EVALUATION OF THE AGRONOMIC AND ENVIRONMENTAL IMPACTS OF MANURE SUBSURFACE DRIP SYSTEMS

Prepared by Sustainable Conservation

Abstract

The agronomic and environmental impacts of the manure SDI system were compared to the effects of flood irrigation. The systems were evaluated on five key metrics. Yields were largely unaffected by manure SDI, though it may have improved yields. The volume of water applied was significantly lower, without harming yields, which means manure SDI showed significantly higher water use efficiency. Nutrient use efficiency was also much higher with manure SDI. Magnesium and salinity loading are both decreased, but further study is needed to understand the effects on soil.

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1.0 Introduction

Many dairies in California face increasing scarcity of water and land to grow forage crops. In the San Joaquin Valley, both surface water and groundwater sources are in decline due to droughts and over-pumping. In order to produce forages, dairies are increasingly relying on lower quality groundwater from deeper wells. The majority of dairies utilize low water use efficiency flood irrigation (FAO Water Resources, Development and Management Service, 1985-90), so there is growing interest in switching to more efficient irrigation methods like SDI. In addition to low water use efficiency, flood also limits the ability of the dairy to control the amount of nutrients that are applied to the field. According to a 2019 report by the Central Valley Dairy Regional Monitoring Program, more precise nutrient application is one of two critical needs to reduce dairies' nitrate leaching to groundwater (CVDRMP, 2019).

A common form of precision irrigation is conventional sub-surface drip irrigation (conventional SDI). Conventional SDI delivers water and synthetic fertilizer nutrients through buried driplines, at the crops' root zone. The targeted delivery means that the amount of water and nutrients applied can be more precisely adjusted to meet crop demands for both volume and timing. Some dairies have started adopting conventional SDI, but that means they must rely on synthetic fertilizers and cannot utilize the nutrients in the manure effluent generated by the dairy cows.

Manure sub-surface drip irrigation (manure SDI) is similar to conventional SDI, but modified to utilize manure effluent instead of synthetic fertilizers; that is a key benefit, as it allows dairies to gain water and nutrient efficiencies while continuing to utilize the nutrients generated by the cows on site. The manure effluent, blended with fresh water, is pumped through pressure regulated emitters buried below the soil surface to feed crops. The manure SDI project was developed to demonstrate and evaluate the efficacy of the manure SDI system on dairies.

A key piece of the manure SDI project has been to analyze the agronomic and environmental impacts of switching from flood irrigation to manure SDI. In order for manure SDI to be viable, it must not harm the farm's ability to produce forage compared to flood irrigation. Manure SDI also has to show that it provides environmental benefits compared to flood irrigation: improved water use efficiency (yields per inch of water applied), improved nutrient use efficiency (yield per pound of nitrogen applied) and reduced loading of potentially problematic constituents like magnesium and salts.

Three dairies in California's San Joaquin Valley were partners on the project. Each dairy offered a field to be the site of the manure SDI system and the data from a comparison flood field that the dairy managed as they normally would. Data were tracked from both fields over the course of two full corn-winter wheat cycles, 2018-2020. The present report presents the analysis of the agronomic and environmental impacts of the project: yields, water applied, water use efficiency, nutrient use efficiency, and salt loading and build-up.

2.0 Materials and Methods

2.1 Dairy Sites

The three dairy partners represented two major dairy regions in California: the North San Joaquin Valley and the South San Joaquin Valley. The dairies also represent different management styles, from a dairy that hires a third party to manage their fields to a dairy who manages a small, on-farm team. Dairy #3 channels all of their manure effluent through a methane digester and used digestate rather than manure effluent throughout the project; for the sake of simplicity, "manure effluent" will be used when discussing multiple dairies and "digestate" will be used when discussing Dairy #3 specifically.

The farm managers selected the manure SDI and the flood field pairs that they knew historically performed comparably based on various characteristics: similar location, soil type (Table 1), field history, variety planted, etc.

The farm managers and their teams made the majority of the decisions about how to manage the crop; they were advised by agronomists hired for this project, but ultimately all decisions were made by the farm managers. The comparison flood irrigated fields were managed as they typically were in the past; the project team did not ask the grower partners to change how those fields were managed to allow a comparison of the manure SDI to each dairy's typical flood irrigation management.

Table 1. Acres of the fields.

	Dairy #1		Dairy #2		Dairy #3	
Irrigation	Manure SDI	Flood	Manure SDI	Flood	Manure SDI	Flood
Acreage	74 acres	52 acres	62 acres	104 acres	74 acres	77 acres

2.2 Sampling

The sample collection schedule for the manure SDI fields is summarized in Table 2. The sampling of the flood fields was the growers' standard schedule and varied by dairy. The exception were soil samples, which were collected from both the flood irrigated field and the manure SDI field.

Yields were tracked by the growers and adjusted to 70% moisture. Irrigation records were recorded weekly by flowmeters built into the manure SDI system for the manure SDI field. The growers' records of the water and manure effluent applied to the flood field were used to track applications to that field. For the Corn 2019 season of Dairy #2, the grower was not able to provide records for the water and manure effluent applied to that flood field, so that field was excluded for that season. Nitrogen applications were tracked by a combination of the flowmeters and the growers' records of manure effluent applications, solid manure applications, and synthetic fertilizer applications.

Table 2. Sample collection for manure SDI field

	Frequency	Location
Blend	Every other week	At manure SDI system
Manure effluent; digestate	Every other week	At manure SDI system
Fresh water	Annually	At manure SDI system
Soil*	Before planting	1', 2', and 3' depths
Plant tissue	At harvest	In field

*Soil samples were collected from both the flood fields and the manure SDI fields.

Soil samples for salinity evaluation were also collected horizontally in relation to the drip tape: at the drip tape, 10 inches out and 20 inches out (midway to the next tape). Each set of soil sample was collected at the depths described in Table 2. These samples were collected at two of the sites, Dairy #1 and Dairy #2.

For logistical reasons, frequency of the blend, manure effluent, and digestate samples varied on occasion. In general, a sample was taken at least once every month. The constituents tested for within each sample is summarized in Table 3.

Table 3. Lab analyses run for each type of sample

Fresh water	Blend; manure effluent; digestate	Soil	Plant tissue
EC	EC	SP (saturated paste)	% moisture
NO_3-N	NO_3-N	pH (saturated paste)	% N
NH_4-N	Total NH_4-N	EC (saturated paste)	% P
NH_3-N	Total TKN	Ca (saturated paste)	% P_2O_5
TKN	Total P	Mg (saturated paste)	% K
TN	Total K	Na (saturated paste)	%K_2O
TDS	CO_3	Cl	Mg
pH	HCO_3	ESP	Protein
Temperature	Cl	GR	Ash
	SO_4	Lime	
	Total Ca	B (saturated paste)	
	Total Mg	NO_3-N	
	Total Na	PO_4-P	
	TDS	K	
	pH	Acid K	
	TSS	Zn	
	FSS	% OM	
	FDS		

2.3 Calculations

The manure effluent samples were cross-referenced to the volumes from the irrigation records to calculate the total nitrogen and magnesium applied. The results of the manure effluent sample closest in time to the irrigation event was used. Similarly, any solid manure applications were cross-referenced with solid manure samples collected and shared by the grower. Additional soil samples were collected for salinity analysis; analysis of those results are presented in a separate report.

Yields and plant tissue samples were tracked and collected for each field individually. Using the plant tissue dry matter results, each yield was adjusted to 70% moisture. Water applied included all sources of water (e.g. germination volumes, irrigation volumes and precipitation volumes). Nitrogen applied included solid manure, manure effluent and synthetic fertilizer. Water use efficiency and nutrient use efficiency were calculated as yield divided by total volume of water applied or total pounds of nitrogen applied.

Precipitation and ET_c values were collected from the nearest representative CIMIS stations. The data was collected for each field, using the planting date as the start date and the harvest date as the end date (Table 4). The total precipitation and ET_c were each summed for each field and used to calculate the total water applied and total water demand for the season.

3.0 Corn Crop Results and Discussion

Problems with the flowmeter at Dairy #2 meant that irrigation records were not available for the flood field, so those data were not available for analysis.

3.1 Yield

Yields varied substantially between seasons and especially between dairies (Figure 1). When considering yields within a given dairy and season, the manure SDI fields generally had higher yields (median for corn: 2.57% higher with manure SDI), but there were seasons when the flood field had a higher yield.

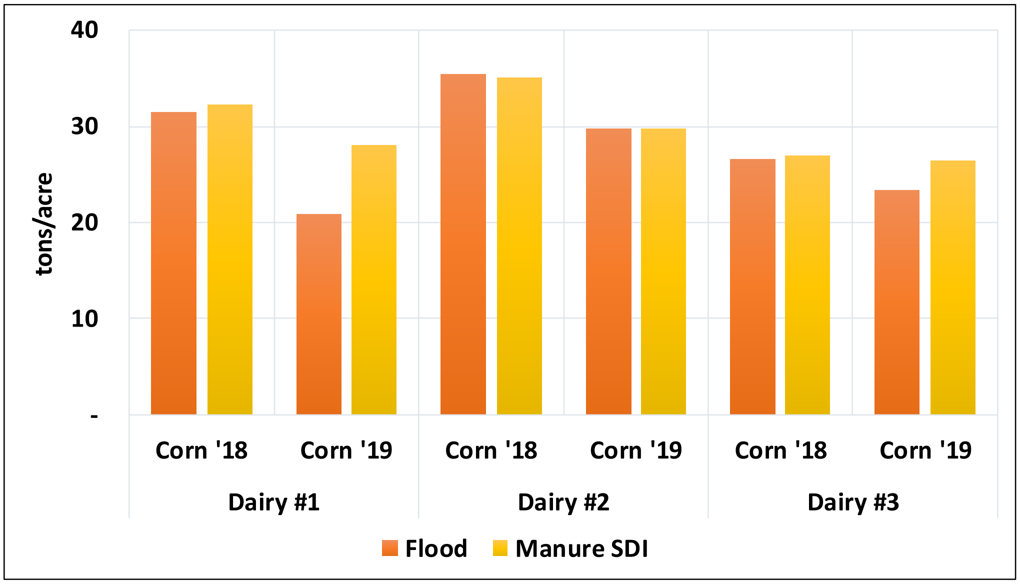

Figure 1. Yields from each of the corn seasons studied, adjusted to 70% moisture.

There are many variables that could have affected yield (e.g. variety, plant date, harvest date, climate, soil type, irrigation volume, irrigation frequency). The project team was able to match several of these. The fields studied had similar soil types and locations, to reduce the confounding effect of weather. They also had similar field histories and management for the prior few years. Within each dairy and season, the same variety was planted at each pair of manure SDI and flood fields; the one exception was for the Corn 2019 season of Dairy #3. A shorter season variety was planted in the manure SDI field; the grower wanted to experiment with germinating using manure SDI, which did not work, so they replanted the field.

Two key variables did not always match between the two fields: planting and harvest dates. Planting and harvest dates for each field within a dairy and season were sometimes separated by weeks, usually for logistical reasons (Table 4). That means that the crops received different heat units, which could have an impact on the yields. As mentioned above, for the Corn 2019 season of Dairy #3 a shorter season variety was planted due to substantial delays. Overall, the manure SDI system generally maintained or slightly increased yields as compared to the traditional flood irrigation systems.

Table 4. Planting and harvest dates for each of the fields of the corn seasons.

Dairy	Field	Crop	Year	Plant date	Harvest date
Dairy #1	Manure SDI	Corn	'18	5/22/2018	9/12/2018
Dairy #1	Flood	Corn	'18	5/22/2018	9/8/2018
Dairy #1	Manure SDI	Corn	'19	6/8/2019	9/23/2019
Dairy #1	Flood	Corn	'19	5/13/2019	8/27/2019
Dairy #2	Manure SDI	Corn	'18	5/22/2018	9/28/2018
Dairy #2	Flood	Corn	'18	N/A	9/26/2018
Dairy #2	Manure SDI	Corn	'19	5/28/2019	9/13/2019
Dairy #2	Flood	Corn	'19	6/10/2019	9/26/2019
Dairy #3	Manure SDI	Corn	'18	7/3/2018	10/19/2018
Dairy #3	Flood	Corn	'18	6/7/2018	9/19/2018
Dairy #3	Manure SDI	Corn	'19	6/3/19 (north half)	9/12/19 (North half); 10/14/19 (South half)
Dairy #3	Flood	Corn	'19	6/1/2019	9/18/2019

3.2 Water Applied

The manure SDI system reduced water applied, oftentimes substantially (Figure 2). Given the long history of SDI systems in general, the reduced water usage is not a surprise, though it remains a key agronomic and environmental benefit of both conventional SDI and manure SDI.

That lower water use was reflected in closer alignment to ET_c: For each season, the manure SDI fields were closer to ET_c than the flood fields (Figure 2, light blue bars). That helps illustrate the increased precision that manure SDI offers compared to flood irrigation, as growers were able to more closely match the crop demand. At the same time, manure SDI is a tool and each grower had to make management decisions based on their on-the-ground observations and experience, so the reduction of water applied by using manure SDI instead of flood irrigation will change dairy-by-dairy and year-to-year.

In most cases, yields were not negatively affected by manure SDI compared to the flood irrigated fields despite less water applied. Paired with the lower water applied, each manure SDI field had higher water use efficiency values than the comparison flood irrigated field. The manure SDI fields had a median 0.33 tons of corn per acre per inch of water applied higher than the comparison flood fields (Figure 3). The water not applied to the corn fields was available for use elsewhere, which is a benefit for both the farmer and the environment. Please note, the ET_c values calculated here were based on the nearest CIMIS stations and the farmers may have been acting on weather stations located on their dairies, with more accurate information. Further study would be needed to examine whether water use could be reduced further by converting to manure SDI.

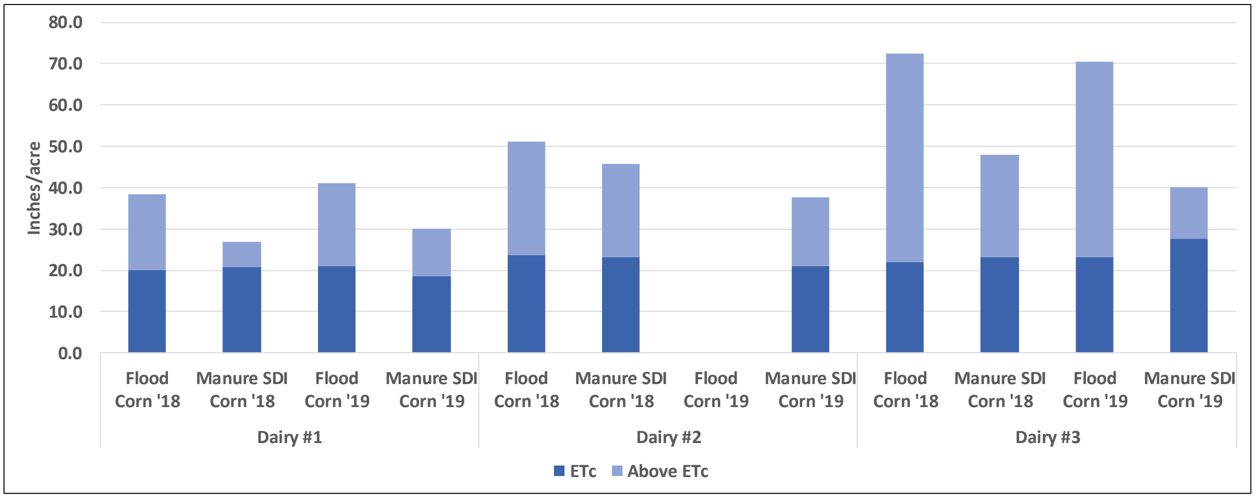

Figure 2. ET_c values and water applied above ET_c for the corn seasons studied. Data were not available for Dairy #2's flood field in the Corn 2019 season.

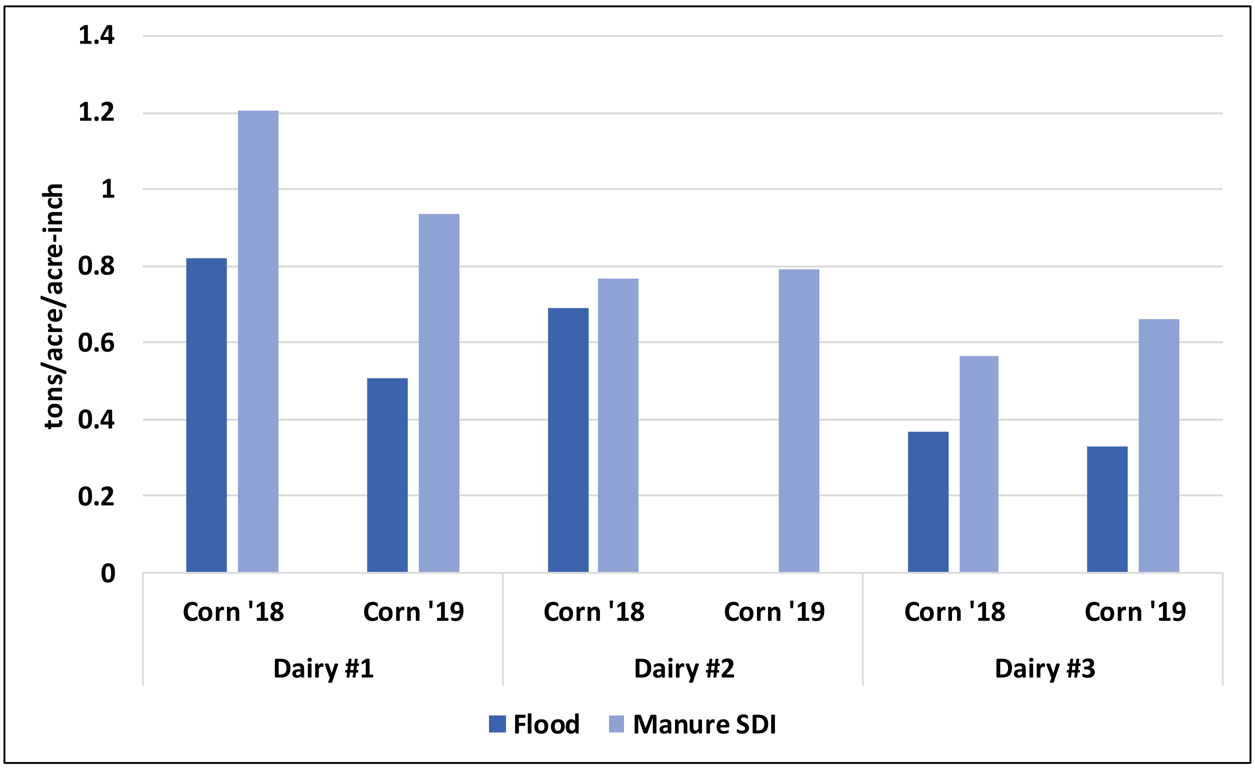

Figure 3. The water use efficiency of the corn seasons. Data were not available for Dairy #2's flood field in the Corn 2019 season.

3.3 Nutrient Use Efficiency

The manure SDI fields generally received less manure effluent than the flood fields as seen with the nutrient use efficiency results (Figure 4). Each manure SDI field was closely monitored by an agronomist consultant, who provided a weekly recommendation of manure effluent and fresh water application rates based on predicted crop demand. The growers made their own choices for the flood irrigated fields, to provide a comparison to their typical practices using flood. The manure SDI allowed the growers to more closely meet crop demand, reducing the amount of water and manure effluent applied compared to the flood irrigated fields and, in turn, likely reducing water loss and nitrogen leaching to groundwater.

The total nitrogen applied analyzed here includes all nitrogen applied records available. Synthetic fertilizer used as a starter fertilizer, applied with the planter, to both the flood and manure SDI fields for each of the corn crops was monitored. Dairy #3 also applied solid manure to both fields in both seasons, but they did not supply a solid manure sample for the second season, so the nitrogen value from the previous year was used to calculate the nitrogen content. Across all three dairies and both corn seasons, the mean percent of nitrogen applied from manure effluent was 84%; if considering both manure effluent and manure solids, it would be 89%. So, the manure SDI was able to support the crop using largely manure nitrogen.

Reduced nitrogen loading is likely with adoption of manure SDI. Water savings is a major draw of SDI, so it's likely that a grower would reduce their blend applications with a manure SDI system. That means less manure effluent is likely to be applied as well as fresh water. As long as yields are not impacted, a grower will not have a motivation to increase nitrogen application, decreasing potential nitrogen leaching.

Before a dairy switches to manure SDI, they need to look at their whole farm nitrogen balance and evaluate their nutrient management plan. Please refer to the technical reports for further discussion: "Nutrient and Salinity Management Guidance for Manure Subsurface Drip Irrigation Systems" and "Considerations for Switching From Flood to Manure Subsurface Drip Irrigation for Forage Production."

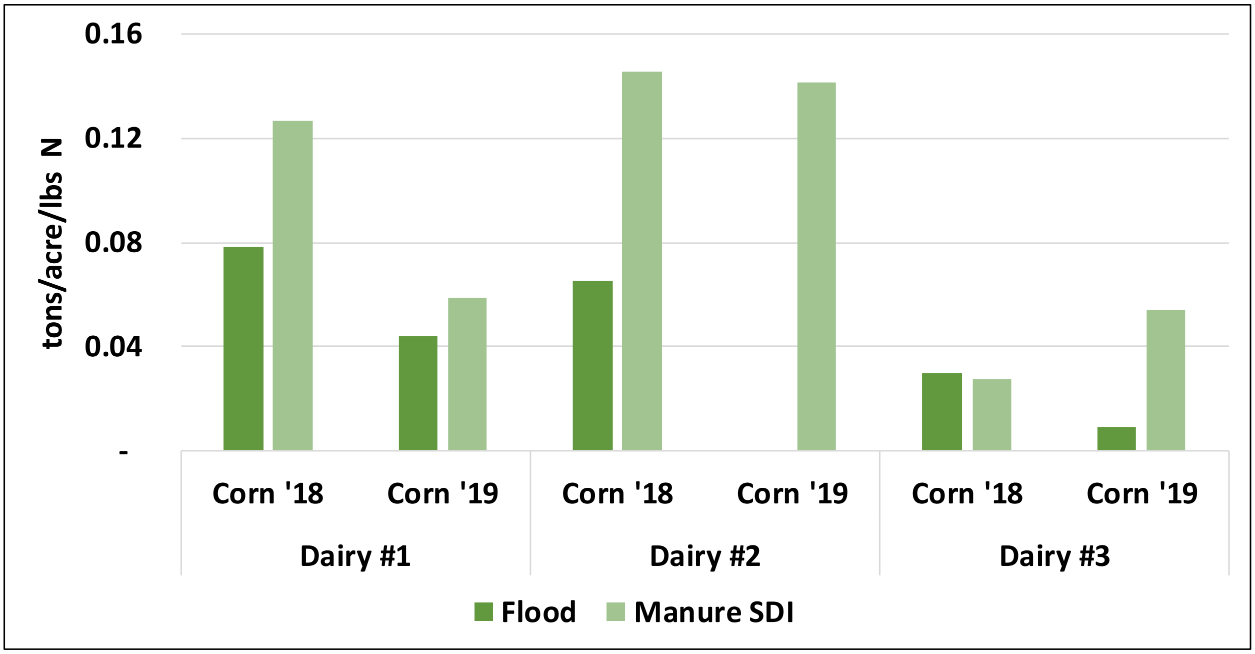

Figure 4. Nutrient use efficiency of each field during the corn seasons. Data were not available for Dairy #2's flood field in the Corn 2019 season.

4.0 Wheat Results and Discussion

4.1 Yield

Similar to the corn yields, the wheat yields were expected to vary between seasons and between dairies. With the exception of the 2017-2018 season of North San Joaquin Valley #1, the manure SDI fields had higher wheat yields compared to their flood irrigated counterparts (Figure 5). The median difference was a 6.86% increase in the manure SDI fields.

As discussed with the corn yield data, there are many factors that could affect crop yield, so it's not clear to what extent manure SDI contributed to the yield variations observed. Planting and harvest dates varied within each pair of fields, similar to the corn crops (Table 5). The precipitation was an additional confounding factor for the wheat crops, as rain was a significant source of water for the crops of Dairy #1 and Dairy #2, as discussed below. Future work should investigate the reasons why most of the manure SDI fields appeared to outperform the flood fields in wheat productivity.

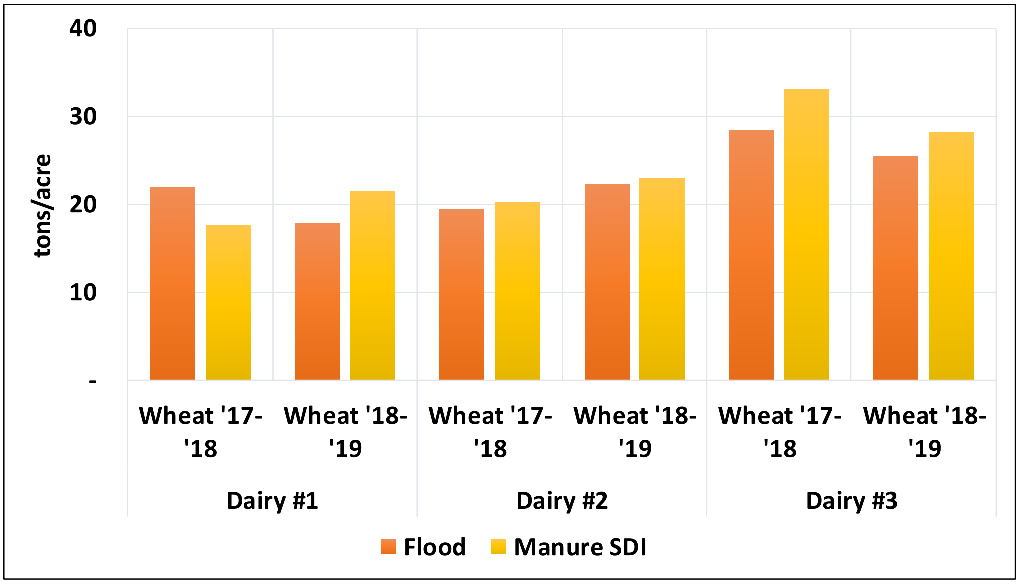

Figure 5. Yields from each of the wheat seasons studied, adjusted to 70% moisture.

Table 5. Planting and harvest dates for each of the wheat seasons.

Dairy	Field	Crop	Year	Plant date	Harvest date
Dairy #1	Manure SDI	Wheat	'18-'19	12/4/2018	5/7/2019
Dairy #1	Flood	Wheat	'18-'19	11/3/2018	4/17/2019
Dairy #2	Manure SDI	Wheat	'18-'19	11/22/2018	5/6/2019
Dairy #2	Flood	Wheat	'18-'19	11/21/2018	5/7/2019
Dairy #3	Manure SDI	Wheat	'18-'19	11/8/2018	5/1/2019
Dairy #3	Flood	Wheat	'18-'19	10/16/2018	5/2/2019
Dairy #1	Manure SDI	Wheat	'17-'18	11/6/2017	5/3/2018
Dairy #1	Flood	Wheat	'17-'18	10/18/2017	4/30/2018
Dairy #2	Manure SDI	Wheat	'17-'18	11/14/2017	5/4/2018
Dairy #2	Flood	Wheat	'17-'18	11/12/2017	4/28/2018
Dairy #3	Manure SDI	Wheat	'17-'18	10/16/2017	5/8/2017
Dairy #3	Flood	Wheat	'17-'18	10/30/2018	5/9/2018

4.2 Water Applied

The water applied data illustrates the influence of planting and harvest dates on irrigation (Figure 6). Even though each pair of fields on each dairy are adjacent to one another, the different planting and harvest dates meant the fields received different amounts of rain. That results in the relative contribution of the water applied as irrigation versus precipitation was quite different within each pair of fields.

The greater irrigation volume at the Dairy #3 was partly due to low precipitation and partly due to attempting to germinate using the manure SDI system (Figure 6c). Based on the results of the project, germination through the drip tape is not recommended. For further details, please see the technical report, "Considerations for Switching From Flood to Manure Subsurface Drip Irrigation for Forage Production."

Although the comparison of water applied versus ET_c did not show a uniform pattern between flood and manure SDI, less water was generally applied with the SDI systems (Figure 7). As noted in the analysis, the precipitation was an important variable that had great impact on water use efficiency and nutrient use efficiency, making conclusions for the analysis difficult. Five of the six manure SDI seasons had higher water use efficiency than the paired flood fields, but the extent to which that was due to the impact of manure SDI on yields requires further study.

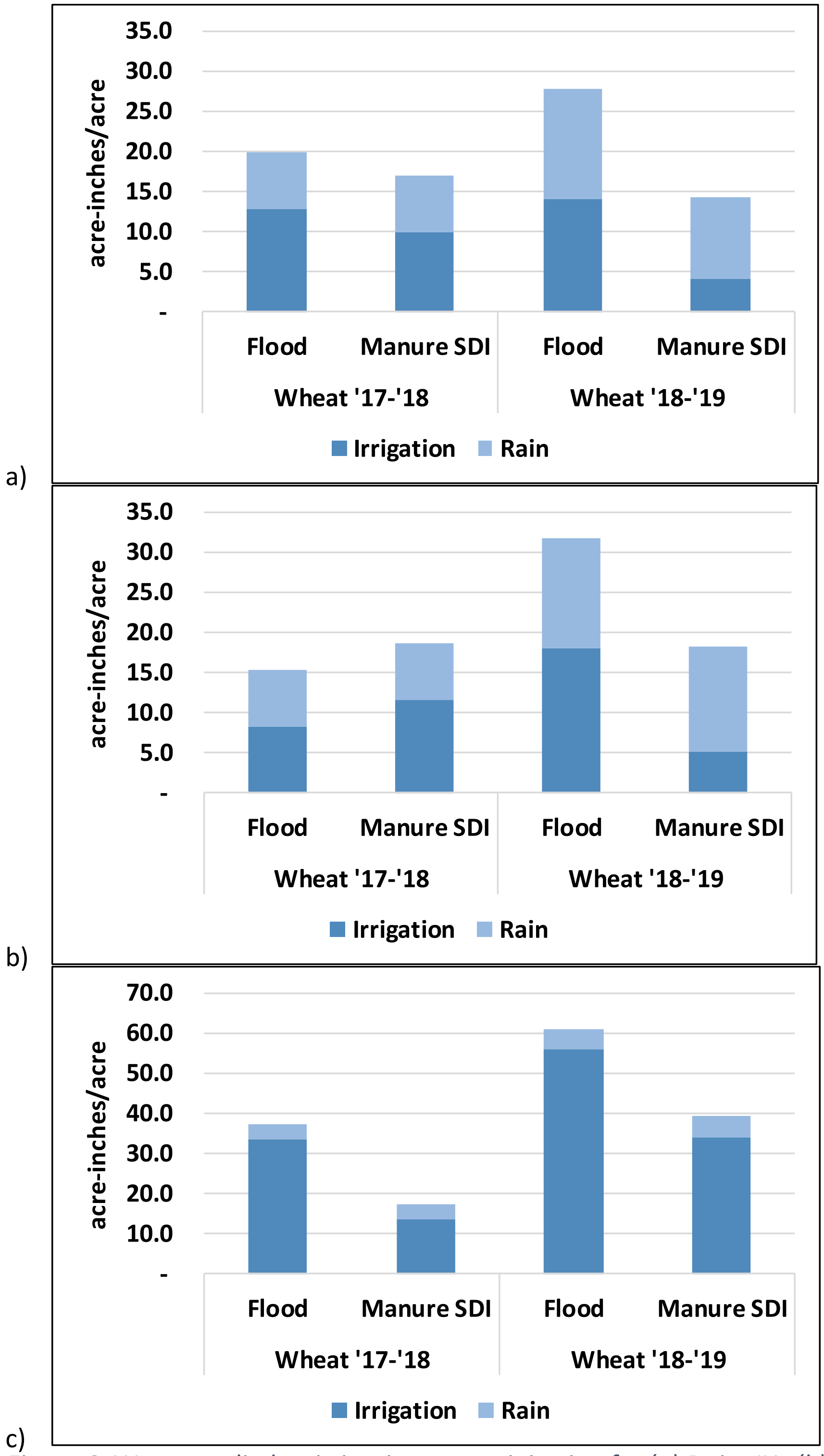

Figure 6. Water applied as irrigation or precipitation for (a) Dairy #1; (b) Dairy #2; (c) Dairy #3.

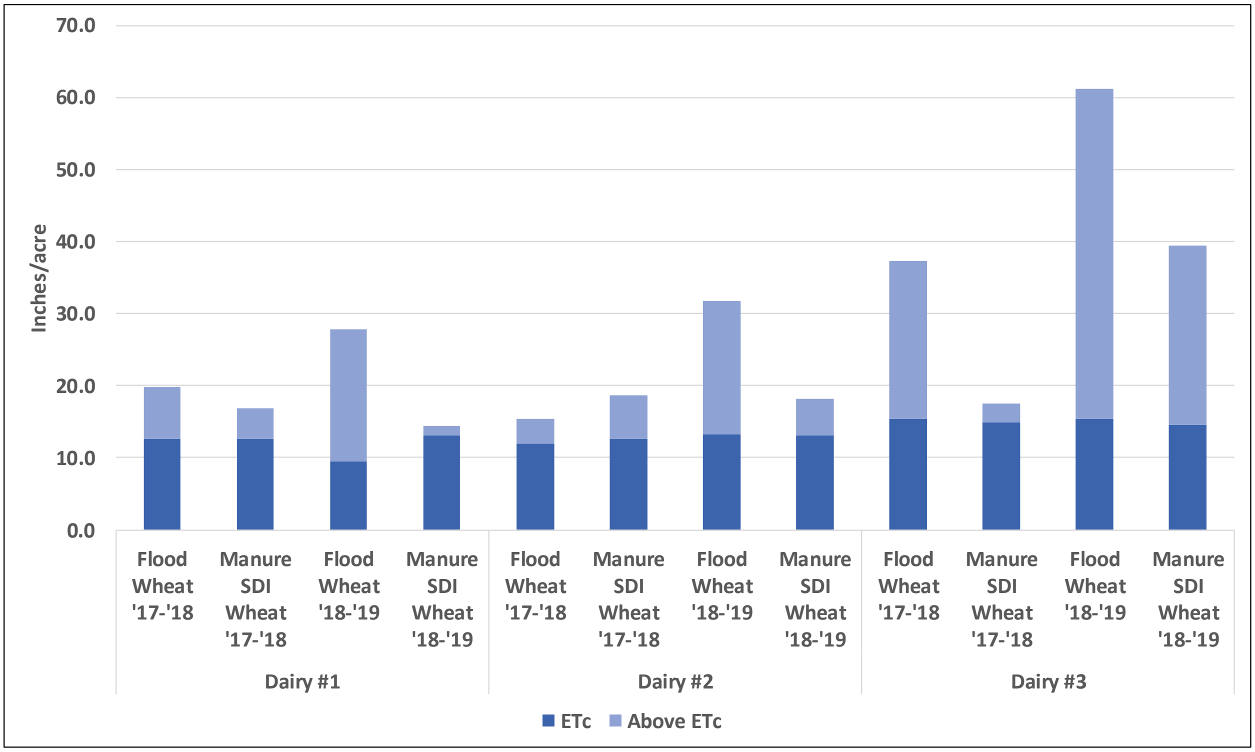

Figure 7. Water applied versus ET_c for the wheat seasons.

4.3 Nutrient use efficiency

Similar to the corn season, the manure SDI fields all showed numerically higher nutrient use efficiency ratios compared to the paired flood fields (Figure 8). All of the available nitrogen applied records were included in the calculations. All of the dairies applied some manure effluent to each of the fields during the wheat seasons.

Dairy #1 applied solid manure for Wheat '17-'18 season to both fields, but not to the crop for the Wheat '18-'19 season. They did not apply any synthetic fertilizer to any of the wheat crops.

Dairy #2 did not apply any solid manure to the wheat crops. They did apply a small amount of synthetic fertilizer to both fields during the Wheat '17-'18 season, but not the Wheat 18'-19' season.

Dairy #3 did not apply any solid manure to the wheat crops. They applied synthetic fertilizer to the manure SDI fields through the manure SDI system. During the Wheat '17-'18 season, most of the nitrogen came from synthetic fertilizer because cavitation of the main digestate pipeline hindered applying digestate onto the fields. In the Wheat '18-'19 season, the synthetic fertilizer was a supplement for the manure SDI field.

Across all three dairies and both wheat seasons, the mean percent of nitrogen applied from manure effluent was about 73%; if considering both manure effluent and manure solids, it would be about 82%. Similar to the corn crops investigated, the manure SDI was able to support the crop nitrogen needs primarily by using manure nitrogen.

The improved yields and lower manure effluent volumes both contributed to the higher nutrient use efficiency with manure SDI. As with the water applied data, the manure SDI system is a tool that growers can use to more precisely match crop demand, but it requires changes in management practices to achieve the most of those benefits. It seems that more closely monitoring the crop's needs, achieved in the project partly by partnering with an agronomist, was helpful to that goal.

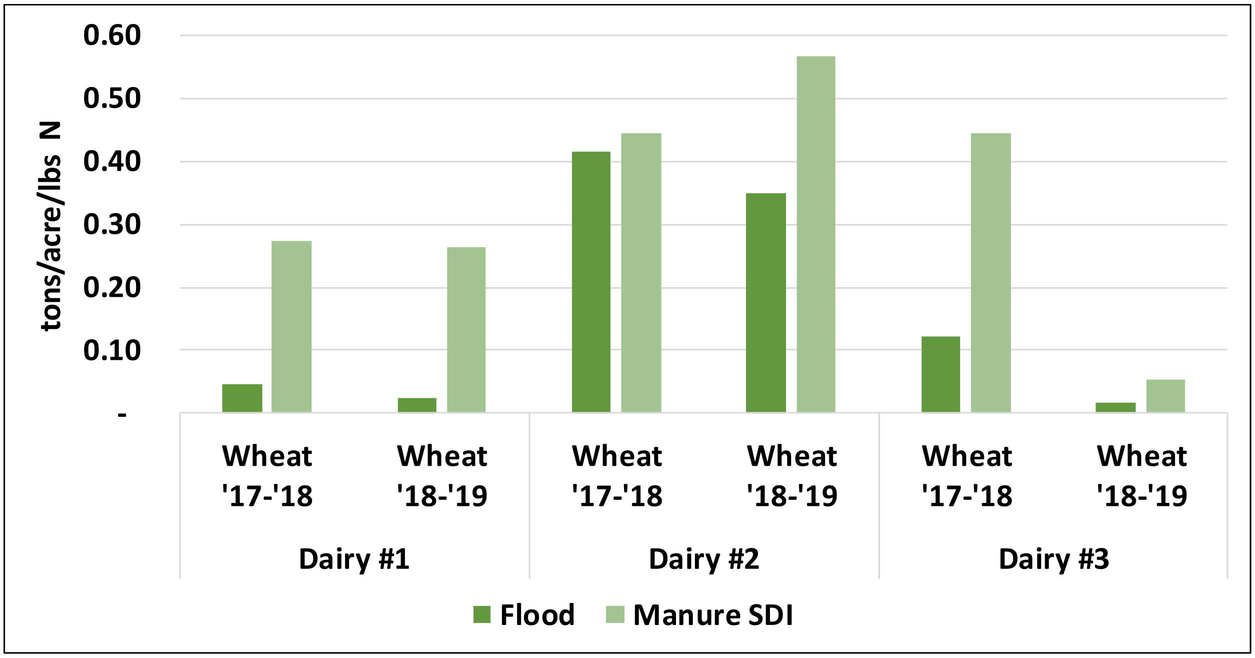

Figure 8. Nutrient use efficiency of each field during the wheat seasons.

5.0 Magnesium Loading and Soil Content

The manure SDI fields generally had lower magnesium loading (Figure 9). The decreased magnesium loading is a function of the lowered manure effluent application, which was driven by the reduced water applications. Similar to nitrogen, as long as crops are not affected, the farmer does not have motivation to increase manure effluent and thus magnesium after switching to manure SDI.

One emerging concern is soil magnesium accumulation. One evaluation of magnesium problems is the calcium to magnesium ratio, since calcium can replace magnesium on the surface of soil particles; the soil samples showed calcium remained the dominant salt in the soils of all three dairies (Figure 10).

The available data does not show a clear trend of changing soil magnesium, largely because there are not enough data. The flood irrigated and the manure SDI fields of Dairy #1 and Dairy #2 showed a decrease in soil magnesium between seasons. In contrast, when comparing 2018 to 2019, the Dairy #3 showed slight increases in the flood and decreased amount in the manure SDI field. The decrease observed may be due to the pre-irrigation: The fields were either flood or sprinkler pre-irrigated, which might leach salts present in the soil. While the present study did not find evidence of magnesium accumulation in the soil due to manure SDI treatment, future investigations may want to monitor the potential for long-term magnesium accumulations in soils.

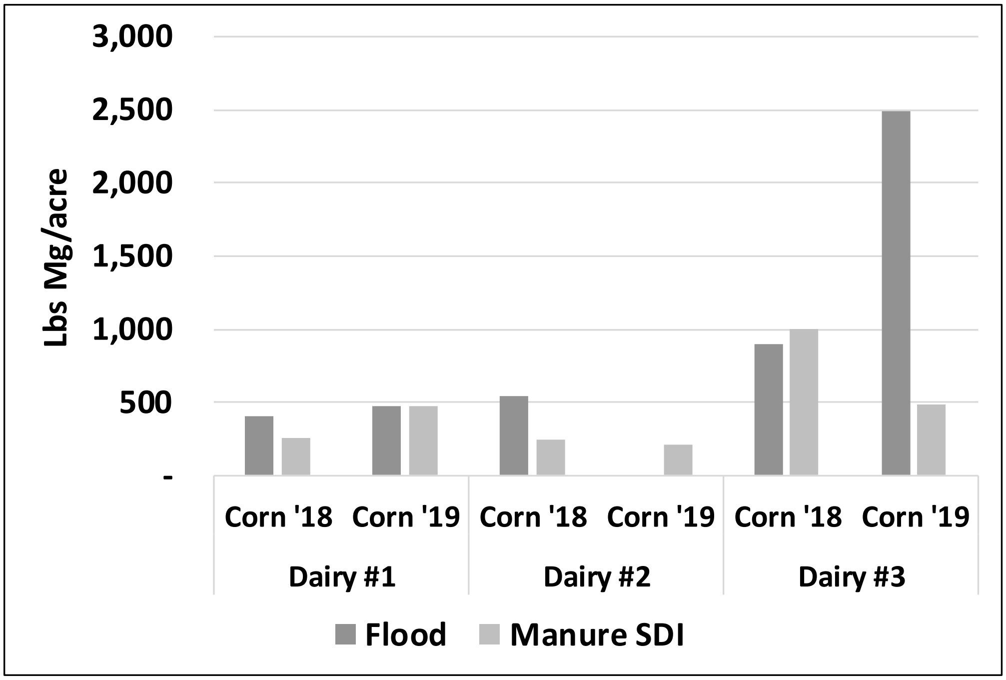

Figure 9. Magnesium loading to each of the fields during the corn seasons. Data was not available for Dairy #2's Corn 2019 season.

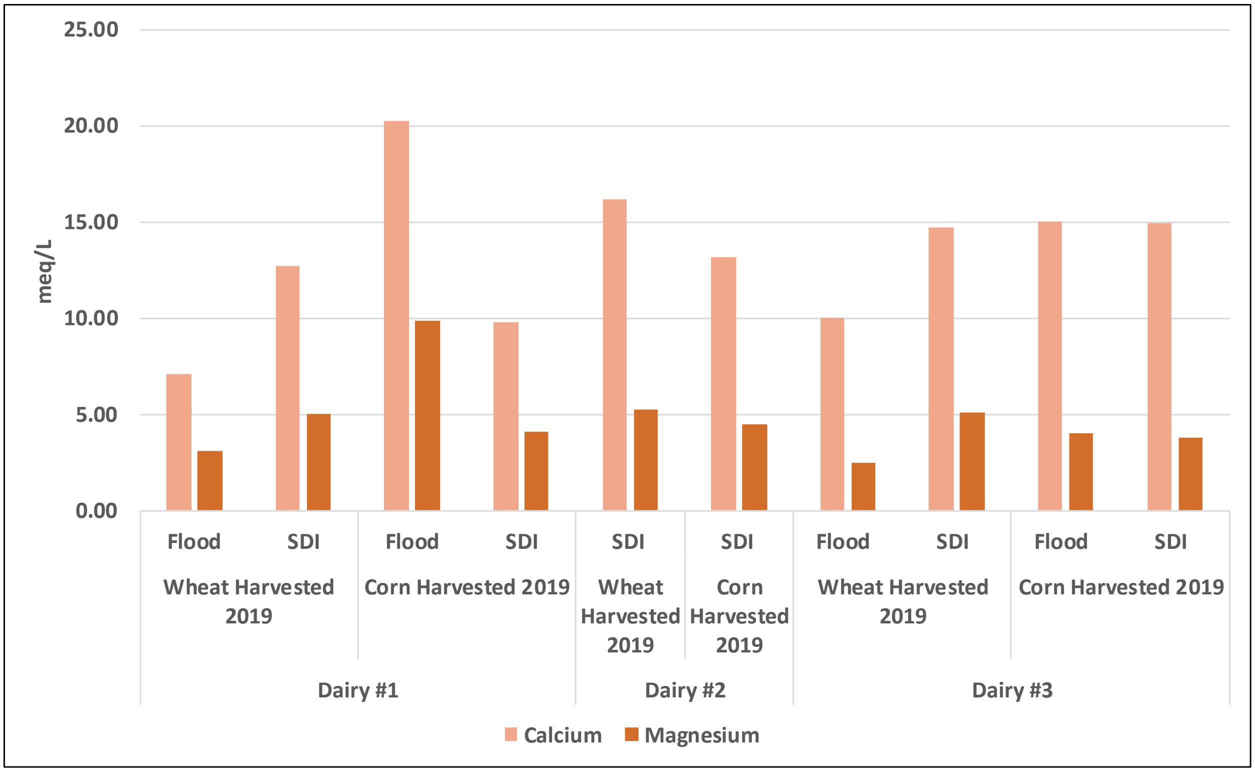

Figure 10. The cation representation of calcium and magnesium. Data was not available for the Dairy #2 flood fields due to communication errors.

6.0 Soil Salinity Content

More extensive soil sampling conducted at the end of the study on two of the dairies suggested salt accumulation in the soil profile was found to be minimal for all fields monitored. The EC values below an 18-inch depth were consistently lower in the manure SDI fields versus the flood field at Dairy #1, but were fairly similar at both fields in Dairy #2 (Figure 11). The higher EC values in the flood field was unexpected and it's not clear why the data show consistently higher EC's in this treatment since more water was applied to this treatment which should translate to a higher level of leaching and lower overall salt content. The blended lagoon water applied through the drip tape did add both calcium and sodium to the soil profile, but not enough to alter the ratio of those salts.

All four fields were germinated using sprinklers or flood, which may have helped flush salts out of the soil. Salinity accumulation at the surface is a potential concern to monitor with any SDI system, but so far does not appear to be much different from the flood irrigated blocks. Routine monitoring is recommended for future evaluations to ensure that there are no long-term problems with use of manure SDI system.

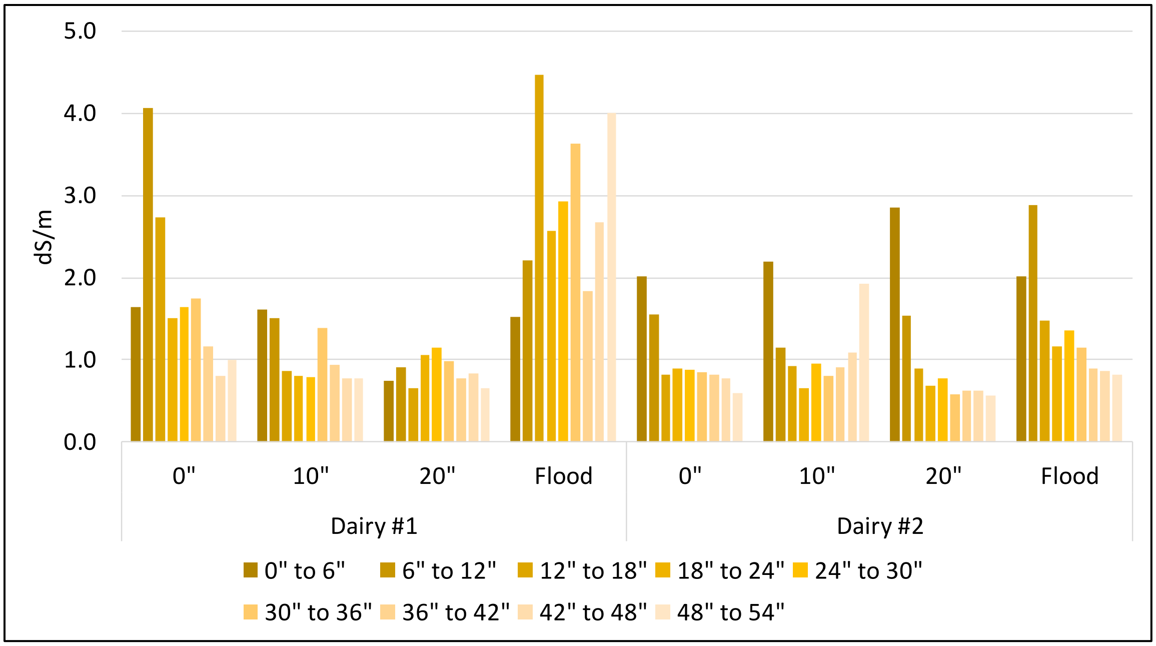

Figure 11. Salt accumulation in the manure SDI and flood fields, after the 2019 corn harvest.

7.0 Conclusions

The multi-year, multi-site data collected suggests the manure SDI system did not have a large impact on yields, negative or positive. The impact of manure SDI on yields is worth closer study in future projects. The amount of water applied to grow similar yields was substantially lower with manure SDI compared to a flood irrigation system and enhanced water use efficiency is clearly a key benefit of the manure SDI system for producers facing water shortages. Similarly, the amount of nitrogen applied to maintain the crop yields were much lower with manure SDI. Combined, this suggests reduced water loss and nutrient leaching below the root zone.

Dairies considering manure SDI should first carefully evaluate their whole farm nitrogen balance and take actions needed, like changing exports or the cropped acres receiving manure effluent, to stay in balance after switching to manure SDI. For more details, please see the technical report, "Nutrient and Salinity Management Guidance for Manure Subsurface Drip Systems."

Magnesium loading was decreased with manure SDI, since manure effluent applications were lower. Soil magnesium showed some changes over the course of the project, but it was not clear what the effect was in the long-term, so this issue is worth further study.

More data and study would be helpful to improve understanding of the agronomic and environmental impacts of manure SDI. The evidence suggests that manure SDI is a tool that allows improvements in water use efficiency and nutrient use efficiency, without lowering yields, but the specific range of impact and the underlying mechanisms are still unclear.

References

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