand may have contributed to the lowering of the water table as compared to the surrounding environment. On the contrary, the drier conditions and lower than 30-year average seasonal rainfall may have led to a lower unsaturated hydraulic conductivity in the soil layer immediately below the root-zone in the non-irrigated treatment. This decreased unsaturated hydraulic conductivity may have impeded the upward flux of water from the water table to meet the crop water demand in the non-irrigated treatment as compared to the irrigated treatment. Therefore, the difference between water table levels in the two treatments was significantly higher in the irrigated treatment during the mid and final periods of growth at both sites. This water deficit experienced by the corn in the non-irrigated treatment may have contributed to the significantly lower yield as compared to that from the irrigated treatment.

**Water table response**

The seasonal average water table depths from the ground surface for both sites are shown in Table 1. A significant difference was found in the depth to the water table between the irrigated and non-irrigated treatments at both CMCDC (p = 0.053) and Hespler (p = 0.0001) sites.

Figures 7 and 8 show the relationship between the growing season water table depth from the ground surface and the recharge events at the CMCDC farm, and Hespler farm, respectively. The depth of the water table from the ground surface remained approximately the same in both treatments prior to the first irrigation event. After the first irrigation event, the water table in the irrigated treatment started to decline as compared to the non-irrigated treatment. The supplemental irrigation may have increased the unsaturated hydraulic conductivity of the soil layer between the bottom of the corn root-zone and the water table promoting the upward flux of water from the water table leading to a lowering of the water table in the irrigated plots.

**Table 1. Average daily water table depth from the ground surface over the growing season for overhead irrigated and non-irrigated treatments.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Water Table Depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CMCDC</td>
</tr>
<tr>
<td>Overhead Irrigated</td>
<td>1.79 a</td>
</tr>
<tr>
<td>Non-irrigated</td>
<td>1.73 b</td>
</tr>
</tbody>
</table>

The better moisture availability in the irrigated treatments due to the supply of water via overhead irrigation system and rainfall events led to better hydraulic connection between the root-zone and the saturated zone that resulted in relatively higher water table contribution in the irrigated treatment. Crop water demand started to gradually decrease as the corn growth stage proceeded towards maturation. As the demand for contribution of water from the water table to the plant roots started to decrease, the water table started to rise gradually as the growth stage proceeded towards maturation in late September. Regardless of the treatment, the water table level in the plots came very close to each other during the maturation stage when the ET was lower.
Soil water distribution within the corn root-zone

Soil water contents were measured using EC-5 sensors (Decagon Devices, Pullman, WA) at 0.2 m intervals within the top 1 m depth of the soil profile throughout the growing season. The daily average volumetric soil water contents (SWC) within the corn root-zone for CMCDC, and Hespler farms are shown in Figs. 9 and 10, respectively. The top 0.2 m soil layer at both study sites were quite responsive to the recharge events (irrigation and/or precipitation). Soil water content quickly increased in the top 0.2 m layer after each irrigation and/or rainfall event. The plants used a part of the recharged water and the remaining water redistributed into the deeper soil layers. It may have led to an increase in the unsaturated hydraulic conductivity of the soil within the corn root-zone and the soil profile below the root-zone. As a result, water from the water table moved up into the root-zone by upward flux.

In both treatments, soil water content within the soil profile remained very close to each other at each depth prior to the first irrigation event. Soil water content increased in the irrigated treatment within the top 0.2 m to 0.6 m soil layers after each irrigation and/or rainfall event. However, in the non-irrigated treatment, soil water content increased only after each rainfall event. The bottom layers of both treatments were receiving infiltrated part of the recharged water as well as the upward flux from the shallow water table. This upward flux from the shallow water table may have met a part of the plant water requirement.

Growth period specific average soil water contents (volumetric) for CMCDC farm, and Hespler farm are given in Table 2 and 3, respectively. At both sites, average soil water contents were significantly higher in the irrigated treatment as compared to the non-irrigated treatment from ground surface to 1.0 m depth during initial, mid, and final growth periods. However, soil water contents within the soil profile were not significantly different at initial period. Supplemental irrigation was applied during the mid- and final-periods at both sites. The application of irrigation, precipitation, and relatively higher potential of upward movement of shallow groundwater increased the soil water content within the soil profile in the irrigated treatment as compared to the non-irrigated treatment. However, the non-irrigated treatment was receiving water from rainfall and shallow ground water table as a result of upward flux of groundwater to meet the plant water requirement.

**CONCLUSION**

The purpose of the study was to investigate the impact of overhead irrigation on corn yield and quality under Manitoba conditions at two different sites. A significantly higher corn yields (16%) (p = 0.021) and (9%) (p = 0.025) were observed in the irrigated treatments as compared to the non-irrigated treatment at CMCDC and Hespler sites, respectively. Significantly higher corn yield in the irrigated treatment showed the importance of the application of supplemental irrigation through overhead irrigation system in the Canadian Prairies.

A field research was conducted to determine the impact of water contribution from shallow water table under overhead irrigation and no irrigation treatments on corn yield, in a fine sandy loam soil in Southern Manitoba. Observation wells were installed in the surrounding plots of the experimental field to monitor the local groundwater gradient, no significant flow to the surrounding plots occurred in both treatments at both sites. Both treatments were receiving water through rainfall and by upward flux from the water table. However, supplemental irrigation resulted in better hydraulic connection allowing

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**Table 2. Growth period specific average volumetric water contents at CMCDC farm. (Different letters beside the means indicate significant difference (p = 0.05) between the treatments by depth within each growth stage; IR – Irrigated, NI – Non-irrigated)**

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>Depth (m)</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Period</td>
<td>IR</td>
<td>0.21 a</td>
<td>0.21 a</td>
<td>0.22 a</td>
<td>0.21 a</td>
<td>0.19 a</td>
</tr>
<tr>
<td></td>
<td>NI</td>
<td>0.20 a</td>
<td>0.19 b</td>
<td>0.23 a</td>
<td>0.21 b</td>
<td>0.19 a</td>
</tr>
<tr>
<td>Mid Period</td>
<td>IR</td>
<td>0.20 a</td>
<td>0.20 a</td>
<td>0.23 a</td>
<td>0.22 b</td>
<td>0.18 a</td>
</tr>
<tr>
<td>Final Period</td>
<td>IR</td>
<td>0.23 a</td>
<td>0.23 b</td>
<td>0.25 a</td>
<td>0.20 b</td>
<td>0.25 a</td>
</tr>
</tbody>
</table>

**Table 3. Growth period specific average volumetric water contents at Hespler farm. (Different letters beside the means indicate significant difference (p = 0.05) between the treatments by depth within each growth stage; IR – Irrigated, NI – Non-irrigated)**

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>Depth (m)</th>
<th>0.2</th>
<th>0.4</th>
<th>0.6</th>
<th>0.8</th>
<th>1.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Period</td>
<td>IR</td>
<td>0.24 a</td>
<td>0.23 a</td>
<td>0.24 a</td>
<td>0.23 b</td>
<td>0.26 a</td>
</tr>
<tr>
<td></td>
<td>NI</td>
<td>0.23 a</td>
<td>0.18 b</td>
<td>0.25 a</td>
<td>0.20 b</td>
<td>0.25 a</td>
</tr>
<tr>
<td>Mid Period</td>
<td>IR</td>
<td>0.24 a</td>
<td>0.23 b</td>
<td>0.27 a</td>
<td>0.24 b</td>
<td>0.25 a</td>
</tr>
<tr>
<td>Final Period</td>
<td>IR</td>
<td>0.24 a</td>
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<td>0.27 a</td>
<td>0.24 b</td>
<td>0.25 a</td>
</tr>
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significantly more upward flux from the water table at both sites. Overhead irrigation systems improved the unsaturated hydraulic conductivity of the soil below the root-zone in the irrigated treatment as compared to the non-irrigated treatment. Therefore, increased upward flux from the water table was observed in the irrigated treatment, which showed a corresponding decline in the water table. This upward flux of water increased the soil water content within the 0.8 to 1.0 m soil layers of both treatments. However, comparatively higher soil water content was observed in the irrigated treatment, which shows that the water table contribution was higher in the irrigated treatment as compared to the non-irrigated treatment.

The corn kernel quality is affected by the availability of nutrients and water. Groundwater quality analysis done prior to the study showed an average nitrate concentration of 55 ppm. Significantly lower yield in the non-irrigated treatment may be attributed to the dry conditions and contribution of poor quality water from the water table.

The potential contribution from shallow groundwater resources may be determined by observing the groundwater depth and weather conditions. On the basis of this information, depth of overhead irrigation or irrigation interval may be adjusted in irrigation scheduling. However, the groundwater quality should also be taken into account. Groundwater quality should be analysed to ensure it meets irrigation water quality standards. Similar studies could be conducted in different soil structures and crops to enable us to use the shallow groundwater effectively and to reduce the need for supplemental irrigation. The results indicate the contribution from shallow groundwater needs to be taken into account in irrigation scheduling.

Fig. 7. Water table depth, rainfall, and irrigation amounts at CMCDC farm.

Fig. 8. Water table depth, rainfall, and irrigation amounts at Hespler farm.
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