doi:10.2489/jswc.2022.00060

Capture of surface water runoff for irrigation of corn in western Illinois: Implications for nutrient loss reduction

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Abstract: Supplemental irrigation with the runoff from agricultural fields (runoff irrigation) not only has the potential to reuse nutrients in agricultural runoff but could potentially reduce fertilizer input to farms, leading to reduced nutrient export from agricultural fields. A three-year field study designed to evaluate the impact of runoff irrigation on corn (*Zea mays*) yield and nutrient uptake was conducted in a farmer-operated field at the Metropolitan Water Reclamation District of Greater Chicago (MWRD) site in Fulton County, Illinois. The study comprised three treatments: (1) 50% agronomic nitrogen (N) and phosphorus (P) fertilizer rates with no irrigation (control), (2) 50% agronomic N and P fertilizer rates with irrigation, and (3) 100% agronomic N and P fertilizer with no irrigation. Each treatment was assigned to a 76 m by 18 m plot, planted with corn in 2016, 2017, and 2018. Runoff irrigation increased grain, stover, and total dry matter yields by an average of 38%, 45%, and 27%, respectively, as compared to the control. On average, 50% agronomic fertilizer rate, coupled with runoff irrigation, produced similar grain yields as 100% agronomic fertilizer rate. At the 50% agronomic fertilizer rate, N uptake averaged 231 ± 37 kg N ha^{-1} in 2017 and 290 ± 54 kg N ha^{-1} in 2018 with irrigation, as compared to 162 ± 36 kg N ha^{-1} in 2017 and 179 ± 34 kg N ha^{-1} in 2018 without irrigation. Similarly, P uptake was greater with irrigation than without irrigation for the same P fertilizer rate. The fertilizer replacement value (FRV) of the runoff irrigation was estimated to be 73 kg N ha^{-1} and 6 kg P ha^{-1} in 2018. This represents a potential of reducing N and P fertilizer application rate by 30% and 8%, respectively, by supplemental irrigation without reducing corn yield. The runoff irrigation is a potential best management practice that can be further explored for adoption in Illinois for contributing to the statewide Nutrient Loss Reduction Strategy.

Key words: corn yield—fertilizer replacement value—irrigation runoff—nutrient loss—nutrient uptake

Nutrients exported from agricultural land have partly contributed to eutrophication and other negative impacts in aquatic ecosystems (Moog and Whiting 2002; Buda et al. 2009; Tiessen et al. 2010; Li et al. 2011; Smith et al. 2015). It is of concern in the midwestern United States, where off-site nutrient transport has been identified as a major contributor to the growing hypoxic zone in the Gulf of Mexico (Alexander et al. 2008). According to the US Environmental Protection Agency (USEPA), four states in the Corn Belt, including Illinois, contribute to about 48% of the nitrogen (N) loads and about 43% of the phosphorus (P) loads that flow into the Gulf of Mexico (USEPA 2007, 2008).

A portion of the fertilizer applied to agricultural fields for production of row crops, mainly corn (*Zea mays*), is often lost through runoff to aquatic systems due to inefficient plant uptake (Asghari and Cavagnaro 2011; Sigua et al. 2017; Keikha and Keikha 2013; Gheysari et al. 2009). Loss of nutrients from agricultural land to aquatic systems not only impacts the environment but reduces nutrient use efficiency (NUE) and increases the cost of crop production. Management to improve efficient use of fertilizer nutrients in agriculture is very critical to farming sustainability and to minimize N and P export from agricultural fields (Hagin et al. 2003; Liu et al. 2017).

The NUE of applied fertilizer can be increased by management practices that optimize crop yield with reduced nutrient inputs (Hawkesford 2014; Noor 2017). In a survey, Stuntebeck et al. (2011) reported that runoff at the edge of fields contained nutrients at concentrations of <0.01 to 42.6 mg total P L^{-1} and <1.0 to 180 mg total N L^{-1}, suggesting the potential for significant nutrient loss from agricultural fields through runoff water. A potential management practice to minimize nutrient loss from agricultural fields is to reuse nutrients in runoff by irrigating crops with the nutrient-rich runoff water during periods of water deficit. Irrigation with runoff water (runoff irrigation) can also have potential to improve the NUE of the applied fertilizer (Han et al. 2015). The prevalent dry summer climate in Illinois often causes soil water to be insufficient for crop growth (Cooke 2009; Zhang et al. 2021); thus, irrigation during the summer can optimize the crop yield.

Irrigation affects soil properties critical for root growth such as oxygen (O) diffusion rate and plant available water content (Tahiri et al. 2020). Luo et al. (2013) and Zhang et al. (2017) reported that irrigation with runoff water improved crop rooting systems, and consequently enhanced the utilization of fertilizer nutrients by crops. Runoff water can be collected in retention basins or ponds near agricultural fields and applied to production areas in periods of water deficiency in the field. Water storage and reuse also reduce

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Received April 6, 2021; Revised September 22, 2021; Accepted October 13, 2021.

the potential for offsite nutrient transport to aquatic systems.

To better understand its potential as a best management practice to reduce nutrient transport to rivers and streams, there is a need for information on the fertilizer value of runoff irrigation. It is necessary to know if runoff irrigation can significantly compensate for reduced levels of fertilizer application, particularly at the field scale. Thus, the objective of the study is to evaluate the effect of captured runoff water from agricultural fields, that is reused for irrigation, on nutrient use by plants, and to determine the potential amount of fertilizer that can be replaced by runoff irrigation. We hypothesize that optimum corn yield and nutrient uptake can be obtained at reduced fertilization with supplemental runoff irrigation.

Materials and Methods

Study Field and Layout. The three-year study was done on a field operated by a farmer at a site owned by the Metropolitan Water Reclamation District of Greater Chicago (MWRD) in Fulton County, Illinois. The annual precipitation for the study area was 979, 914, and 978 mm in 2016, 2017, and 2018, respectively. The soil is classified as fine-loamy, mixed, active, calcareous, mesic Alfic Udarent (USDA NRCS 1997) and derived from mine spoil. The 0.2 ha northeast portion of the field was divided into three blocks with a size of 76 m by 18 m, each assigned to one of the following three treatments applied annually for the three years:

- T50: nonirrigated controls (50% agronomic N and P fertilization with no irrigation);
- T50I: irrigated (50% agronomic N and P fertilization supplemented with runoff irrigation); or
- T100: fertilizer reference (100% agronomic N and P fertilization with no irrigation).

Because soil tests indicated that there was a high level of uniformity in soil properties at the study site, and since it was not practical to set up irrigation systems for subplots, each block was divided into three sections, producing a pseudo replication or quasi-experimental design suggested by Payne (2006). Thus, the study was considered to be a nonrandomized replicated design, and data were analyzed as such. In 2016, 2017, and 2018, fertilizer (urea, diammonium phosphate [DAP] and muriate of potash [MOP]) were applied annually in March and the field was disked in May. However, in 2016, a 100% agronomic rate of fertilizers was applied by the farmer in early March to the entire field (including the experimental plots area) before the study started. Therefore, additional fertilizer was applied to the T100 plot to distinguish the 50% agronomic rate treatment. Thus, in 2016, T100 received 366 kg N and 100 kg P ha^{-1} (1.5x agronomic rate), while T50 and T50I both received 244 kg N and 67 kg P ha^{-1} (1.0x agronomic rate). In 2017 and 2018, however, the T100 plot received 100% agronomic rate of N and P fertilizer at 244 kg N and 67 kg P ha^{-1} y^{-1} (table 1). The other two treatments (T50 and T50I) received half the agronomic rates (122 kg N and 33.5 kg P ha^{-1} y^{-1}). In addition, the three treatments received 67 kg ha^{-1} of potassium (K) annually. The agronomic N rate used in this study was equivalent to the maximum return to N (MRTN) for the field as used in Illinois. The MRTN is a web-based tool (ISU Extension 2021) used in midwestern states including Illinois to determine N recommendation for crops (Ransom et al. 2020). Corn (Dekalb 55-09 RIB hybrid) was planted in May for each of the three years (2016 through 2018) in the field plots at 12,550 stands ha^{-1}. Field operations, including conventional tillage, disking, planting, and herbicide application, were done by the farmer along with remainder of the field. Other operations in the study such as fertilizer application, irrigation, crop harvesting, and sampling, were done by research staff.

Soil samples taken in 2017 before treatment application show similarity in bulk density, N (nitrate [NO_3^-] and ammonium [NH_4^+]), and soluble P for the three treatments and suggests minimal variability in chemical and physical properties of the field area used for the study. The mean soil bulk density of the three treatments was 1.06 g cm^{-3} for 0 to 5 cm depth and 1.31 g cm^{-3} for 5 to 15 cm depth. The water extractable P and NO_3 + nitrite (NO_2)-N averaged 3.2 mg P kg^{-1} and 21.6 mg N kg^{-1} for 0 to 5 cm depth, and 3.2 mg P kg^{-1} and 19.5 mg N kg^{-1} for 5 to 15 cm depth, respectively.

Irrigation. Drip irrigation equipment was installed in the T50I subfield after germination each year and removed before harvest. Water for irrigation was pumped from a nearby retention pond that received runoff from a portion of the 25 ha field. The water applied to the plot was measured using an inline flow meter that recorded pumped volume. The irrigation schedule was based on forecasted rainfall during the growing season rather than soil moisture as described below. For easy operation by farmer, we designed the irrigation frequency in such a way that it would supplement the rain to wet the field totally twice per week during the growing season from June to August. Thus, for any week with one and no rain event forecasted, there were one and two irrigations scheduled for the T50I treatment, respectively. No irrigation was applied during any week with two or more rain events forecasted. For each irrigation event, water was applied to bring the soil moisture back to field capacity when the water started to drain out from the surface. The total amount of water irrigated, which was related to the rain pattern during the growing seasons over the study years, was 19 mm in 2016, 61 mm in 2017, and 40 mm in 2018.

Measurements, Sampling, and Sample Analysis. One composite of grab water samples was collected from the pond at the start of each irrigation event. The samples were stored on ice in a cooler in the field and shipped immediately to the MWRD laboratory in Chicago, Illinois, for analysis. The water samples were analyzed for total kjeldahl nitrogen (TKN), NO_3^--N, and NH_4^+-N using a Lachat Quickchem flow injector autoanalyzer (Zellweger Analytics, Milwaukee, Wisconsin). Total P in the water samples was also analyzed using standard colorimetry methods following digestion as outlined by the USEPA-600 (USEPA 1983). The mass of nutrient added with irrigation water was calculated as the product of the concentrations and measured water flow.

Harvesting was done in September of each year, and corn grain and stover dry matter were measured. Plant tissue was sampled annually at harvest from each plot for analysis. Corn total dry matter yield and grain yield were measured and sampled from the three center rows with a length of 3 m for each row. Stover and grain samples were dried, weighed, and ground in a Wiley mill using a 2 mm screen and analyzed for N and P following acid digestion.

Data Analysis. Nutrient uptake was calculated as the product of nutrient concentrations and dry matter yields.

The N fertilizer replacement value (FRV_N) by irrigation was estimated as point estimate using plant N uptake as follows in equation 1:

Table 1

Total nutrients (fertilizer and irrigation) and water (rain and irrigation)* received in 2016, 2017, and 2018 in each of the treatment plots.

		Rainfall and irrigation water (mm [%])			Nutrient applied as fertilizer (kg ha^{-1})		Nutrients added with irrigation water (kg ha^{-1} [%])	
Year	**Treatments**	**Rainfall**	**Irrigation**	**Total**	**N**	**P**	**N**	**P**
2016	50% agronomic N/P	306	–	306	244	67	–	–
	100% agronomic N/P	306	–	306	244	67	–	–
	50% agronomic N/P + runoff irrigation	306	19* (6)†	325	366	100	3.8* (2)‡	0.6 (1)
2017	50% agronomic N/P	202	–	202	122	34	–	–
	100% agronomic N/P	202	–	202	244	67	–	–
	50% agronomic N/P + runoff irrigation	202	61 (23)	263	122	34	9.3 (7)	1.5 (4)
2018	50% agronomic N/P	358	–	358	122	34	–	–
	100% agronomic N/P	358	–	358	244	67	–	–
	50% agronomic N/P + runoff irrigation	358	40 (10)	398	122	34	8.2 (6)	1.2 (4)

Notes: N = nitrogen. P = phosphorus.

*For the months of June, July, and August.

†Percentage (%) in parentheses stands for percentage of irrigation water as total water (rain plus irrigation) received.

‡Percentage (%) in parentheses stands for percentage of nutrients added with irrigation water relative to total nutrients (fertilizer plus irrigation) added.

$$FRV_N = \frac{(\text{total N uptake}_{T50I} - \text{total N uptake}_{T50}) \times \text{fertilizer N applied in kg ha}^{-1} \text{ for T100}}{\text{total N uptake}_{T100}} \quad (1)$$

where FRV_N = N fertilizer replacement value; total N uptake$_{T50I}$ = total corn N uptake at 50% fertilizer with irrigation; total N uptake$_{T50}$ = total corn N uptake at 50% fertilizer without irrigation; and total N uptake$_{T100}$ = total corn N uptake at 100% fertilizer without irrigation. The P fertilizer replacement value (FRV_p) was estimated using the same formula with the corn P uptake.

The assumption of normality was verified by the Kolmogorov-Smirnov test for all the data sets. The data were analyzed by the one-way analysis of variance approach (ANOVA) using SAS (Littell et al. 1996). The treatments were compared by Turkey's test using SAS software (SAS Institute 1995). Statistical differences were evaluated based on a significance (α) level of 0.05.

Results and Discussion

Rainfall and Irrigation. Weekly rainfall data for the study area during the active growing seasons (June through August) of 2016 through 2018, downloaded from the Global Historical Climatology Network (Menne et al. 2020), are shown along amount of supplemental irrigation applied to irrigated field plot (T50I) (figure 1). Rainfall was moderate but not sufficient during each active growing period (June to August) of each year. Although supplemental irrigation was only a small fraction of total rainfall (<10%), it coincided with critical periods for plant growth in July and August, such as pollination and grain-filling period. Therefore, irrigation helped to minimize potential crop stress during those critical periods. The concentrations of total N and P in runoff irrigation water used ranged <1.0 to 3.0 mg N L^{-1} and 0.17 to 0.59 mg P L^{-1}, respectively. The total amount of nutrients applied through irrigation ranged from 3.8 to 9.3 kg N ha^{-1} (averaged 7.1 kg N ha^{-1} y^{-1}) and 0.6 to 1.5 kg P ha^{-1} (averaged 1.1 kg P ha^{-1} y^{-1}), which were very low compared to agronomic fertilizer N and P rate applied during each year of the study (table 1).

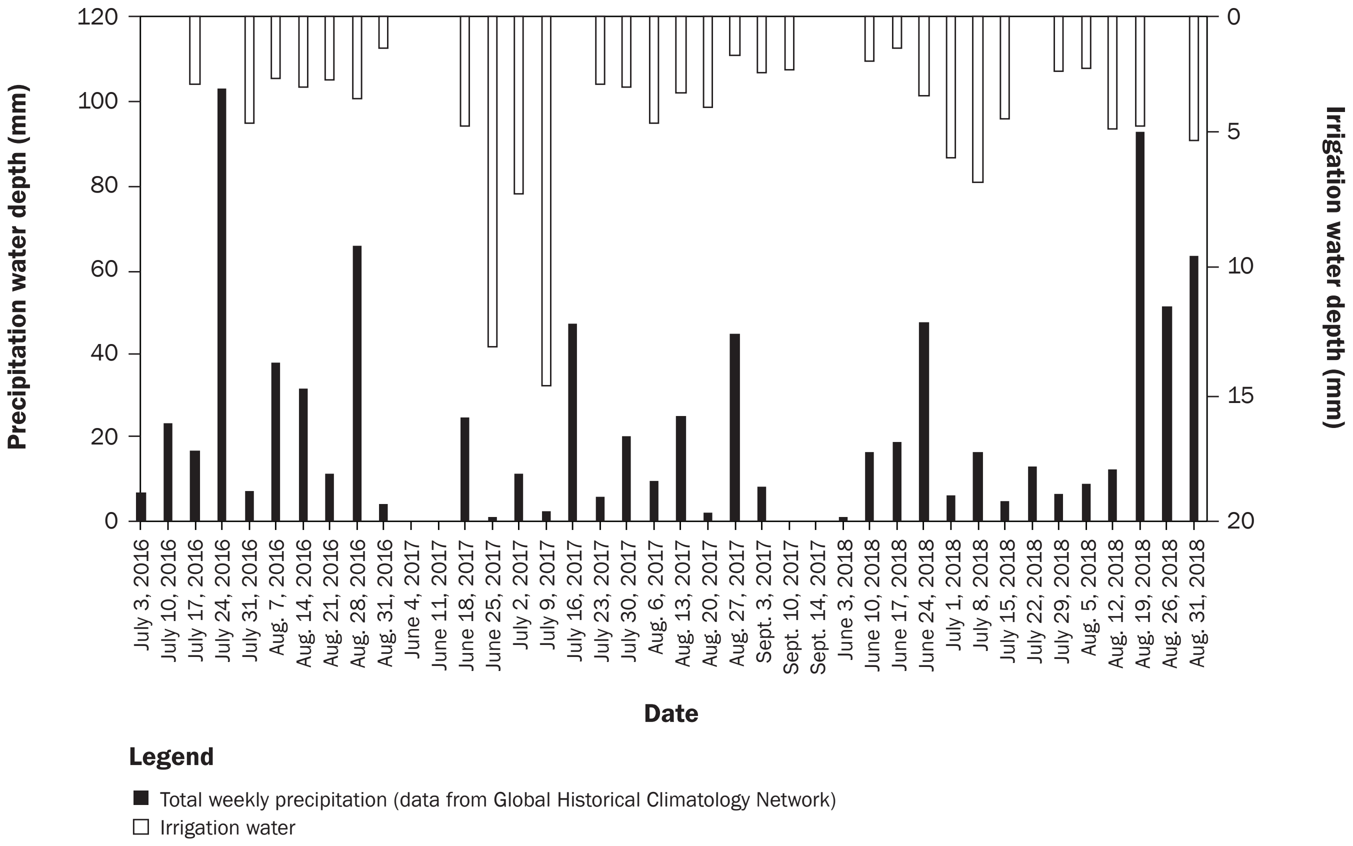
Corn Grain and Stover Yields. Corn grain yield at half fertilizer rate was greater with than without irrigation during the 2017 and 2018 growing seasons (table 2). In 2016, the difference in grain yield between T50 and T50I treatments was not significant, likely due to adequate nutrients applied by farmers to all fields including the irrigated and nonirrigated treatments. However, at 50% agronomic fertilizer rate, corn stover dry matter was still greater with than without irrigation in 2016 (table 2). Higher corn stover dry matter was also observed with than without irrigation in 2017. The corn stover dry matter at 50% agronomic fertilizer rate with irrigation was even greater than (2016 and 2017) or comparable to (2018) with 100% agronomic fertilizer rate. Low corn yield was observed at 100% agronomic fertilizer rate in 2017 due to crop damage by animals (deer).

The total dry matter (grain plus stover) over the three years ranged from 12.5 to 23.2 dry t ha^{-1} for T50, 16.9 to 26.9 dry t ha^{-1} for T50I, and 10.3 to 26.1 dry t ha^{-1} for T100. At 50% agronomic fertilizer rate, total dry matter (DM) yields were greater with than without irrigation in 2016 and 2017, but the difference was not significant in 2018. In 2016 and 2018, total DM yields at the 50% agronomic fertilizer rate increased with irrigation to levels comparable to values obtained at 100% agronomic fertilizer rate. In general, and at the 50% agronomic fertilizer rate, irrigation increased grain, stover, and total biomass by an average of 38%, 45%, and 27%, respectively, over the three years.

Nutrient Concentrations, Uptake, and Fertilizer Replacement Value. Nutrient (N and P) concentrations analyzed in corn grain and stover samples taken in 2017 and 2018 (but not in 2016) are shown on table 3. The effect of reduced fertilizer rate was reflected in nutrient concentrations, especially in 2018 where N concentrations in both grain and stover were lower at the 50% (nonirrigated) than at the 100% agronomic fertilizer rates (table 3). However, the field plots that are irrigated with 50% agronomic fertilizer rate and the 100% agronomic fertilizer rate had similar corn grain and stover N concentrations (table 3). The N concentration in corn stover of irrigated 50% agronomic fertilizer rate (10.8 and 15.9 g N kg^{-1} in 2017 and 2018, respectively) was, on average, 28%

Figure 1

Weekly precipitation for study location (Global Historical Climatology Network; Menne et al. 2020) and irrigation during the active growing period from planting to before maturity in 2016, 2017, and 2018.



higher compared to nonirrigated 50% agronomic fertilizer rate (9.7 and 11.0 g N kg^{-1} in 2017 and 2018, respectively). A similar trend was observed for the corn grain N content in 2018, but the difference in corn grain N was not significant in 2017.

The P concentration in corn tissue was minimally affected by fertilizer application rate, as the differences in P concentrations of corn grain and stover between T100 and T50 treatments were not significant in 2017 and 2018. This was probably partly because soil P was much higher than crop requirement due to residual P from historical high rates of fertilizer P applied, especially in 2016 where at least the agronomic fertilizer rate was applied to all treatments. However, irrigation increased P concentrations of corn grain and stover in 2017.

Supplemental irrigation increased N uptake in 2017 and 2018. The N uptake in the 50% agronomic fertilizer rate tended to be greater in the irrigated than in the nonirrigated treatment (figure 2). The corn N and P uptake were either similar or greater for irrigation-supplemented 50% agronomic fertilizer rate (157 to 398 kg N ha^{-1} and 29 to 60 kg P ha^{-1}) compared to that in the 100% agronomic fertilizer rate (104 to 452 kg N ha^{-1} and 19 to 70 kg P ha^{-1}).

The fertilizer replacement value (FRV) of runoff irrigation was not evaluated for 2017 because crop damage by deer compromised corn yield in the 100% agronomic fertilizer rate treatment. In 2018, FRVs of runoff irrigation were 73 kg N ha^{-1} and 6 kg P ha^{-1}, equivalent to 30% and 8% of N and P fertilizer savings, respectively (table 4).

Discussion. The concentrations of N and P in runoff irrigation water at the site (<1.0 to 3.0 mg total N L^{-1} and 0.17 to 0.59 mg total P L^{-1}) was within the range of values reported in a survey of nutrients in runoff at the edge of fields by Stuntebeck et al. (2011). The concentrations were also similar to the 0.36 to 3.63 mg N L^{-1} and 0.56 to 0.91 mg P L^{-1} values in runoff water reported in other studies (Daniels et al. 2019; Adeli et al. 2011). Wide range of concentrations of nutrients is expected in runoff water from agricultural fields as the concentrations can be affected by many variables such as the nutrient source and application rate, topography, and rain events (Stuntebeck et al. 2011). The low concentration of nutrients in the runoff water from the retention pond used in this study compared to that in original runoff was due to dilution of N and P from precipitation and denitrification losses of N during the storage in the pond. Typical pond conditions such as occasional warm temperatures, low dissolved O, and high dissolved organic carbon (C) favors denitrification. Ponds are known to be natural sink for nutrients because N could be lost in the pond by processes such as denitrification with storage (Piehler and Smyth 2011; Gold et al. 2017). Lower N and P concentrations of water in ponds compared to the original runoff water were also reported by Fairchild and Velinsky (2006) and Saunders and Kalff (2001) and were attributed to denitrification and precipitation

Table 2

Corn grain and stover dry matter yields in 2016, 2017, and 2018 in plots that received fertilizer at full (100% agronomic nitrogen/phosphorus [N/P] rate) and half (50% agronomic N/P rate) agronomic rate, and half agronomic rate plus irrigation (50% agronomic N/P rate + irrigation).

Dry matter	Treatments	2016	2017	2018
Corn grain (Mg ha^{-1})	50% agronomic N/P	12.9 ± 0.9b*	8.1 ± 1.3b	4.1 ± 0.7c
	100% agronomic N/P	14.8 ± 1.3a	6.7 ± 0.6b	8.6 ± 1.1a
	50% agronomic N/P + runoff irrigation	13.2 ± 1.2ab	9.3 ± 1.8a	6.7 ± 0.9b
Corn stover (Mg ha^{-1})	50% agronomic N/P	11.4 ± 1.6c	5.4 ± 1.1b	10.9 ± 1.2b
	100% agronomic N/P	12.5 ± 1.7b	4.5 ± 0.8b	13.7 ± 0.4a
	50% agronomic N/P + runoff irrigation	14.8 ± 1.4a	10.1 ± 1.9a	11.3 ± 1.7ab
Total dry matter (Mg ha^{-1})†	50% agronomic N/P	23.2 ± 1.3b	12.5 ± 2.3b	14.2 ± 1.6b
	100% agronomic N/P	26.1 ± 2.7a	10.3 ± 1.2b	20.8 ± 1.2a
	50% agronomic N/P + runoff irrigation	26.9 ± 2.2a	18.2 ± 3.4a	16.9 ± 2.2ab

*Mean ± standard deviation. Treatment means of same dry matter followd by same letter are not different at *p*-value of 0.05 by Tukey's test.

†Total dry matter of corn grains and stovers

Table 3

Concentrations of phosphorus (P) and nitrogen (N) in grain and stover of corn in 2017 and 2018 in plots that received fertilizer at full (100% agronomic N/P rate) and half (50% agronomic N/P rate) agronomic rate, and half agronomic rate plus irrigation (50% agronomic N/P rate + irrigation).

		N (g kg^{-1})		P (g kg^{-1})	
Dry matter	Treatments	2017	2018	2017	2018
Corn grain	50% agronomic N/P	13.2 ± 0.3ns*	14.1 ± 0.8b	2.53 ± 0.09b	3.23 ± 0.07a
	100% agronomic N/P	13.3 ± 0.5	16.4 ± 0.3a	2.59 ± 0.05b	2.88 ± 0.14ab
	50% agronomic N/P + runoff irrigation	13.4 ± 0.1	16.1 ± 1.1a	2.75 ± 0.05a	2.61 ± 0.29b
Corn stover	50% agronomic N/P	9.7 ± 0.3b	11.0 ± 2.6b	1.41 ± 0.67b	1.85 ± 0.34ns
	100% agronomic N/P	10.6 ± 1.0a	16.8 ± 1.6a	1.66 ± 0.18b	2.27 ± 0.40
	50% agronomic N/P + runoff irrigation	10.8 ± 1.0a	15.9 ± 0.8a	2.20 ± 0.16a	1.88 ± 0.11

*Mean ± standard deviation. Treatment means of same dry matter followed by same letter are not different at *p*-value of 0.05 by Tukey's test. ns = not significant at *p*-value of 0.05 by Tukey's test.

in ponds. With minimal amount of nutrients applied directly through runoff irrigation, the observed positive effect of runoff irrigation on crop yield and nutrient uptake in the study could be attributed mainly to the improvement in utilizing fertilizer nutrients by crop under better soil water conditions due to irrigation.

The positive effect of runoff irrigation on corn grain yield and nutrient uptake observed in this study was consistent with other similar studies (Stone et al. 2010; Maharjan et al. 2016; Canatoy 2018). There was no increase in grain yield by irrigation in 2016 due to adequate nutrients applied by farmers to all fields including the irrigated and nonirrigated treatments. However, the corn stover biomass responded to irrigation, probably due to the plant's luxurious assimilation of high nutrients in soils. The low corn yield observed at 100% agronomic fertilizer rate, relative to those at 50% rate observed in 2017, is likely due to crop damage by animals such as deer. The farmer, consistent with a traditional corn–soybean (*Glycine max* L.) rotation, planted soybean in the rest of the field in 2017. Only the study plots were planted with corn, which made experimental plots exposed to deer damage in 2017 and thereby compromised the treatment. Other studies (Payero et al. 2006; Aguilar et al. 2007; Jahansouz et al. 2014) also reported the potential for increased corn yield with irrigation. Insufficient water during the vegetative period induces early senescence, limits photosynthesis, and can stress and reduce corn grain yield (Pandey et al. 2000). This study further confirms that irrigation has the potential to increase grain yield and dry matter yield at reduced fertilizer application rates, though our study lacks irrigation treatment without fertilizer application to isolate the direct effect of water on crop yield. However, the level of reduction in fertilizer input that can be implemented under irrigated production for maintaining the same crop yield can depend on many factors such as soil type, crop type, and rainfall amount and distribution.

Greater nutrient uptake by corn in the treatment that received irrigation than in the nonirrigated treatment demonstrated the potential of supplemental irrigation at enhancing crop nutrient use. Providing adequate soil moisture through supplemental irrigation, especially at critical periods, increases uptake of nutrients in soil by plants as the additional water can improve crop rooting systems and even facilitate critical plant metabolic activities (Golla 2021). Management to improve N and P use efficiency in corn production through the combination of reduced fertilizer application rates and supplemental irrigation during critical periods has the potential to reduce nutrient losses with no negative impact on corn yield. Other studies also indicated higher crop yield can be achieved with low input systems (reduced fertilizer inputs) that integrate advanced molecular breeding and transgenic approaches, rational use of fertilizers with right doses at right time, and integrated agronomic management to increase NUE (Hawkesford 2014; Noor 2017). This study shows the reuse of runoff

Figure 2

(a) Total nitrogen (N) and (b) phosphorus (P) uptake by corn in 2017 and 2018 in plots that received fertilizer of full (100% N and P rate) and half (50% N and P rate) agronomic rate, and half agronomic rate fertilizer plus irrigation (50% N and P rate + irrigation). Bars of same year with same letter are not different at *p*-value of 0.05 by Tukey's test.

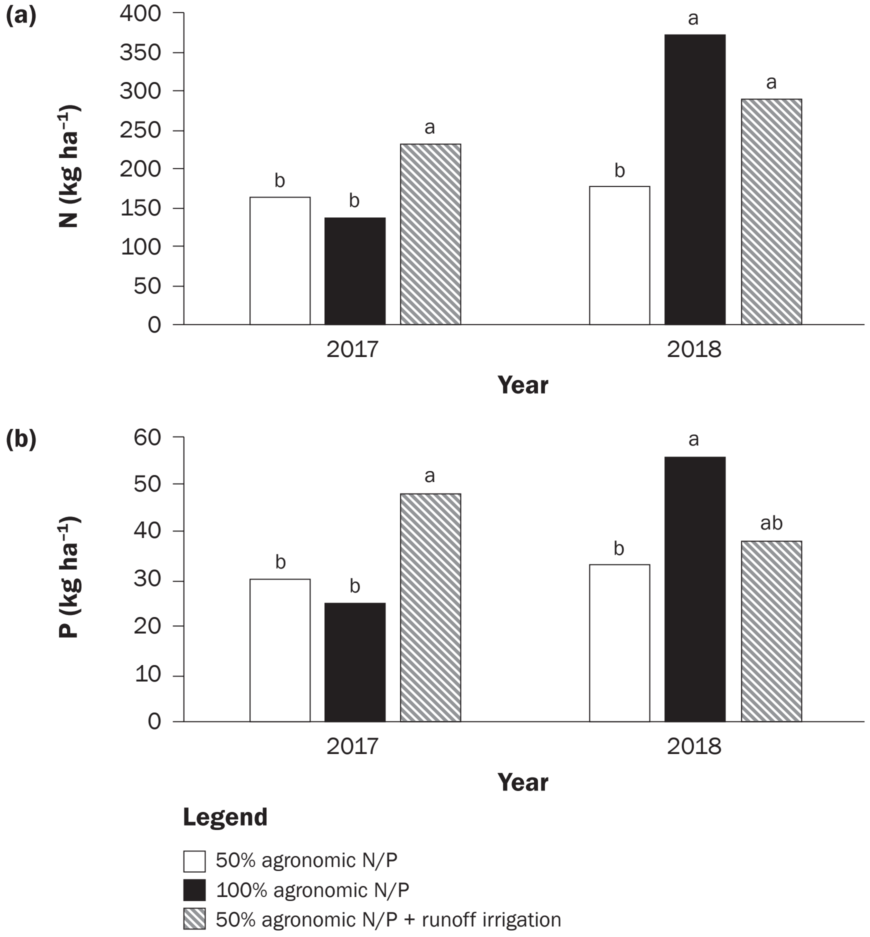


Table 4

Fertilizer replacement value (FRV) of supplemental irrigation in west Illinois, based on crop nitrogen (N) and phosphorus (P) uptake in 2018.

Nutrient	FRV (kg ha^{-1})	Agronomic nutrient rate (kg ha^{-1})	Percentage of agronomic nutrient rate (%)
Nitrogen	73	244	30
Phosphorus	6	67	9

water through irrigation as a complement to reduce fertilizer application and minimize nutrient losses from agricultural fields.

The FRV values showed that irrigation using captured field runoff has the potential to reduce the fertilizer application, leading to reduction of N loss by 30% (figure 3). Since the supplemental irrigation increased NUE and had potential to optimize crop yield with fertilizer reduction, irrigation with runoff water can be recommended for corn production at reduced fertilizer rate in Illinois. More studies might be needed to determine the exact factors that contribute to FRV value of supplemental irrigation. Common management to reduce fertilizer application includes accounting for residual soil N, mineralization of soil organic matter and residues, deep banding, and fertilization that targets time that crops really need the nutrients. This study identified irrigation as an option to improve NUE, thus ensuring optimum crop yield at reduced fertilizer rate and thereby minimizing nutrient loss.

Summary and Conclusions

This study suggests that irrigation with runoff water from agricultural fields enhances corn growth and has potential to achieve optimum crop yield at reduced fertilization. Reduction in fertilizer inputs will eventually minimize nutrient loss from agricultural fields. At 50% agronomic fertilizer rate, irrigation increased corn total biomass by an average of 26% over the three-year period. Supplemental irrigation at 50% agronomic fertilizer rate increased fertilizer use efficiency such that the added water provided an equivalent of fertilizer value at 30% for N and 8% for P. The study indicates that under reduced fertilizer application rates, optimum corn yields can be achieved through supplemental irrigation. Thus, this study demonstrates the potential of irrigation with field runoff or any other sources of water to minimize fertilizer inputs, maximize corn nutrient utilization, improve crop yields, and ultimately contribute to the reduction of nutrient loss from crop fields.

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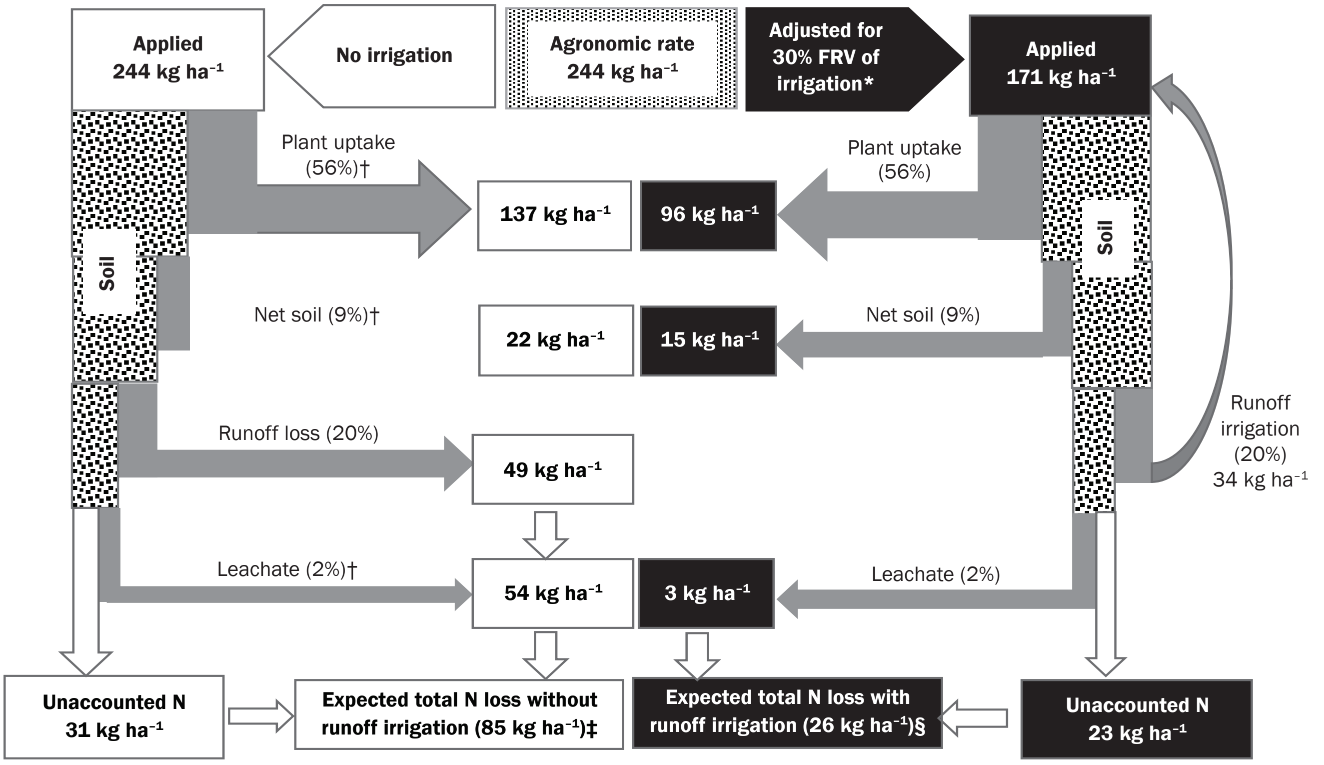
Figure 3

Hypothetical fate of applied nitrogen (N) with (black) and without (white) adjustment of agronomic rate with 30% fertilizer replacement value (FRV) of supplemental irrigation applied.



*The 30% FRV obtained from this study.

†Values obtained from Rimski-Korsakov et al. (2012).

‡Expected total N loss (without runoff irrigation) was 85 kg ha^{-1} and estimated as agronomic rate (244 kg ha^{-1}) – plant uptake (137 kg ha^{-1}) – net N left in soil (22 kg ha^{-1}).

§Expected total N loss (with runoff irrigation) was 26 kg ha^{-1} and estimated as agronomic rate adjusted for 30% FRV of irrigation (171 kg ha^{-1}) – plant uptake (96 kg ha^{-1}) – net N left in soil (15 kg ha^{-1}) – N in runoff water (34 kg ha^{-1}).

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