LIFE CYCLE COST AND ANALYSIS OF IMPLEMENTING DRAIN TILE SYSTEM IN ROW CROP OPERATIONS

Keywords: Row Crop, Drainage, Life Cycle Costs, Life Cycle Analysis, Farm Managment, System Implementation

Abstract: *Tile drain systems have been used for many years in agriculture; however, their popularity has increased over recent years. At the same time, questions around the costs and environmental impacts of these systems have increased. These concerns have left many operations and individuals questioning if the systems benefits outweigh it's costs. This paper presents a Life Cycle Costs (LCC) and Life Cycle Anaylsis (LCA) for implementing a new tile drain system into a traditional row crop operation. The results found that the use of four-inch single wall correcated pipe was the best piping for both economic and envirormental impacts. The model presented here, is the first model present an LCC and LCA for a tile drain system, and will provide the needed baseline to compare differnet system designs and materials for implementing a tile drain system.*

Introduction: In the United States, 14% of the cropland has tile drains present, primarily concentrated in the Midwest states of Illinois, Indiana, Iowa, Michigan, Minnesota, Ohio, and Wisconsin (Zulauf and Brown, 2019). Although this percentage has continued to increase in recent years, tile drains are not a new technology for agriculture crop production and have been used for decades in the US. A tile drainage system is a network of subsurface pipes that collect excess water from the soil and move it offsite. These systems can greatly benefit farming operations by allowing historically higher saturated acres to be placed into row crop production. In addition, they allow more flexibility with crop operation dates while also increasing crop yields and soil health. Along with these potential benefits, the innovation of new pipe materials provides a more cost-effective and environmentally-friendly system than the traditional clay drain tiles previously used (Bowman, 2020; Stika, 2019).

Although newer tile drains present several positive benefits, significant concerns revolve around leaching materials into the water system, soil erosion, and loss of wetland habitats. Couple these concerns with the number of older systems still in use today, and the tile drains might very well be an issue for the environment. Given the uncertainty, this project performed a life cycle analysis, cost, and design analysis to add a tile drainage system to an existing row crop field to address these concerns. The objectives for this project are to 1) establish a hypothetical farm, 2) calculate a design for a tile drain system on that farm, 3) perform a life cycle cost analysis on the system, 4) perform a life cycle assessment on the system, and 5) determine and estimate potential areas of uncertainty and sensitivity in the project.

Since tile drains are primarily used in highly saturated areas with a clear possibility of row crop production, a hypothetical farm was established to assess the system's implementation. This farm was set in western Kentucky at the top of the Mississippi Delta, an area known for highly productive soils and potentially saturated soils from the Ohio and Mississippi rivers. The project established the area as a 40-acre crop field with a 0-2% ground slope on silt loam soil, which is common in the area (NRCS). Furthermore, the operation used a corn and soybean rotation. Due to the possibility of a double-crop soybean for this operation, adding a tile drain system would be extremely important to allow the crops to have a longer growing season. Lastly, due to the topography of this farm and the cost of the system, the drains will have to move the water without the help of a pumping system. A series of constraints was developed based on the hypothetical farm (Table 1).

Next, a series of design equations and constraints were developed to ensure a working system provided (Tables 2 & 3). Coupled with the decision variables, it will establish the system's design. From the possible designs, a life cycle costs and life cycle analysis will be employed to compare the different designs and materials of the system. The final recommendation will analyze these results and provide suggestions for the best economically and environmentally system.

System Design: The system must drain every part of the field, be a minimum of 3 feet below the soil and a maximum of 6 feet, be able to drain the water using gravity, and have enough main pipes to move the water offsite properly. From these constraints, the design equations calculated the drainage coefficient (Hooghoudt Equations), estimated the pipe slope (Manning's Equation), and calculated the needed amount of pipe to cover the parameters.

The decision variables were established, including pipe material and size, installation equipment, drain spacing, and depth of the pipes. The pipe material and size were both discrete variables with the options of PVC, single wall, or dual wall piping with the option of a 3, 4, 6, or 8-inch pipes on the laterals and a 10, 12, 14, or 20-inch pipes for the main lines. Similarly, the installation equipment was also discrete, with the option of using either a backhoe or trencher for installation. Both are continuous variables for the pipe depth and spacing with a 3-6 foot range for lateral pipe depth and a 30-100 foot spacing for lateral pipes. An Excel model was developed to combine the variables and the design equations with the decision variables established.

Due to the limitation from the pipe depth being no greater than 6 feet, the model found that the maximum length of a lateral pipe would be 300 feet, no matter the material or pipe diameter. This will ensure that the pipe maintains a 1% slope for water draining and drains the proper amount within 48 hours of rainfall. Using the lateral length, drain spacing was determined using the online guide from iGrow for each pipe diameter. The total width of the field was then divided by the spacing, and the total length of the field was divided by the lateral length to calculate the total number of lateral and main lines needed to cover the field. Results were then checked using iGrow to ensure the lateral pipes feeding into each main would not overflow any of the main lines. Finally, both the lateral and main lines were totaled to calculate the total length of pipe needed for the system. Those resulting estimations were used to calculate the drain design in Excel. This first portion of the Excel sheet uses the design equations and information to calculate the material and construction specifications (Engineering Toolbox, 2004; Pacific Corrugated Pipe Co.; Timewell Drainage Products, 2019). Results include the excavation volume, backfill volume, and transportation measurements for the project and will estimate these changes of the pipe size used.

LCC: To compare these different materials and designs, they must all be over the same lifetime, use a common use, and be normalized to the same units of measure. All pipe materials have the same service lifetime of 100 years for this project. Therefore, no replacement cost was needed. All designs and materials could be calculated as a total amount and then divided by the total acres of the field to produce a per-acre cost for each design and material. Ultimately, this per acre approach was chosen because most agriculture estimates are presented in a per acre format to help farmers scale to their operation. Economic costs were normalized to present value since all lifetimes were equal.

Unit costs were added into the model using RS means with the LCC underpinnings satisfied. The majority of the items were directly listed in the software. However, to estimate the most accurate costs for pipes, a trend line was calculated for each pipe material where the cost per foot of the pipe as a function of the pipe's diameter. This cost estimation was performed for the lateral and main pipes to avoid any cost breakpoints due to sizing. Further unit costs were found for both excavating, backfilling, and transportation. Due to a lack of information in RS Means, the traditional use of a pipe trencher was not available. Therefore, a backhoe was used to estimate excavation and backfilling costs. As for transportation, the estimation was based on $3.15 per gallon diesel and fuel efficiency of 6 miles per gallon. (Table 4)

LCA: Evaluating and understanding the costs associated with the system and comparing the differences between designs or materials is not enough information to provide the entire picture; the environmental impacts are also needed. To assess the environmental impacts, a life cycle analysis was created to evaluate the impacts of building the tile drain system and provide the ability for different designs, materials, or decision variables to be compared. The scope of the analysis was set using a functional unit on a per-acre basis. This project found no consistent minimum flow rate for each design; instead, there was only a maximum flow rate. No design exceeded the maximum, and therefore each system would have to be increased beyond reasonable thresholds to achieve those flow rates and would not be realistic. This resulted in the first major finding of the project; since all of the pipe sizes present the needed flow rates, the model will always select the smallest pipe size since it will provide the lowest cost and environmental impacts. However, results were calculated on the various pipe sizes to provide a complete evaluation.

With the functional unit set, TRACI was used to calculate the climate change impacts estimates for the various materials and operations of the system (Table 5). These estimations were in terms of per kg CO_2 eq/kg for each material, kg CO_2 eq/m^3 for excavation and backfilling, and kg CO_2

eq/metric ton-km for transportation. To calculate the correct impacts, each item was converted into the proper measurement and multiplied by the appropriate impact estimate. These various categories were added together to provide a total climate change impact for the systems to be compared with one another.

Uncertainty and Sensitivity: Although the project can compare various designs of a system and materials or operations used for each system, all of these estimates are built upon underlying assumptions or values. Most of these values have been well researched with established results for many years. However, if the system were being used for a real-life operation, we would risk different values. For this reason, the project used uncertainty analysis to see which inputs might affect outputs. The parameters for the uncertainty analysis were interest rate, Hazen Williams C (Lindeburg, 2019), deliver distance, and pipe slope. The interest rate and delivery distance were assumed values for the hypothetical farm. Therefore, the impact of those parameters is not shown in previous literature and needs to be studied. The pipe slope was found from the design equations, but this slope could be inconsistent since the farmers installed the systems. Finally, the Hazen Williams C has been well known for the materials in this study for over 50 years. However, studies have shown the possibility of a small range of variability in commercially produced piping. The parameters used a uniform distribution since all outcomes within each range were equally likely. The range for each parameter can be seen in (Table 6).

To access the uncertainty of these parameters, a Monte Carlo simulation was performed for 1000 different trails. Although more trials would produce a more accurate simulation, due to computing power and the software used in this project, 1000 trials were found acceptable. Next, using Excel, random numbers were generated between each range for each parameter. Those numbers were then fed into the model using a macro.

The sensitivity analysis of this project centered around one potential issue. These systems are placed under an active farming operation that uses tillers and other machinery to work the ground. Furthermore, the operations can be performed by either inexperienced workers or workers who are unaware of the drain system under the surface. For these reasons, there is a possibility that the system could not serve an entire lifetime or require repairs during its lifetime.

To analyze this issue, the parameter of pipe lifetime was investigated for each material using a one at a time sensitivity analysis. This risk would be completely random; therefore, the study used a 25, 50, and 75 year lifetime.

Relative Sustainability of Design Alternatives: Results from the model were first compiled by each material type where the lateral and main pipe size was used. For each combination, the total costs and climate change impact were documented. The model illustrated that pipe size was the primary factor in cost and impacts from these initial results. Therefore, the smallest pipe size was used to compare the material types. Although there was an option for a three-inch pipe, there was no reliable or consistent literature on the pricing and weights for that size in particular.

For this reason, the four-inch pipe was chosen as the smallest size with reasonable confidence in the estimation. The four-inch lateral and ten-inch main pipes provided the needed flow rate without exceeding the maximum rate allowed for the soil. Using the same size pipe allows for a similar and more realistic comparison of the materials.

The results from the model suggested that the use of the single wall high-density corrugated pipe was far cheap than the other options. With a total cost of $57,347.30 per acre, the single wall pipe was less than half of the cost of the second-best option, PVC. As for the dual wall high-density pipe, the per-acre cost was over four times the cost of the single wall. It is worth noting that this was a consistent comparison of costs between materials no matter what pipe size was used. Given the scale of this project, that difference for the entire field would be 2.8 million for PVC and 7.2 million for the dual wall.

As for the LCA component of the model, both high-density pipes held much lower climate change impacts than the PVC. Although the dual pipe has an extra layer of piping, the single wall was only around 1% less kg CO_2 eq than the dual wall. However, the single wall pipe was still the lowest option for climate change impacts. On the other hand, the PVC material was a 50% increase in climate change impacts compared to the single wall material.

The previously mentioned decision variables did not play any role in comparing the different materials. Since the system's design was based on the various decision variables, the model used the same design for all different materials. However, those variables did come into play when comparing the different pipe sizes. Since a larger pipe has more material, the unit costs and impacts were higher for the larger pipes. Full results can be found in Tables 7 & 8.

Recommendation: Before the model was completed, the initial ranking of designs and materials was going to use a weighted ranking system. The LCC results are weighted heavier than the LCA since traditional farming operations would need the system to be economically feasible before considering the environmental implications. However, it became overwhelmingly clear during the project that one system and design would perform well above all others. As mentioned in previous sections, the single wall corrugated high-density piping outperformed the other materials by holding a significantly lower cost and lower climate change impacts when compared to the other materials. Since neither the flow rate nor durability was a problem, this material will likely always be suggested due to its performance. The design of choice for the system came from a similar realization within the project. The smallest pipe for both the lateral and main lines would be suggested. This result is again due to the lower cost of the material and the lower climate change impacts. The suggestion from the project would be to use a four-inch pipe since the information about a three-inch pipe is unclear in previous literature. However, if an operation has the opportunity to use a three-inch pipe that holds close estimates to the information in the project's model, the smaller pipe would be suggested. As was the case with the material, there are no limitations or advantages of using the smaller pipe in terms of flow rate, durability, or water-holding capability. All sizes are able to perform the necessary levels needed for this system if installed properly.

The suggested results depict the best performing system, but how confident are these results. The uncertainty analysis described in the previous section of the paper further confirmed the suggested results. The results showed minimal variability when the various inputs were used in a Monte Carlo model. For both the LCC and LCA, the average percent increase in outputs was less than 0.1% for all materials. Additionally, the maximum and minimum results from the uncertainty analysis were all within 0.1% of the suggested results. The project can suggest no concern of uncertainty within these parameters from these numbers.

As for the issue of premature problems from farming operations, the sensitivity analysis results were as expected. If the system experienced a problem before the 100 year lifetime was complete, the project's costs would increase by the amount of materials needed to replace the system. Although these are straightforward results, it is worth noting that the operation would likely only replace the line or lines damaged in a real-world application. If this were the case, a much lowest cost and climate change impact would be illustrated. Due to the design of a tile drain system, the lateral pipes are the most likely lines to be damaged. Since the project limits those lines to 300 feet, the project would suggest that the highest cost from damaged lines would be to replace 300 feet of lateral lines. If this were the case, the replacement cost would be less than 0.035% of the costs for the entire project and less than 0.011% of the climate change impacts of the entire project. Therefore, similar to the uncertainty, the issue of damaging the pipelines was not an area of concern for the project due to the low percentage increase from the one at a time analysis. The full results from the uncertainty and sensitivity analysis can be seen in Table 9 & 10.

Conclusion: The model was much more straightforward than initially planned. The drastic difference in pipe sizes and materials ultimately left only one valid solution. However, these results are still valuable to provide a full illustration and comparison of the different combinations. The strength of this project is providing the needed information that fills the gap in the literature for tile drain systems. Previous studies have not provided a comparison of different materials.

Furthermore, these results confirm that the most commonly used pipe and material of the single wall pipe is the best option both economically and environmentally and illustrate the areas in which that pipe performs better than others. The results also provide a clear numeric value of tile drains that previous literature only provides a general estimation. Although these results do not illustrate a one and only one design system for all farms, the results still offer information that was not previously available nor updated and furthers the literature around tile drain systems in agriculture.

The project also showed limitations within the model. The most obvious limitation was the need for more accurate information on the three-inch piping. The ability to accurately estimate the model with this pipe could drastically lower the economic and environmental results and likely change the study's recommendation. Better information or recommendations on pipe depths, both minimum and maximum, would further the study results. The model limited the length of the pipe to 300 feet due to this constraint, but there is very little literature around whether this maximum depth is accurate. The model led to the cautious side and used the highest maximum depth to provide an accurate model. However, the longer lateral lines would lead to fewer main lines and lower overall cost and climate change impacts.

The final limitation of the model was centered around the information available on installation equipment. As mentioned in previous sections, the costs of a trench plow or a skid steer were not available in the TRACI software for the needed practices. This resulted in the model using a backhoe instead, which contributed to a higher cost for construction in both the LCC and LCA. If a trench plow were used for excavating and a skid steer for backfilling, the construction process would be more efficient, resulting in lower costs and impacts. As for using other decision-making criteria to address the best recommendation could have been used for a survey or ranking of the impacts and parameters. However, most of these impacts or parameters are well defined in previous literature.

Future work on tile drain systems in agriculture is greatly needed. Although these systems have been used for many years, much of the literature is either outdated or unsatisfactory. Due to the industry, many publications provide estimations that underestimate the actual cost of the system or ones that do not include the labor or machinery for installation. Further work should provide an accurate model that addresses this study's limitations and incorporates the difference in systems installed by the operation. Although much of the literature see this self-installation as "free labor," an accurate model should incorporate this labor into the model as either the cost savings from not using a construction company or as an opportunity cost of the labor. Overall this project fills a significant gap within the literature and provides a clear recommendation for installing a tile drain system. Although there are limitations to the study, the results and recommendations should be used for further research in this area.

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Appendices

Table 1 - Constraints of the Model	
Total Acres of the Field	40 Acres
Soil Type	Silt Loam
Min Pipe Depth	3 Feet
Max Pipe Depth	6 Feet
Field Slope	0-2 %
Max Velocity (ft/sec)	5
Drainage Coefficient (Dc)	0.5
Pipe grade	1%

Table 2 - Parameters of the model	Pipe Material		
	PVC	Single Wall	Double Wall
Hazen Williams C	140	140	140
Distance to Jobsite (Miles)	15	15	15
Pipe Service Life (Years)	100	100	100
Project lifetime	100	100	100

Table 3 – Design Equations

Equation Name	Equation	Reference
Hooghoudt Equation	$Dc = \frac{(8 * K_2 * d * h)}{L^2} + \frac{(4 * K_1 * h^2)}{L^2}$	Panuska, 2017
Manning Equation	$Q = \frac{(1.49)}{n} * AR^{\frac{2}{3}} * \sqrt{S}$	Oregan State University
Number of Lateral Lines	$\frac{Total\ Field\ Width}{Lateral\ Spacing}$	
Number of Main Lines	$\frac{Total\ Field\ Length}{Lateral\ Length}$	

Table 4 - Unit Costs		
Item	**Cost**	**Reference**
PVC Pipe Cost (Cost per linear foot)	(1.721 * Pipe Diameter) + 4.202	RSMeans
Single Wall Pipe Cost (Cost per linear foot)	(1.186 * Pipe Diameter) -2.3885	RSMeans
Dual Wall Pipe Cost (Cost per linear foot)	(5.5329 * Pipe Diameter) - 10.239	RSMeans
Excavating	$7.75 ($/yd^3)	RSMeans
Backfilling	$7.75 ($/yd^3)	RSMeans
Transportation	$0.52 ($/mile)	Based on $3.15 diesel and 6 miles to the gallon

Table 5 - Impacts from TRACI		
Item	**Unit process**	**Database**
PVC Pipe Material	bulk polymerised {GLO}| market for | APOS, U	Ecoinvent 3
Dual Wall Pipe Material	high density, granulate {US}| polyethylene, high density, granulate, recycled to generic market for high density PE granulate | APOS, U	Ecoinvent 3
Single Wall Pipe Material	high density, granulate {US}| polyethylene, high density, granulate, recycled to generic market for high density PE granulate | APOS, U	Ecoinvent 3
Excavation	Backhoe {GLO}| market for | APOS, U	Ecoinvent 3
Backfilling	Backhoe {GLO}| market for | APOS, U	Ecoinvent 3
Transportation	light commercial vehicle {GLO}| market group for transport, freight, light commercial vehicle | APOS, U	Ecoinvent 3

Table 6 - Uncertainty and Sensitvity				
Uncertainty				
Parameter	**Unit**	**Distribution**	**Values**	**Reference**
Interest Rate	%	Uniform	5.0-8.0	Assumed Value
Hazen Williams C	No unit	Uniform	120-150	Lindeburg, 2019
Distance to Job Site	Miles	Uniform	10-35	Assumed Value
Sensitivity				
Parameter	**Unit**	**Type**	**Values**	**Citation**
PVC Pipe Lifetime	Years	OAT	80, 100, 120	Folkman, 2014
Dual Wall Pipe Lifetime	Years	OAT	50,75,100	
Single Wall Pipe Lifetime	Years	OAT	50,75,100	

Table 7 - Full Results					
LCC - PVC		Main Pipe Size			
	5170915.83	10	12	14	20
Lat Pipe size	3	$5,061,269	$6,636,072	$8,206,390	$12,928,520
	4	$5,170,916	$6,745,719	$8,316,037	$13,038,166
	6	$5,371,519	$6,946,322	$8,516,640	$13,238,769
	8	$5,550,183	$7,124,986	$8,695,304	$13,417,434
LCC - Single		Main Pipe Size			
	2293892.09	10	12	14	20
Lat Pipe size	3	$ 2,205,391	$ 3,147,169	$ 4,084,461	$ 6,907,515
	4	$ 2,293,892	$ 3,235,670	$ 4,172,962	$ 6,996,015
	6	$ 2,456,068	$ 3,397,845	$ 4,335,137	$ 7,158,191
	8	$ 2,600,973	$ 3,542,751	$ 4,480,043	$ 7,303,096
LCC - Dual		Main Pipe Size			
	9495136.98	10	12	14	20
Lat Pipe size	3	$ 9,088,409	$ 12,578,604	$ 16,064,313	$ 26,532,618
	4	$ 9,495,137	$ 12,985,332	$ 16,471,041	$ 26,939,347
	6	$ 10,237,683	$ 13,727,879	$ 17,213,588	$ 27,681,893
	8	$ 10,899,987	$ 14,390,182	$ 17,875,892	$ 28,344,197
LCA - PVC		Main Pipe Size			
	1499463.23	10	12	14	20
Lat Pipe size	3	1,449,477	1,897,600	2,223,674	4,479,412
	4	1,499,463	1,947,587	2,273,661	4,529,398
	6	1,578,653	2,026,776	2,352,850	4,608,588
	8	1,695,573	2,143,696	2,469,770	4,725,508
LCA - Single		Main Pipe Size			
	972562.149	10	12	14	20
Lat Pipe size	3	965,550	1,273,945	1,498,346	3,050,726
	4	972,562	1,280,957	1,505,358	3,057,739
	6	997,125	1,305,520	1,529,921	3,082,302
	8	1,028,485	1,336,880	1,561,281	3,113,662
LCA - Dual		Main Pipe Size			
	982254.91	10	12	14	20
Lat Pipe size	3	980,177	1,288,572	1,512,973	3,065,353
	4	982,255	1,290,650	1,515,051	3,067,432
	6	1,010,259	1,318,654	1,543,055	3,095,436
	8	1,040,654	1,349,049	1,573,450	3,125,831

Table 8 - Results at a Per Acre Scale				
	LCC	Pipe Material (10 inch Main)		
		PVC	Single Wall	Double Wall
Lat Pipe size	3	$ 126,531.72	$ 55,134.79	$ 227,210.21
	4	$ 129,272.90	$ 57,347.30	$ 237,378.42
	6	$ 134,287.97	$ 61,401.69	$ 255,942.08
	8	$ 138,754.57	$ 65,024.33	$ 272,499.68
	LCA	Pipe Material (10 inch Main)		
		PVC	Single Wall	Double Wall
Lat Pipe size	3	36236.9214	24138.74075	24504.41719
	4	37486.58082	24314.05373	24556.37276
	6	39466.31873	24928.12987	25256.47677
	8	42389.31634	25712.12335	26016.35447