PROFITABILITY ANALYSIS OF NOVEL ROBOTIC MANURE APPLICATION METHODS

Kapil Arora, Iowa State University, U.S.A.

Abstract: Concept of applying manure to a crop when needed can help with environmental issues of water quality in Iowa and the Upper Midwest in USA. Novel technologies have emerged which allow manure application on growing corn beyond V4 plant growth stage. Dribble Bar (Agrometer SDS 8000) allows manure application from planting up to a corn height of 1-meter (V9 growth stage) whereas 360 RAIN Robotic Irrigator allows diluted manure irrigation from planting to R5 corn growth stages. In addition to manure application during the growing season, both methods can reduce water stress on the corn plant during dry weather or drought conditions. This reduced stress can potentially result in an increase in corn grain yields. This paper compares the costs of manure application using Dribble Bar and 360 RAIN with the traditional method of fall or spring manure application with a drag-hose system when no crop is growing in the farm fields. A profitability analysis is then presented to show how the increased costs of manure application with these two specialized technologies can potentially be offset with increased income due to better corn grain yields. Such in-season manure application has potential to provide greater environmental benefit to the society with better nutrient management.

Introduction

Liquid swine manure application in Iowa typically takes place after corn or soybean harvest in the Fall season or prior to corn planting in the Spring season. This method exposes the manure nutrients to the elements of nature and increases the potential for their loss from farm fields as there are no plant roots growing in the soil to take them up. The loss of manure nutrients can be reduced if animal nutrients are applied in-season after planting.

Applying liquid-based nutrients in-season beyond V4 stages of corn growth using innovatively designed high-clearance robotic technologies has not been researched. In-season application of liquid swine manure along with water application is a novel and unified irrigation strategy to reduce nutrient losses from farm fields. This new practice has the potential to improve profitability with increased corn yields over traditional methods of manure application. The cost of manure application using these technologies hasn't been researched as such technologies are expensive and at the same time manure must be diluted with water and applied at a low manure solids content.

Fall or Spring liquid manure application using a drag hose system traditionally is a one-time application where the manure is pumped from storage pits through an umbilical cord (drag hose) to the field tractor and applicator. The cost of manure application with this method is relatively low as the equipment can be moved to different fields and cover a large area. An alternative is where liquid swine manure can be applied during V4 and V9 stages of corn growth using a dribble bar. This new dribble bar, developed by Agrometer, Denmark, https://www.agrometer.dk/en/ is a manure applicator which allows in-season manure application for corn plant height up to 1-meter. The third alternative is a robotic irrigator, developed by 360

RAIN, https://www.360yieldcenter.com/products/360-rain/ which can apply manure over a longer portion of the corn growing season. This robotic irrigator is limited to a small area, requires multiples applications of diluted manure over the same area, and thus, can have high application costs in comparison with the typical drag hose system.

In-season liquid manure application, whether diluted with additional water or not, has the potential to relieve plant water stress during dry weather. Water in the manure itself can help the corn plants to reduce heat stress and thus improve yields. Yield improvement response related to manure application with these novel methods has not been researched yet but is probably different between the robotic irrigator and the dribble bar due to the different timing of in-season manure application. These yield improvements can help offset the cost of manure application to make these methods of manure application attractive over the traditional method of using a drag hose. Comparison of "total cost" of manure application per hectare with the increased income due to improved crop productivity can help determine if such in-season manure application methods are economically viable.

An economic value cannot be ascertained on the environmental benefit to the society based on efficient nutrient management such strategy presents. Potential exists to minimize nutrient losses in Fall and early Spring season by transferring nutrient application to late Spring and Summer season when corn plants have developing root system. It is too early to put an economic value to such a benefit. Both Iowa State University and Ohio State University have initiated a research project to quantify the reduction in nutrient losses with such in-season manure application strategy.

Objectives

The main objective is to calculate the total cost of manure application across three methods of manure application i.e. drag hose system, dribble bar system, and robotic irrigator system. The second objective is to estimate increased income due to improved corn crop productivity and to perform net profitability analysis.

Methods

Total fixed costs and total variable costs for the three manure application methods will be determined for comparing cost per hectare. A typical drag hose system consists of pit pump to pump to application field, two agitation pumps with tractors, umbilical cord (drag hose), its cart and tractor, applicator tractor, and manure applicator bar. This system can move to different farms as it applies the full manure application rate in a single application, thus, covering a large area during the number of favorable days available for manure application. Cost of labor, fuel, repairs, and maintenance, permitting, and insurance are variable costs included in the analysis. The window of application, after harvest in the Fall, is about 30 days. An additional 10 days of manure application can take place with such a system prior to planting corn is the Spring.

A dribble bar manure applicator (Agrometer SDS 8000) allows manure application in-season during early growth stages of corn until about 1-meter plant height. This manure applicator is a self-propelled machine but still needs manure pumped to it with an umbilical cord. The fixed assets in this system are the dribble bar, umbilical cord drag hose, pit pump, hose cart, hose cart tractor, pit agitation pumps with tractors . The window of manure application is about three weeks (21 days) after corn plants have reached V4 growth stage and up to V9 growth stage. After this growth stage, this dribble bar applicator can be used on alternate crop areas where alfalfa or hay are being grown in the cropping system. In comparison, the robotic irrigator (360 RAIN) has an application window of about 10 weeks as its high clearance allows for manure application from V4 to R5 corn growth stages. With this method, manure needs to be diluted to lower its solids content. Thus, a separate water supply source, i. e. a well or a pond, is needed as a source of dilution water. In this case, manure needs to be pumped or delivered to a manure mixing tank. Manure can then be metered into the water supply line to the 360 Rain Robotic Irrigator. The manure mixing tank, manure supply pump, water supply (well or pond), and a water supply pump are additional fixed assets compared to the other two manure systems. The 360 RAIN Robotic Irrigator is limited to 160 acres (65 hectares) as its setup involves a water supply line which has a limited length and is needed over the same area for repeated applications. Both Agrometer SDS 8000 and 360 RAIN are precision manure applicators and thus require GPS based RTK Precision equipment for guidance and manure application. Typical drag-hose manure application with tractor operated tool bar does not require such guidance equipment as the tractor operator can operate without GPS Guidance. A manure application rate of 4,000 gallons per acre (37,417 liters per hectare) was used in the analysis as it is the typical application rate for finishing swine manure in Iowa.

Corn crop yield improvements are expected with both Agrometer SDS 8000 and 360 RAIN as both methods deliver water in addition to the delivering of nutrients to the corn plant. According to Glewen (2022), the corn plant has water and nutrient needs from germination onwards, but the plant is more sensitive to water limitations from V4 growth stage up to R5 stage when the grain fill is complete. Due to clearance limitations, Agrometer SDS 8000 can apply liquid manure only up to 1-meter corn plant height (approximately V9 growth stage). In comparison, 360 RAIN can apply diluted liquid manure and meet the water needs of the corn plant across all growth stages. Percent corn yield improvements were calculated over the base yield using percent loss in yield in absence of water as identified by Lauer (2018). The average yield improvements can range from 3 percent to 6.8 percent per day of drought stress with drought during pollination (R1 growth stage) having the highest impact on yield. Yield improvements of 10% and 20% were analyzed for increased income using a base yield of 200 bushels per acre. Using corn grain weight of 56 pounds per bushel, the base yields used in analysis were 12,554 kilograms per hectare (Ag Decision Maker, 2022).

Results

Fixed costs and variable costs for the three manure application systems were calculated for all three systems. Traditional drag-hose system was considered to cover 3,642 hectares (9,000 acres) annually. Drag-hose system costs, applying 37,417 liters per hectare (4,000 gallons per acre) were \$173 per hectare (\$70 per acre) or 0.46 cents per liter (1.75 cents per gallon).

Dribble-bar system (Agrometer SDS 8000) was determined to be able to operate for 600 hours annually in a continuous corn or corn-soybean cropping system. This dribble-bar system was considered to operate for 10 hours per day for 30 days in Fall season, 10 days in Spring season, and 20 days after planting. Dribble bar can deliver 200 m^3/h (average flow capacity) of liquid manure and can thus cover 4.53 hectares per hour (11.2 acres per hour) with an 85% field efficiency when applying 37,417 liters per hour. Annual area covered by Dribble-Bar (36-m or 118 feet boom width), was determined to be 1,363 hectares (3,368 acres) for 600 hours of operation as this system covers the same area twice due to system design. The system is able to cover greater area based on the rated drive speed of 12 km/h (7.5 miles/h) but is limited by manure flow rate capacity. The system may be able to cover additional acres annually if it is used on pastures or alfalfa cropping systems. In the analysis presented in this paper, only the continuous corn or corn-soybean cropping system were considered. The dribble bar system costs, applying 37,417 liters per hectare (4,000 gallons per acre) were $425 per hectare ($172 per acre) or 1.14 cents per liter (4.3 cents per gallon).

Robotic Irrigator (360 RAIN) is designed for in-season application of water or diluted manure and can achieve a drive speed of 0.73 km/h (0.45 miles/h). At such drive speeds, it is not efficient for this equipment to be utilized for manure application in Fall season or Spring season as other more efficient methods exists. As such, only in-season application was considered in this analysis. With 18.3-meter boom width, this robotic irrigator can cover 16.3 hectares per day (33.7 acres per day) with a 24-hour operation at the above-mentioned drive speed. Thus, a quarter section of row-cropped field (64.7 hectares or 160 acres) can easily be covered in seven days with an operational efficiency of 65% or operating 16 hours per day. Split manure applications, diluted with water, were considered for application over a ten-week time-period in this analysis. A total of 10.2 cm (4 inches) of water application as irrigation water was considered for this robotic irrigator, thus, resulting in 1.02 cm (0.4 inches) application depth each week or 0.51 cm (0.2 inches) application depth with one pass down the crop rows and the second application pass back on the same rows. Percentage of manure, as part of water, was considered as adjustable to meet corn crop nutrient needs. Cost of well water was considered for its electrical cost to pump water. No tractor was needed in the analysis to move the fixed lay-flat hose from the mixing tank to the hydrant, which was then connected to 360 RAIN. This robotic irrigator system costs, applying 37,417 liters per hectare (4,000 gallons per acre) of swine finishing manure were $401 per hectare ($162 per acre) or 1.07 cents per liter (4.06 cents per gallon). This system, however, has the potential to provide improved yields due to better nutrient management and reducing water stress.

Discussion

Lauer, J. (2018) summarized the percent yield loss per day of water stress on a growing corn crop (Table 1). This summary shows that no stress exists in the upper Midwest region in early crop growth stages as the soils have sufficient water to meet the evapotranspiration needs of the seedings and of the corn plants from their germination stage up to V12 leaf stage. Thus, both drag-hose system and the dribble bar system do not have any yield benefit due to reduced water stress. The dribble bar system was only used for manure application during V4 to V9 corn growth stage. System modifications may be considered to allow the dribble bar to continue to irrigate with well or pond water as its boom appears to have enough clearance.

Table 1: Estimated corn evapotranspiration and yield loss per stress day during various stages of growth (adopted from Lauer, L. 2018).

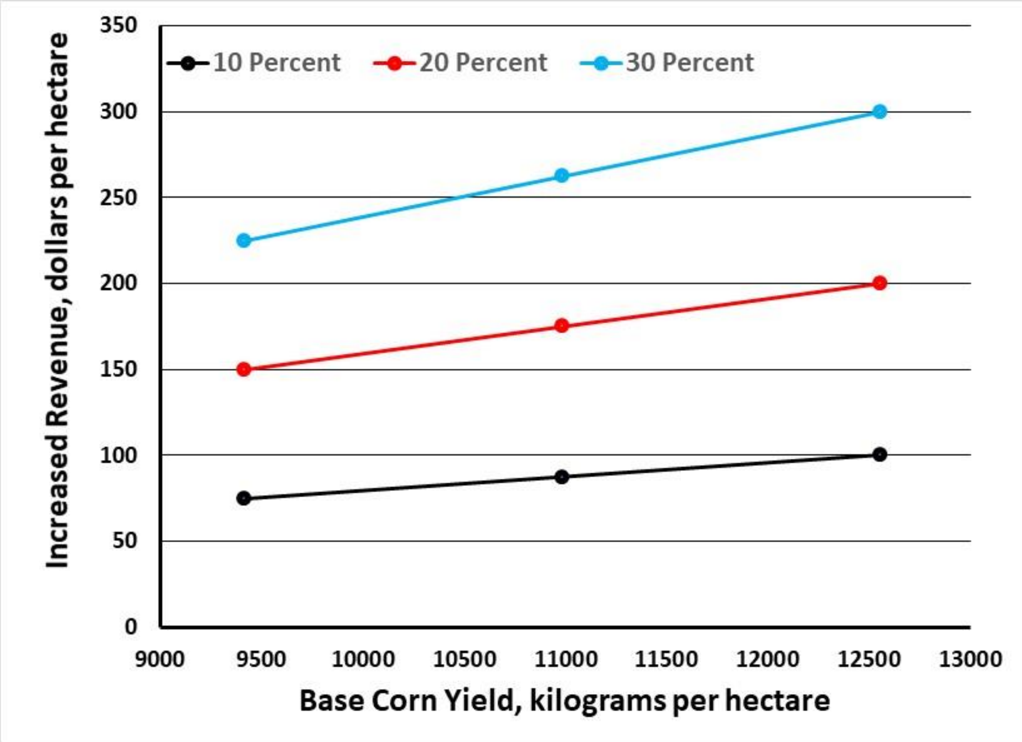
Corn Plant Growth Stage	Evapotranspiration inches per day	Percent yield loss per day of stress (min-ave-max)
Seedling to 4 leaf	0.06	—
4 leaf to 8 leaf	0.10	—
8 leaf to 12 leaf	0.18	—
12 leaf to 16 leaf	0.21	2.1 - 3.0 - 3.7

16 leaf to tasseling	0.33	2.5 - 3.2 - 4.0
Pollination (R1)	0.33	3.0 - 6.8 - 8.0
Blister (R2)	0.33	3.0 - 4.2 - 6.0
Milk (F3)	0.26	3.0 - 4.2 - 5.8
Dough (R4)	0.26	3.0 - 4.0 - 5.0
Dent (R5)	0.26	2.5 - 3.0 - 4.0
Maturity (F6)	0.23	0.0

In Iowa and most midwestern state, severe water stress due to lack of adequate water has not been recorded. As such, high yield improvements due to reduced water stress are not expected with the 360 RAIN Robotic Irrigator. Reduced water stress, when combined with improved nutrient management, can potentially result in a 10% to 15% yield improvement based on the data provided in Table 1. There are, however, parts of midwestern states where soil type variations, drainage issues, and weather patterns do not result in high yields of corn. As such, the improvements (reduced water stress and better nutrient management) can result in yield improvements of 20% or 30%. Such improvements can result in improved net income as there will be additional corn to sell.

Figure 1 shows the increased revenue for 10%, 20% and 30% yield improvements over the base corn yields of 9,416, 10,985, and 12,554 kilograms per hectare (150, 175, and 200 bushel per acre) using a 19.7 cents per kilogram ($5 per bushel, 56 pounds per bushel) corn market price. In Iowa, a ten percent and a twenty percent yield improvement on a 12,554 kilograms per hectare (200-bushel per acre) corn crop will result in $100 and $200 in increased revenues, respectively. Any swine finishing operation will spend a minimum of $173 per hectare ($70 per acre) or 0.46 cents per liter (1.75 cents per gallon) utilizing a drag-hose system costs when applying 37,417 liters per hectare (4,000 gallons per acre). This is the base cost of applying manure and needs to be subtracted from the total cost of manure application for the robotic irrigator to arrive at the added cost of manure application. Thus, yield improvements need to provide $228 per hectare or $92 per acre additional revenue to offset the added cost of manure application with robotic irrigation.

Figure 1 shows the yield improvement in terms of increased income using $5.00 per bushel corn price or 19.685 cents per kilogram using 56 pounds per bushel corn grain unit weight.



With the dribble bar system, the additional cost of applying manure in season is $252 per hectare ($102 per acre) after subtracting the base cost of applying manure with a drag-hose system. Assuming Agrometer SDS 8000 is modified and can be utilized to apply irrigation water or diluted manure, the dribble bar system can also gain the benefits of improved yields. Its operating costs will be slightly higher due to increased operations for the ten-week period as considered for robotic irrigation with 360 RAIN.

Overall, in-season manure application with novel robotic methods has the potential to reduce water quality impacts of nutrients reaching water bodies. Iowa State University currently has a project, in collaboration with Ohio State University, to study how much nutrient loss can be reduced by use of such robotic technologies. Society is already bearing a cost for improving water quality by implement in-field practices (for example cover crops) and edge of the field practices (saturated buffers, woodchip bioreactors, wetlands, etc.). In-season nutrient application (manure or commercial fertilizers) can potentially help reduce the nutrient losses which can further help to reach nutrient reduction goals when combined with in-field or edge of the field practices.

Conclusions

Based on the analysis performed, the following conclusions can be summarized:

1. Costs per hectare with a traditional drag-hose system, when applying 37,417 liters per hectare (4,000 gallons per acre) and covering 9,000 acres annually, were $173 per hectare ($70 per acre) or 0.46 cents per liter (1.75 cents per gallon). A thirty-day Fall season and a ten-day Spring season application time-period was used in this analysis.

2. The dribble bar system costs, for the same application rate and an additional twenty-day application time-period in early summer after planting, were $425 per hectare ($172 per acre) or 1.14 cents per liter (4.3 cents per gallon).
3. The robotic irrigator system costs, when applying 37,417 liters per hectare (4,000 gallons per acre) of swine finishing manure over 160 acres with irrigation water over ten-week time period after planting, were $401 per hectare ($162 per acre) or 1.07 cents per liter (4.06 cents per gallon). This system, however, has the potential to provide improved yields due to better nutrient management and reducing water stress.
4. The base cost of applying manure exists as applying manure with the traditional drag-hose system and it needs to be subtracted from the total cost of manure application for the robotic irrigator or dribble bar system to arrive at the added cost of manure application utilizing these two other systems. For the robotic system, yield improvements need to provide $228 per hectare or $92 per acre additional revenue to offset the added cost of manure application.
5. With the dribble bar system, the additional cost of applying manure in season was calculated as $252 per hectare ($102 per acre) after subtracting the base cost of applying manure with a drag-hose system. Assuming Agrometer SDS 8000 can be potentially modified and can be utilized to apply irrigation water or diluted manure, the dribble bar system can also gain the benefits of improved yields.
6. In-season nutrient application (manure or commercial fertilizers) can potentially help reduce the nutrient losses which can further help to reach nutrient reduction goals when combined with in-field or edge of the field practices. When combined with the potential to improve yields (with reduced water stress and better nutrient management), this may help with increased adoption by producers who can both reduce water quality impact and increase their net income.
7. An economic value cannot be ascertained on the environmental benefit to the society based on efficient nutrient management such strategy presents. Potential exists to minimize nutrient losses in Fall and early Spring season by transferring nutrient application to late Spring and Summer season when corn plants have developing root system. More research is needed to quantify efficient nutrient management and reduction in nutrient losses with such in-season nutrient application strategy.

Disclaimer

Trade names of the equipment provided in this paper are for reference of the reader only and do not imply any endorsement by the authors or by Iowa State University.

References

Ag Decision Maker. 2022. Weights and Measurements. Iowa State University, Ames, IA. Available online at https://www.extension.iastate.edu/agdm/wholefarm/html/c6-80.html#:~:text=Because%20a%20hectare%20is%20equal,12.55%20metric%20tons%20per%20hectare. Viewed: May 21, 2022.

Glewen, K. 2022. Determining the Crop Growth Stages of Corn and Soybeans. University of Nebraska, Lincoln, NE. Available online at https://cropwatch.unl.edu/documents/Corn%20Growth%20%20Development%2013-1-1.pdf Viewed: May 21, 2022.

Lauer, J. 2018. What Happens Within The Corn Plant When Drought Occurs?, University of Wisconsin, Madison, WI. Available online at https://dunn.extension.wisc.edu/files/2018/09/CV-Ag-News-Fall-2018-Page-2-Corn-plant-during-drought.pdf Viewed: May 21, 2022.