Economic Analysis of Subsurface Tile Drainage Spacing

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Abstract

This study examined the optimal tile drainage spacing using data for the 1984–2021 period for a drainage experiment in southeast Indiana. Four drainage spacings were compared: 16 feet, 33 feet, 66 feet, and 133 feet. Gross return per acre was highest for the 16-foot spacing. However, net return per acre was highest for the 66-foot spacing. The 66-foot tile drainage spacing also had a higher certainty equivalent of net returns and was the preferred drainage spacing using second-degree stochastic dominance (SSD). Sensitivity analysis related to the discount rate used, the cost of tile installation, and the useful life of the tile drainage system confirmed the attractiveness of the 66-foot spacing. The conceptual framework developed in this study would be useful when examining the feasibility of installing subsurface drainage in poorly drained soils in the U.S. Midwest.

INTRODUCTION

Using the 2017 Census of Agriculture, 56 million U.S. acres were reported as being drained by tile, which represented a 14% increase from the 2012 Census of Agriculture (USDA NASS, 2019). Moreover, according to Zulauf and Brown (2019), the share of acres that was drained in 2017 was greater than 20% in Iowa (53%), Indiana (49%), Ohio (49%), Illinois (39%), Michigan (38%), Minnesota (37%), and New York (20%).

There are numerous benefits associated with tile or subsurface drainage. These benefits may include improved timeliness of fieldwork, improved crop yields, increased infiltration, and reduction in sediment and nutrient losses (Skaggs and van Schilfgaarde, 1999; Kladivko, 2020; Kladivko and Bowling, 2021). Benefits primarily occur on soils classified as poorly or somewhat poorly drained. These soils comprise the majority of the tile-drained lands in the Midwest.

This paper utilized data from a long-term subsurface drainage project in southeast Indiana. Previous studies have examined various agronomic aspects of the drainage spacings used in this project. Kladivko et al. (2004) examined drain flow and nitrate N losses. Drain flow and nitrate N losses were greater for narrower drain spacings. Kladivko, Willoughby, and Santini (2005) examined corn growth and yield response to subsurface drain spacing associated with the project. Although the narrower spacings provided yield improvements in some years, average corn yields were not significantly different among treatments during the 10-year study period (i.e., first 10 years of the drainage project). Further insights into soil drainage and crop yields from the project can be found in Kladivko (2020). Drainage improved timeliness of fieldwork by 1 to 15 days and improved corn yields by 24 bushels per acre compared to the undrained control. However, soybean yields were not different across drainage spacings. In contrast, using data from the north central region of the United States, Mourtzinis et al. (2021) found that the average yield of soybeans with subsurface drainage was 8% higher than yields without subsurface drainage. Kladivko and Bowling (2021) compared nitrate N loads in surface waters for the first 15 years of the drainage project in southeast Indiana with those for the second 15 years. Drain flow and nitrate N losses were greatest for the 5-meter (16-foot) spacing and lowest for the 20-meter (66-foot) spacing. In contrast, nitrate N concentrations did not vary across drainage spacings.

Much of the previous literature on tile drainage has focused on agronomic and water quality aspects. Research that has examined the relationship between net return per acre and drainage spacing is limited. Skaggs, Youssef, and Chescheir (2006) developed a simulation model to determine the drainage spacing corresponding to maximum economic return. Specifically, the authors simulated 50 years of corn yields for four soils near Urbana, Illinois. Net returns were then computed using these yields, corn price, and tile installation cost assumptions. The optimal drain spacing ranged from 19 to 24 meters (62.3 to 78.7 feet) for three soils and 40 meters (131.2 feet) for the fourth soil.

The objective of this paper is to examine optimal tile drainage spacing using 1984–2021 data from a drainage experiment in southeast Indiana. Four drainage spacings were compared: 16 feet, 33 feet, 66 feet, and 133 feet. Analysis included comparisons of crop yields, gross return per acre, and net return per acre.

METHODS

Corn and soybeans were produced on an experimental field in southeast Indiana. Specifically, corn was produced in 24 of the 38 years during the sample period, and soybeans were produced in the other 14 years. Real gross return per acre was computed using marketing year average prices for Indiana (USDA NASS, 2022), crop yields, and the implicit price deflator for personal consumption expenditures (BEA, 2022).

Tile drainage is a long-term investment. Thus, economic analysis of tile or subsurface drainage typically compares added gross returns resulting from higher crop yields to the annual cost of the tile drainage system, which incorporates capital budgeting concepts such as the discount rate and the useful life of tile investment (Hofstrand, 2010). The equivalent annual cost (EAC) method can be used to estimate the annual cost of owning an asset over its useful life (Kenton and Kindness, 2020). Information pertaining to the discount rate, investment cost, and useful life of the drainage system was used to compute the EAC for each drainage spacing. The base case used a 6% discount rate, a cost of tile installation of $1 per foot, and a useful life of 30 years. Net return per acre for each drainage spacing was computed by subtracting EAC from gross return per acre. Sensitivity analysis examined whether the drainage spacing choice changed when a higher discount rate, higher tile installation cost, or longer useful life was assumed.

Before examining risk, t-tests were used to examine the difference in the means across drainage spacings for corn yields, soybean yields, gross return per acre, and net return per acre. Risk was incorporated using both expected utility analysis and stochastic dominance. Expected utility analysis was used to compute the certainty equivalent of net returns for each drainage spacing. The certainty equivalent incorporates average net returns, the variability of net returns, and downside risk. Essentially, the certainty equivalent of net return represents a risk-adjusted return. To calculate the certainty equivalent requires information pertaining to a utility function and risk aversion coefficients. The power utility function was used to compute certainty equivalents in this study. This utility function is often referred to as the constant relative risk aversion utility function and is widely used for modeling risk aversion in production agriculture (e.g., Liu et al., 2018). In addition to constant relative risk aversion, this utility function exhibits decreasing absolute risk aversion as wealth increases. A relative risk aversion level of 3 was used in this study. This risk aversion level represents moderately risk-averse preferences (Hardaker et al., 2015).

Stochastic dominance was also used to examine the choice between drainage spacings. Stochastic dominance compares the entire cumulative distribution function of net return per acre (Hardaker et al., 2015). First-degree stochastic dominance (FSD) and second-degree stochastic dominance (SSD) were utilized. FSD compares the risky alternatives (i.e., drainage spacings in this case) faced by decision-makers who have positive marginal utility, which implies that decision-makers prefer a higher net return per acre to a lower net return per acre. Alternatives included in the FSD set satisfy the criteria that more is preferred to less. FSD is typically not very discriminating. In other words, most activities or choices are typically part of the FSD set. SSD assumes that decision-makers are risk averse—or are concerned about the trade-off between average net returns and risk, measured using the variance of net returns or downside risk. Alternatives included in the SSD set satisfy the criteria that decision-makers are risk averse. SSD has more discriminatory power than FSD and reflects the fact the most decision-makers are risk averse.

DATA

Kladivko (2020) contains background information pertaining to the long-run drainage study in southeast Indiana. The study was conducted at the Southeast Purdue Agricultural Center (SEPAC) on Clermont silt loam soil. As noted by Kladivko (2020), most of the results garnered from the drainage project are generally applicable to other poorly drained soils. The drain spacing experiment consisted of three drain spacings plus an undrained control. Drains were installed at 5, 10, and 20 meters (16, 33, and 66 feet), with an "undrained control" spaced at 40 meters (133 feet). Because the soil is so slowly permeable, the 40-meter spacing was considered to be a good proxy for an undrained field. The drainage systems were installed in 1983, and crop yields were first collected in 1984.

Tile investment and cost per acre are very sensitive to drainage spacing. Tile investment was estimated using drainage spacing information and a tile installation cost of $1 per foot. Cost estimates included materials and installation costs. Costs would be higher for small and/or irregularly shaped fields. Tile investment per acre ranged from $332 for the 133-foot spacing to $2,738 for the 16-foot spacing. Tile investment cost was $1,327 per acre for the 33-foot spacing and $664 per acre for the 66-foot spacing. EAC for the base case scenario was computed using a 6% discount rate, an installation cost of $1 per foot, and a 30-year useful life. Note that the tile was installed close to 40 years ago at the SEPAC site. For the base case scenario, EAC was approximately $24 per acre for the 133-foot spacing, $48 per acre for the 66-foot spacing, $96 per acre for the 33-foot spacing, and $199 per acre for the 16-foot spacing. Obviously, crop yields would have to be substantially higher for the 16-foot spacing option for it to be preferred to the other drainage spacings.

Table 1 presents the summary statistics for the tile drainage site in southeast Indiana and the t-test results. Gross return per acre and net return per acre were adjusted for inflation using the implicit price deflator for personal consumption expenditures and are expressed in real 2021 dollars. Corn yield was significantly higher for the 16-foot spacing and significantly lower for the 133-foot spacing. Average corn yield for the 16-foot spacing was over 24 bushels per acre higher than that for the 133-foot spacing. Differences in soybean yields, on the other hand, were minimal. The gross return results were similar to the corn yield results. Gross return per acre was significantly higher for the 16-foot spacing and significantly lower for the 133-foot spacing. As noted above, cost increases as drainage spacing narrows. This fact helps explain the net return per acre results depicted in Table 1. Net return per acre was significantly higher for the 66-foot spacing and significantly lower for the 16-foot spacing. The difference in the net return per acre for the 33-foot and 133-foot spacings was not statistically significant. The 33-foot spacing has a higher corn yield and gross return per acre but also exhibits a substantially higher tile investment and EAC per acre than the 133-foot spacing.

RESULTS

The base case results are illustrated in the first line of Table 2. The 16-foot spacing results are not illustrated because this drainage spacing was not part of the FSD set. The average net return for the 66-foot spacing was $37 per acre higher than the average net return for the 133-foot spacing and $47 per acre higher than the average net return for the 33-foot spacing. The certainty equivalent of net return for each drainage spacing and scenario in Table 2 was computed using a relative risk aversion level of 3, which represents moderate risk aversion. The certainty equivalent of net return can be thought of as a risk-adjusted return. The difference between the certainty equivalent of net returns for the 66-foot and 133-foot spacing narrowed to $25 per acre and widened to $65 per acre for a comparison between the 66-foot and 33-foot spacings. The SSD results for the base case scenario were consistent with the certainty equivalent results. The 66-foot spacing was the only drainage spacing included in the SSD set. This indicates that this drainage spacing would be preferred by all risk-averse decision-makers. It is also important to note that the results for the base case are consistent with those found by Skaggs, Youssef, and Chescheir (2006).

Average net returns and the certainty equivalent of net returns are sensitive to changes in the base case assumptions pertaining to the discount rate, tile installation cost, and useful life of the drainage system. Table 2 presents the average net return and certainty equivalent of net returns for the base case as well as the sensitivity of the results to increases in the discount rate, cost of tile installation, and a longer useful life for the tile. It is important to note that each assumption was changed in isolation of the other assumptions. For example, the line depicted as using a 7.5% discount rate used a $1 installation cost and assumed a useful life of 30 years.

Increasing the discount rate or the cost of tiling (i.e., installation cost per foot) reduced average net returns and the certainty equivalent of net returns but did not appreciably change the base case results. Using the certainty equivalent of net returns—which incorporates net return, variability in net returns, and downside risk—the 66-foot spacing is preferred under the relatively higher discount rate and cost of tiling scenarios by a rather large margin to the 33-foot spacing and the 133-foot spacing (i.e., the undrained control) alternatives. Also, increasing the useful life of the tile drainage system increases average net returns and the certainty equivalent of net returns but does not change the relative results illustrated in the base case scenario.

Although this analysis shows little economic difference between the 33-foot spacing and the undrained control, several important qualifications should be noted. The undrained control in this field, although wetter than the other spacings, was not as wet as other, larger undrained fields in the area; thus the yields were not as low as in more typical Clermont soil fields. Also, in later years of the experiment, yield differences were much larger because of much wetter spring conditions, leading to yield losses of 50 or more bushels per acre for the undrained control. As precipitation has increased over the past few decades, these wetter springs are likely to make the benefit of drainage versus none even more pronounced. Finally, this experimental field (approximately 15 acres) had better surface drainage than most large fields in the area, meaning there was little surface ponding of water. Therefore, the undrained control was not as bad for crop growth as it would be if portions of the field remained ponded for days. These limitations to the study suggest that the undrained control would likely be worse than what our analysis suggests.

SUMMARY AND CONCLUSIONS

This paper examined optimal tile drainage spacing using data for the 1984–2021 period from an experimental field in southeast Indiana. Four drainage spacings were compared: 16 feet, 33 feet, 66 feet, and 133 feet. Gross return per acre was highest for the 16-foot spacing. However, due to high tile investment and cost per acre for this spacing, the net return per acre for this spacing was significantly lower than for the other drainage spacings. The 66-foot spacing had a significantly higher average net return than the other spacings. Moreover, the 66-foot spacing was favored when risk was added to the analysis. Specifically, the 66-foot spacing was preferred to other drain tile spacings regardless of the risk aversion level.

The analysis in this paper provides a framework that can be utilized when making tile installation decisions. In addition to agronomic and water quality aspects such as soil erosion, nutrient runoff and leaching, and crop yields, it is imperative to incorporate crop prices and the annualized cost of tile in drainage spacing decisions.

REFERENCES

BEA. 2022. Personal Consumption Expenditures Price Index. U.S. Bureau of Economic Analysis. Accessed July 1, 2022. www.bea.gov/data/personal-consumption-expenditures-price-index.

Hardaker, J.B., G. Lien, J.R. Anderson, and R.B.M. Huirne. 2015. *Coping with Risk in Agriculture: Applied Decision Analysis*, 3rd ed. Cambridge, MA: CABI Publishing.

Hofstrand, D. 2010. “Understanding the Economics of Tile Drainage.” *Ag Decision Maker* C2-90.

Kenton, W., and D. Kindness. 2020. “Equivalent Annual Cost (EAC): What It Is, How It Works, Examples.” Investopedia.

Kladivko, E. 2020. “Soil drainage and crop yields: Insights from long-term SEPAC study.” Purdue University Extension.

Kladivko, E.J., and L.C. Bowling. 2021. “Long-term impacts of drain spacing, crop management, and weather on nitrate leaching to subsurface drains.” *Journal of Environmental Quality* 50 (3): 627–638.

Kladivko, E.J., J.R. Frankenberger, D.B. Jaynes, D.W. Meek, B.J. Jenkinson, and N.R. Fausey. 2004. “Nitrate Leaching to Subsurface Drains as Affected by Drain Spacing and Changes in Crop Production System.” *Journal of Environmental Quality* 33 (5): 1803–1813.

Kladivko, E.J., G.L. Willoughby, and J.B. Santini. 2005. “Corn Growth and Yield Response to Subsurface Drain Spacing on Clermont Silt Loam Soil.” *Agronomy Journal* 97 (5): 1419–1428.

Liu, Y., M.R. Langemeier, I.M. Small, L. Joseph, W.E. Fry, J.B. Ristaino, A. Saville, B.M. Gramig, and P.V. Preckel. 2018. “A Risk Analysis of Precision Agriculture Technology to Manage Tomato Late Blight.” *Sustainability* 10 (9): 1627–1636.

Mourtzinis, S., J.F. Andrade, P. Grassini, J.I. Rattalino Edreira, H.J. Kandel, S. Naeve, K.A. Nelson, M. Helmers, and S.P. Conley. 2021. “Assessing benefits of artificial drainage on soybean yield in the North Central US region.” *Agricultural Water Management* 243: 1–8.

Skaggs, R.W., and J. van Schilfgaarde, eds. 1999. *Agricultural Drainage*. American Society of Agronomy.

Skaggs, R.W., M.A. Youssef, and G.M. Chescheir. 2006. “Drainage design coefficients for eastern United States.” *Agricultural Water Management* 86 (1–2): 40–49.

USDA NASS. 2019. *2017 Census of Agriculture: United States Summary and State Data* Volume 1, Geographic Area Series, Part 51, AC-17-A-51.

USDA NASS. 2022. Quick Stats. Accessed July 1, 2022. https://www.nass.usda.gov/Quick_Stats.

Zulauf, C., and B. Brown. 2019. “Use of Tile, 2017 US Census of Agriculture.” *farmdoc daily* (9): 141.

Table 1. Summary Statistics for Tile Drainage Experimental Field in Southeast Indiana, 1984–2021

	Drainage Spacing			
	16 ft	33 ft	66 ft	133 ft
Corn Yield (bu/acre)	170.9[a]	165.9[b]	164.5[b]	146.4[b,c]
Soybean Yield (bu/acre)	59.4[a]	58.2[a,b]	59.4[a,b]	57.6[a]
Gross Return ($/acre)	$713[a]	$694[b]	$693[b]	$632[c]
Net Return ($/acre)	$514[c]	$598[b]	$645[a]	$608[b]

Note: a, b, and c indicate whether the values were statistically different. Values with unlike letters were statistically different.

Table 2. Sensitivity Analysis of Net Return per Acre to Discount Rate, Cost of Tiling, and Useful Life of Drainage System

	33 ft		66 ft		133 ft	
	Avg	CE	Avg	CE	Avg	CE
Base Case	$598	$475	**$645**	**$540**	$608	$515
Discount Rate						
7.5%	$582	$455	**$637**	**$531**	$604	$510
9.0%	$565	$435	**$628**	**$521**	$600	$505
Cost of Tiling, per Foot						
$1.25	$574	$445	**$633**	**$526**	$602	$508
$1.50	$550	$415	**$621**	**$512**	$596	$501
Useful Life, Years						
40	$606	$484	**$649**	**$545**	$610	$518
50	$610	$489	**$651**	**$547**	$611	$519

Notes: Avg = average net return per acre; CE = certainty equivalent of net return per acre (defined in the text). Bold values indicate preferred drainage spacing for each scenario. For the base case, the discount rate was 6.0%, the cost of tile drainage per foot was $1, and the useful life of the drainage system was 30 years.