Tennessee Fruit and Vegetable Farmers' Willingness to Adopt Alley Cropping Systems

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Abstract. Alley cropping is an agroforestry practice that involves the planting of trees or shrubs alongside herbaceous crops within the same production system. Potential benefits of alley cropping include crop diversification, enhanced productivity of annual crops, reduced soil erosion, improved pollinators and wildlife habitat, decreased incidence of pests and diseases, carbon sequestration, and reduced nitrogen leaching. Despite these potential benefits, the adoption of alley cropping remains low. In Tennessee, specifically, only about 2% of the farms have used agroforestry practices, including alley cropping. We surveyed Tennessee fruit and vegetable farmers to assess their willingness to adopt alley cropping and the differences in characteristics of those willing and not willing to use this production practice. In general, those respondents who are willing to adopt alley cropping are more familiar with this production system and are facing or have faced production challenges that could be alleviated by adopting this production practice, such as low organic matter and crop heat stress. Our results also suggest that the type of trees or shrubs incorporated in this system and adequate payment for adoption that covers investment and maintenance costs could affect Tennessee fruit and vegetable farmers' willingness to use this system.

Alley cropping, which is a type of intercropping system, is an agroforestry practice that involves the planting of trees or shrubs alongside herbaceous crops within the same production system (MacFarland 2017). Specifically, trees or shrubs are planted in rows that form alleyways where companion crops, which can include various annual crops such as grains and vegetable crops, are grown (MacFarland 2017; Wilson and Lovell 2016). Potential benefits of alley cropping include crop diversification, improved productivity of annual crops, reduced soil erosion, improved pollinators and wildlife habitat, decreased incidence of pests and diseases, carbon sequestration, reduced nitrogen leaching, and increased crop system resilience to extreme weather events (Adesina et al. 2000; Beer and Theuvsen 2020; Kang 1997; MacFarland 2017; Otter and Beer 2021; Tsonkova et al. 2018; Wilson and Lovell 2016; Wolz and DeLucia 2019).

Despite these potential benefits, the adoption of alley cropping systems around the world remains low (Beer and Theuvsen 2020; Pattanayak et al. 2003; Wolz and DeLucia 2019). Although there are no data available regarding the adoption of alley cropping among US farmers, combined statistics for the use of any of the related agroforestry practices of alley cropping, silvopasture, forest farming, riparian forest buffers, or windbreaks suggest the adoption of each of these in the United States is relatively low. According to the 2022 Census of Agriculture, 32,717 farm operations in the United States used alley cropping, silvopasture, forest farming, riparian forest buffers, or windbreaks (US Department of Agriculture 2024), representing approximately 1.7% of all US farm operations. In Tennessee, 1015 operations used these practices, representing 1.6% of all farm operations in the state (US Department of Agriculture 2024). We presume that a large percentage of these 1015 farms may be using simpler agroforestry systems than alley cropping like silvopasture, which is the establishment or management of trees and forages on the same land unit (Natural Resource Conservation Service 2016). Therefore, we suspect that a small percentage of these farms use alley cropping. Barriers to adoption of alley cropping include the complexity of managing systems combining crops and trees, additional labor requirements, high initial investment with delayed or unknown returns, lack of market mechanisms to monetize environmental benefits (e.g., carbon sequestration and reduced soil and water erosion), and lack of information and technical assistance to implement this practice (Adesina et al. 2000; MacFarland 2017; Otter and Beer 2021; Tsonkova et al. 2018; Wilson and Lovell 2016; Wolz and DeLucia 2019).

Only a few studies have specifically examined farmer interest in adopting alley cropping systems (Adesina et al. 2000; Beer and Theuvsen 2019, 2020; Borremans et al. 2016; Otter and Beer 2021; Otter and Deutsch 2023). Most of these studies have focused on German farmers' intentions to adopt alley cropping. To the best of our knowledge, there are no studies that focused specifically on US farmers' interest in adopting alley cropping.

Evaluating fruit and vegetable farmers' interest in adopting alley cropping systems in the Southeast United States is of particular importance because previous studies predict the potential of severe changes in climate in this region, including increased frequency, duration, and intensity of heat waves and extreme precipitation events (Anandhi and Bentley 2018; Gao et al. 2012; McNulty et al. 2015). Fruit and vegetable crops are especially susceptible to these extreme weather events (Bhattacharjee et al. 2022; Scheelbeek et al. 2018). Alley cropping could help make these production systems more resilient to these changes. For example, the trees in an alley cropping system can help

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mitigate heat stress on vegetable crop production (Jose et al. 2004).

Evaluating Tennessee farmers' interest in adopting alley cropping is of particular importance given that the Tennessee Natural Resources Conservation Service office Technical Guide does not include alley cropping in its conservation standard practices, and the Tennessee NRCS field office does not offer investment cost-share or incentive payments for farmers adopting this practice (Natural Resource Conservation Service 2024). Although some states in the US Southeastern region include alley cropping in the NRCS state office technical guide (i.e., North Carolina, South Carolina, Florida, Virginia, Louisiana, and Arkansas), none of them offer an investment cost-share for farmers adopting this practice (Natural Resource Conservation Service 2024). For NRCS to provide financial and/or technical assistance for alley cropping in Tennessee, the state must recognize it as a standard conservation practice. To identify whether there is a need to include alley cropping in the conservation practice standard, interest among Tennessee growers in adopting this practice should be assessed. Furthermore, the establishment of a cost-share or incentive program in Tennessee requires a better understanding of the cost of implementing this practice and the payment farmers will be willing to accept to adopt alley cropping.

Considering the potential benefits of implementing alley cropping in fruit and vegetable production systems and the unknown interest in adopting this practice among Tennessee fruit and vegetable farmers, this study aims to explore farmers' willingness to adopt alley cropping, using data from a 2024 survey of Tennessee fruit and vegetable farmers. This study specifically evaluates 1) Tennessee fruit and vegetable farmers' familiarity with alley cropping, willingness to adopt alley cropping, and reasons for being willing and not willing to adopt this production system; 2) the differences in characteristics between those who are willing and those not willing to adopt alley cropping; and 3) farmers' willingness to adopt a specific alley cropping system at different payment or economic incentive levels. This last assessment is important given that previous studies suggest that economic incentives in the form of payments could affect alley cropping adoption (Arimi and Omoare 2021; Borremans et al. 2016; Valdivia et al. 2012; Wilson and Lovell 2016).

Materials and methods

We conducted a survey of Tennessee fruit and vegetable farmers between January and June of 2024. The survey instrument was approved by the University of Tennessee Institutional Review Board (UTK IRB-24 to 07960-XM). We used a mix-mode survey approach, incorporating Web and paper versions of the survey instrument to improve response rates and reduce coverage and nonresponse error (Dillman et al. 2009). We sent the Web version of the survey on 6 Feb 2024 to individuals for whom we had e-mail addresses. We sent reminder e-mails on 19 Feb 2024. A paper version of the survey was mailed to individuals for whom we did not have e-mail addresses and to those who did not respond to the Web survey by 1 Mar 2024. The initial mailing was on 5 Mar 2024, and follow-up surveys and reminders were sent on 25 Mar and 31 Mar 2024, respectively. The paper and online versions of the survey instrument contained the same questions. We publicized the survey at the Pick TN Products Conference on 16 Feb 2024. We provided conference attendees with a QR code they could use to complete the survey using their mobile phones. We also allowed conference attendees to fill out the paper version of the survey and deposit it anonymously in boxes we placed at a booth. We also advertised the survey through social media platforms, specifically Facebook and a Tennessee fruit and vegetable farmer listserv managed by the University of Tennessee Vegetable Extension Program.

The survey instrument included 30 to 36 questions depending on respondents' answers to specific questions that directed them to different survey sections. About 75% of the questions were multiple choice. The survey was designed to take about 20 min to complete. The survey contained ten sections. The first section included an introduction that explained the purpose of the survey and that included screening questions that filtered out respondents younger than 18 years old and who did not produce fruits and vegetables in the open field in 2023. The second section included questions about crops grown and production challenges faced (e.g., low organic matter, heat stress). The third section assessed familiarity with alley cropping and respondents' overall willingness to adopt alley cropping.

The fourth section of the survey included questions to evaluate respondents' willingness to adopt alley cropping given a specific alley cropping system scenario and a corresponding payment or compensation to adopt this system. This section of the survey also asked farmers their reasons for being willing or not willing to adopt the alley cropping system scenario. If respondents indicated they were willing to adopt alley cropping, we asked them how many acres or row feet they would be willing to use alley cropping on.

The fifth section of the survey included questions to assess whether respondents have used alley cropping in the past. If the respondent indicated they had used alley cropping in the past, they were asked questions about the trees or shrubs they used in their system, when they implemented this practice and on how many acres, and when they stopped using this practice. Respondents who indicated they had used alley cropping in the past were asked about the benefits they experienced from implementing this practice. Those respondents who indicated they had never used alley cropping did not answer or skipped the abovementioned questions.

The sixth section of the survey asked respondents questions about production practices they use (e.g., irrigation, mulch, crop rotation, cover crops). The seventh section assessed respondents' use of information sources (e.g., university extension, consultants, and other farmers). Sections eight to ten included questions about the respondents' farm operations and themselves, including acres in production, percentage of acres owned, number of workers on the farm, farm income, percentage of household income from farming, age, education, and risk preferences. In this study, we only present information from questions that addressed the objectives presented in the introduction section.

The contact list of fruit and vegetable producers used to conduct the survey was provided by the Tennessee Department of Agriculture. The contact

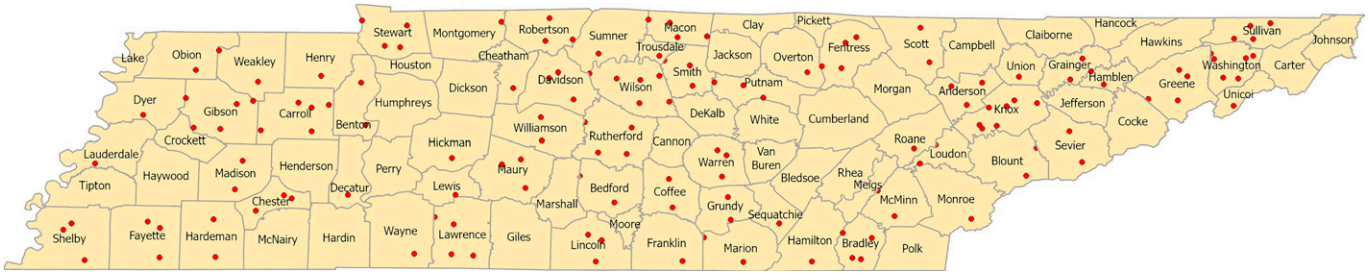

Fig. 1. Respondents to a 2024 survey of Tennessee fruit and vegetable farmers about willingness to adopt alley cropping based on the county where the farm is located (each dot represents one response).

list included farmers who in 2023 participated in either a program that aims to assist Tennessee farmers in marketing (i.e., Pick Tennessee Products) or a program that provides cost-share for farm improvements (i.e., Tennessee Ag Enhancement). The contact list included 879 fruit and vegetable farmers. From this initial list, eight indicated they were not fruit and vegetable growers, one respondent indicated running a hydroponic operation, one respondent indicated growing crops in an indoor environment, one operation had only greenhouses, and two respondents believed their operations were too small to add any value to the survey. There were 216 complete surveys, including 124 online and 92 mail surveys, for a 25% response rate. Survey respondents represented farms from West, Middle, and East Tennessee counties (Fig. 1).

We evaluated the representativeness of the survey sample by comparing the survey sample to the population of vegetable farms according to the 2022 Census of Agriculture data (US Department of Agriculture 2024) in terms of distribution of farms based on acres in vegetable production. Among survey respondents who provided information about acreage in crop production, 78% indicated producing vegetables. Similar to Velandia et al. (2020), who also indicated that a large percentage of respondents in their survey sample were growing vegetables, we considered acres in vegetable production as a reasonable basis for comparing the survey sample and the census data.

The survey sample farm size distribution closely follows the farm size distribution of vegetable farms in Tennessee according to the 2022 Census of Agriculture (Fig. 2). A large percentage (84%) of Tennessee vegetable farms are small, with reported acres in vegetable production between 0.1 and 4.9 (Fig. 2). The survey sample tends to underrepresent farms in that small farm category (70%) and overrepresent vegetable farms between 5 and 49.9 acres (25.81%). It is possible that farmers with more land available for production were more likely to respond to the survey, given that these farmers have land they could use to add tree crops to their production systems. Therefore, these farms could perceive alley cropping as a viable option for their farm operations. Alemayehu and Simeneh (2024) suggested that farmers with larger farms would be more likely to have land available to implement agroforestry systems, including alley cropping, and therefore be interested in this practice. Therefore, we hypothesized that larger operations were more interested in a survey about alley cropping and, therefore, more likely to respond to the survey.

We evaluated farmers' willingness to adopt alley cropping in two sections of the survey. First, we asked respondents to indicate whether they were willing to adopt alley cropping after providing a definition of alley cropping and the potential benefits associated with this production system: "Alley cropping is an agroforestry practice where agricultural or horticultural crops are grown in the alleyways between widely spaced rows of woody plants. Specifically, alley cropping is defined as the planting of rows of trees and/or shrubs to create alleys within which agricultural or horticultural crops are produced. The trees may include valuable hardwood veneer or lumber species; fruit, nut, or other specialty crop trees/shrubs; legume trees for nitrogen fixation; or desirable softwood species for wood fiber production. Alley cropping can diversify farm income, increase crop production, improve landscape aesthetics, enhance wildlife habitat, and provide crop protection and conservation benefits. Alley cropping provides specific benefits such as reducing water surface runoff and soil erosion, improving utilization and reducing offsite movement of nutrients, modifying the microclimate for improved crop production, providing habitat for wildlife and beneficial insects, and increasing carbon storage."

Surveyed farmers had three options they could select when answering whether they were willing to adopt alley cropping: 1) yes, 2) no, and 3) I do not know. Then, we evaluated respondents' willingness to adopt alley cropping by presenting detailed information about a specific alley cropping system design and payments they would receive if they adopted alley cropping. Again, they had the same response options: 1) yes, 2) no, and 3) I do not know.

We provided the respondents with information about a specific alley cropping system that includes black locust trees (*Robinia pseudoacacia*) and vegetable production in alleys. This system is being evaluated in a field study at the University of Tennessee Organic Crops Unit, and it is complementary to the 2024 Tennessee fruit and vegetable survey described above. This system was chosen as the primary system to be evaluated in this survey because it represents a broadly adaptable system in which the primary benefits of the woody component (i.e., black locust trees) in the short and medium term are related to the provisioning of ecosystem services, potentially improving the vegetable crop microclimate, and providing nitrogen to the system over time through biological nitrogen fixation of this leguminous tree species. This system contrasts with systems that use woody species with a potentially harvestable product in the short to medium term (e.g., fruit- or

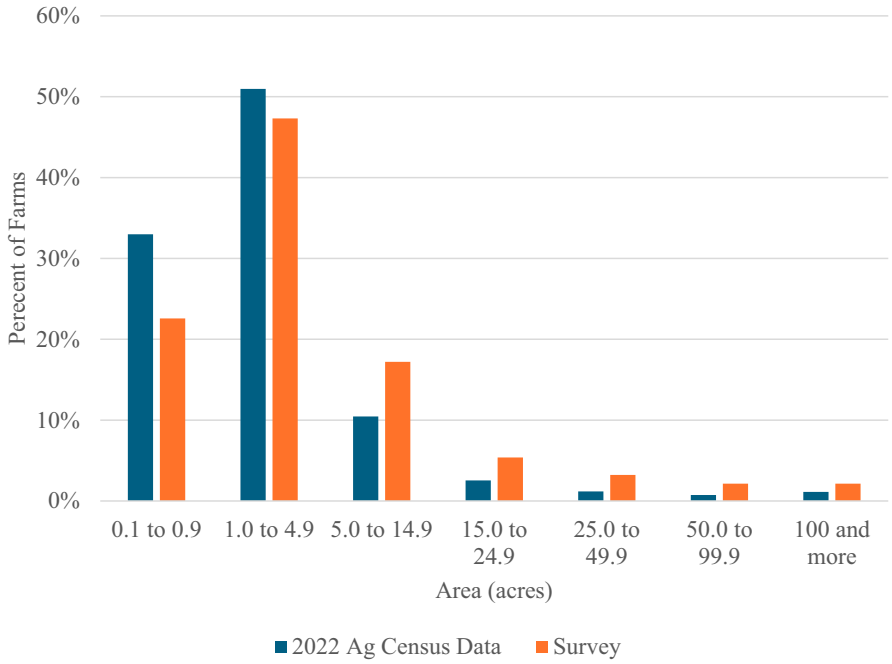

Fig. 2. Percentage of farms in each farm size category based on acres in vegetable production according to the 2022 Census of Agriculture (Ag) data (US Department of Agriculture 2024) and the survey sample from a 2024 survey of Tennessee fruit and vegetable farmers about the willingness to adopt alley cropping (1 acre = 0.4047 ha).

nut-producing species). These types of systems introduce additional adoption considerations related to the production and marketing of an additional product. For example, a fruit tree implies additional consideration related to where to market these products, as well as additional labor to harvest the fruit crops. We provided information about the costs associated with implementing this black locust–vegetable alley cropping system: "The cost per tree will be $1.09, which implies a total tree cost of $270 per acre. There will be other costs associated with establishing the system, such as planting costs. The planting costs are estimated at $119 per acre. Therefore, total costs associated with planting the trees, including tree costs, are estimated at $390 per acre. There could be income loss from taking part of the land out of production to plant trees. Future costs include pruning of trees and other maintenance costs. You will grow vegetable crops in the alleys. Black locust will not provide income in the short to medium term, but it is a woody legume species that provides shade while allowing sufficient light to be transmitted to the crops in alleys and a high nitrogen fixation rate that could potentially reduce fertilizer use."

We also provided additional information about the benefits of implementing this production practice. Then, we asked survey respondents to indicate their willingness to adopt this production system if a one-time payment was offered. Results from previous studies suggest that economic incentives in the form of payments or cost-share programs positively affect the adoption of agroforestry practices in general and alley cropping specifically (Arimi and Omoare 2021; Borremans et al. 2016; Valdivia et al. 2012; Wilson and Lovell 2016). Therefore, we explored survey respondents' willingness to adopt the black locust tree alley cropping system given different payment levels. There were four versions of the survey, each with a different payment amount: 1) $270/acre one-time payment; 2) $330/acre one-time payment; 3) $390/acre one-time payment; and 4) $450/acre one-time payment. The four versions of the survey were randomly assigned among respondents.

The payment scenarios were created by estimating planting costs, including the costs of the black locust trees (*R. pseudoacacia*). Black locust tree costs were estimated using published costs for bare-root planting stock from a US nursery from which the University of Tennessee purchased these trees for the alley cropping field trial located at the University of Tennessee Organic Crops Unit. Planting costs were estimated using information from the Illinois, Indiana, Michigan, Missouri, Ohio, and Wisconsin NRCS practice scenarios' documentation for fiscal year 2023. These documents provide planting cost information for alley cropping (NRCS practice 311) for those states that include alley cropping in their conservation standard practices. The $270/acre payment scenario assumed only the cost of trees was covered with the payment. The $330/acre payment scenario assumed the costs of the trees and half of the planting cost were covered with this payment. The $390/acre payment scenario assumed tree and planting costs were covered with the payment. Finally, the $450/acre payment scenario covered tree and planting costs, as well as compensated farmers for potential income losses due to the adoption of alley cropping. This maximum payment was estimated using the average payment per tree (i.e., bare-root planting stock) offered in Illinois, Indiana, Michigan, Missouri, Ohio, and Wisconsin by NRCS in the fiscal year 2023.

Analysis. We used a *t* test to compare the sample means to the population means. Specifically, we conducted a *t* test to evaluate whether the sample means were equal to the stated population means according to the 2022 Census of Agriculture for those variables for which population means were available (i.e., age, average farm size, and gross on-farm revenue). For example, using a *t* test, we tested the null hypothesis that the average age of survey respondents was equal to 59, the average age of Tennessee farmers according to the 2022 Census of Agriculture (US Department of Agriculture 2024).

We used independent sample *t* tests to evaluate differences in selected farmer and farm business characteristics captured by continuous variables between respondents willing and those not willing to adopt alley cropping. We evaluated differences in farm and farm business characteristics captured by dichotomous variables using an equality proportion test. Additionally, we used the pairwise comparison of means test to evaluate differences in the percentage of respondents willing

to adopt alley cropping across all payment scenarios (i.e., $270, $330, $390, $450) (StataCorp 2023).

Results and discussion

Farmer and farm business characteristics. Survey respondents were 55 years old, on average, which is statistically significantly lower than the average age of farmers in Tennessee (59 years), according to the 2022 Census of Agriculture data (US Department of Agriculture 2024). Approximately 59% of the survey respondents indicated having a bachelor's degree or higher education (Table 1). Regarding survey respondents' self-reported risk preferences, respondents were asked, "When you compare yourself to other operators in your industry, would you say that you are willing to take more or less risks with respect to the following aspects of your operation?" They were provided with a 5-point Likert scale, where 1 represents much less willing, and 5 represents much more willing to take risks with production, marketing, and financial aspects of the farm operation compared with other operators in their industry. The average score was 3.47. This means that, on average, survey respondents perceived themselves as somewhat more willing to take risks compared with other operators in their industry.

The average farm size reported by respondents was 161 acres (including vegetable, fruit, and other crops), which is close to and not statistically significantly different from the average farm size in Tennessee (i.e., 170 acres) according to the 2022 Census of Agriculture data (US Department of Agriculture 2024). On average, respondents indicated that they owned nearly 90% of the acres they operated. Approximately 46% of respondents reported annual gross on-farm revenue above $25,000. The 2022 Census of Agriculture data (US Department of Agriculture 2024) specified that 81% of Tennessee farms have less than $25,000 in farm sales. A statistically significantly lower percentage of survey respondents (54%) have less than $25,000 in on-farm revenue compared with the percentage of Tennessee farms with gross on-farm revenue, captured by farm sales, below $25,000 (81%). Regarding the percentage of household income from farming, 46% of respondents indicated having a percentage of household income from farming above 25%. The average number of workers (i.e., paid and unpaid workers) employed in the farm businesses captured in the survey sample was 8, with a minimum of 1 and a maximum of 103 workers.

Approximately 31% of the respondents indicated that their farm operations are US Department of Agriculture (USDA)–certified organic, Certified Naturally Grown, or USDA-certified organic exempt or follow organic or naturally grown standards. When asked about the production challenges they face or have faced in their farm operations, 59% of the survey respondents indicated water and/or wind erosion were a concern on their farms, 51% indicated low organic matter was a concern

Table 1. Summary statistics for selected farmer and farm business characteristics based on data from a 2024 survey of Tennessee fruit and vegetable farmers.

Business characteristic	*n*	Mean	*SD*	Minimum	Maximum
Age (yr)	149	55.40	14.22	28	85
BS degree or higher = 1 if farmer has a bachelor's degree or higher; 0 otherwise	154	0.58		0	1
Risk: Average score regarding farmer willingness to take risk compared with similar operations related to financial management, production, and marketing, where 1 is "much less" and 5 is "much more"	153	3.47	0.84	1	5
Farm size acres, acres in crop production[i]	134	160.88	1159.85	0.01	10,780
Percentage of total acres owned	134	89.49%	28.75%	0%	100%
No. of workers (number of paid and unpaid workers employed on the farm in 2023)	130	8	15	1	103
Percentage of household income from farming above 25% = 1 if the percentage of household income from farming is more than 25%; 0 otherwise	131	0.46		0	1
Farming income above $25,000 = 1 if annual gross on-farm revenue is above $25,000; 0 otherwise	133	0.46		0	1
Environmentally friendly production system = 1 if the operation is USDA-certified organic, or Certified Naturally Grown, or USDA-certified organic exempt or follows organic or naturally grown standards; 0 otherwise	151	0.31		0	1
Erosion = 1 if farmer indicated water or wind erosion have been a concern on the farm; 0 otherwise	152	0.59		0	1
Low organic matter = 1 if farmer indicated soil compaction has been a concern on the farm; 0 otherwise	152	0.51		0	1
Heat stress = 1 if farmer indicated heat stress is one of the most important challenges faced on the farm; 0 otherwise	165	0.37		0	1

[i] 1 acre = 0.4047 ha.

SD = standard deviation; USDA = US Department of Agriculture.

Table 2. Farmer familiarity with and willingness to adopt alley cropping based on data from a 2024 survey of Tennessee fruit and vegetable farmers.

Familiarity or willingness	*n*	Mean	Minimum	Maximum
Familiarity_AC = 1 if the farmer is not familiar at all, 2 if the farmer is slightly familiar, 3 if the farmer is moderately familiar, and 4 if the farmer is very familiar with alley cropping	165	1.97	1	4
AC_WTA = 1 if farmer is willing to adopt alley cropping and 0 if not willing to adopt or uncertain about adoption ("I don't know")	165	0.46	0	1
ACS_WTA = 1 if farmer is willing to adopt alley cropping with black locus trees and 0 if not willing to adopt or uncertain about adoption ("I don't know")	163	0.22	0	1

on their farm operations, and 37% of the survey respondents indicated heat stress was one of the most important challenges they face in their farming operations.

Willingness to adopt alley cropping. Before asking respondents about their willingness to adopt alley cropping, we asked them to indicate their familiarity with this production system using a 4-point Likert scale, where 1 is not familiar at all, and 4 is very familiar. On average, respondents were slightly familiar with alley cropping, with a rating of 1.97. When asked about their willingness to adopt alley cropping without providing a specific system description (e.g., type of trees or bushes and crops grown in alleys), 46% of respondents indicated being willing to adopt alley cropping (Table 2).

When asked about their willingness to adopt a specific alley cropping system with black locust trees (*R. pseudoacacia*) and vegetable production in alleys at different payment levels, only about 22% of the respondents indicated that they were willing to adopt this system (Table 2). From the 46% respondents who initially indicated being willing to adopt alley cropping, 41% (30 farmers) also indicated being willing to adopt alley cropping system with black locust trees (*R. pseudoacacia*), while 59% indicated they were not willing to adopt this system regardless of the payment or economic incentive provided for adoption (Table 3). About 93% of the survey respondents who indicated not being willing to adopt alley cropping did not change their mind when presented with the black locust tree alley cropping scenario at different payment levels, while 7% of the respondents changed their mind and indicated being willing to adopt the black locust tree alley cropping scenario when payment is provided for adoption (Table 3).

Differences between respondents willing and those not willing to adopt alley cropping. In Table 4, we compare the farmer and farm business characteristics of survey respondents who indicated being willing to adopt alley cropping with those not willing to adopt or uncertain about the adoption of alley cropping when no specific system is described and when the black locust tree scenario is presented to them. Table 4 shows that when no specific alley cropping system scenario is presented, and no payment is provided for adoption, those respondents who indicated being willing to adopt alley cropping were younger ($P = 0.0025$ for the age comparison) and more willing to take risk ($P = 0.0395$ for the risk preferences' comparison) than those not willing to adopt alley cropping. These results are consistent with previous studies suggesting that older farmers have a shorter planning horizon, and they may be less likely to invest money and time in a practice from which they might not be able to see the benefits during their lifetime (Adesina et al. 2000; Kronenberg et al. 2023). Regarding risk preferences, our results are consistent with those of previous studies suggesting that because of the high upfront investment and the long period before benefits are realized with alley cropping, more risk-averse individuals would be less likely to adopt alley cropping (Adesina et al. 2000; Beer and Theuvsen 2020; Otter and Beer 2021; Otter and Deutsch 2023).

A larger percentage of respondents willing to adopt alley cropping had a bachelor's degree or higher (68% vs. 51%) compared with the percentage of those who indicated they were not willing to adopt alley cropping or being uncertain about the adoption of this practice who reported this level of education ($P = 0.0165$ for the level of education comparison). When respondents were presented with a specific alley cropping system scenario and a payment for adoption, the results presented in Table 4 also suggest that a larger percentage of those respondents willing to adopt this alley cropping scenario had a bachelor's degree or a higher level of education (69% vs. 55%) compared with the percentage of those not willing to adopt or uncertain about adoption reporting this level of education ($P = 0.0656$ for the level of education comparison). Farmers with a higher level of education (i.e., bachelor's or graduate degrees) could be more willing to adopt alley cropping than farmers with lower levels of education because they might be able to better understand more complex production systems, like alley cropping. Also, more educated farmers might be able to better understand alley cropping returns from investment, climate change impacts, and how alley cropping could help mitigate these impacts on their farms (Alemayehu and Simeneh 2024; Arimi and Omoare 2021; Beer and Theuvsen 2020).

Finally, for those respondents willing and not willing to adopt or uncertain about the adoption of the black locust tree alley cropping scenario, we observed a difference in the percentage of income from farming (Table 4). Specifically, we observed a lower percentage of those willing to adopt the specific alley cropping scenario indicating a percentage of income from farming above 25% (31% vs. 50%) than the percentage of those not willing to adopt or uncertain about adoption reporting a percentage of income from farming above 25% ($P = 0.0398$ for the percentage of household income

Table 3. Cross-tabulation of the number of survey respondents who are willing to adopt alley cropping and those willing to adopt alley cropping given a black locust scenario.

	ACS_WTA		
	0 = Not willing to adopt or uncertain about adoption	1 = Willing to adopt	Total
AC_WTA			
0 = Not willing to adopt or uncertain about adoption	83	6	89
1 = Willing to adopt	44	30	74
Total	137	36	163

AC_WTA = willingness to adopt alley cropping; ACS_WTA = willingness to adopt alley cropping with black locus trees.

from farming comparison). Farmers who have a higher percentage of income from farming might be less likely to adopt a production system that provides ecosystem benefits but not economic benefits in the short to medium term. Arbuckle et al. (2009) suggest that landowners who have financial motivations for owning the land, in other words, that they use the land primarily to generate farm income, are less likely to be interested in adopting agroforestry practices, such as alley cropping.

In terms of farm size in acres and the number of workers employed in the farm business (Table 4), those survey respondents willing to adopt alley cropping operated smaller farms and employed fewer workers on their farms than those not willing to adopt or uncertain about the adoption of alley cropping ($P = 0.0708$ for the farm size comparison, and $P = 0.0225$ for the number of workers comparison). This result is opposite to what previous studies suggested, where farm size and number of workers positively affect the adoption of alley cropping, given the additional land and labor requirements of implementing this production practice (Adesina et al. 2000; Alemayehu and Simeneh 2024). The contradictory result might be explained by the higher risk faced by larger operations in terms of acres and the number of workers when adopting a more complex production system. Alley cropping could have long-term benefits but, in the short run, could imply additional investments and taking land out of production to plant trees that might not generate income in the immediate future. In other words, larger operations generating higher farm revenue might have more to lose in the short run when adopting alley cropping than small operations generating less farm revenue.

Regarding production systems used on their farms, a higher percentage of survey respondents willing to adopt alley cropping used environmentally friendly production practices (e.g., USDA-certified organic) than the percentage of those respondents not willing to adopt or uncertain about adoption who indicated using these production practices ($P = 0.0012$ for the production system comparison). There was a higher percentage of respondents among those who indicated being willing to adopt alley cropping who indicated they face or have faced production issues related to low organic matter and heat stress than the percentage of those not willing or uncertain about adoption who indicated facing these issues ($P = 0.0349$ for production issues related to low organic matter comparison, and $P = 0.0461$ for production issues related to heat stress comparison). As shown in Table 4, these findings were similar when comparing survey respondents who are willing and not willing or uncertain to adopt the black locust tree alley cropping system ($P = 0.0299$ for production issues related to low organic matter comparison, and $P = 0.0002$ for production issues related to heat stress comparison). Finally, as expected, those respondents willing to adopt alley cropping, in general, and specifically

Table 4. Selected variable means for respondents willing to adopt and those not willing or uncertain about the adoption of alley cropping when no specific system is described and when the black locust tree scenario is presented to respondents, and statistical significance of mean differences.

	No system description		Black locust tree scenario	
Variable	**AC_WTA = 1**	**AC_WTA = 0**	**ACS_WTA = 1**	**ACS_WTA = 0**
Age (yr)	51.91***	58.41	53.29^{ns}	55.72
BS degree or higher	0.68**	0.51	0.69*	0.55
Risk	3.61**	3.37	3.62^{ns}	3.43
Environmentally friendly production system	0.43***	0.21	0.39^{ns}	0.28
Farm size acres[i]	6.61*	301.94	4.59^{ns}	204.07
Percentage of total acres owned	90.33%^{ns}	88.74%	93.37%^{ns}	88.37%
No. of workers	5.52**	10.87	4.78^{ns}	9.17
Percentage of household income from farming above 25%	0.47^{ns}	0.45	0.31**	0.50
Farming income above $25,000	0.44^{ns}	0.47	0.40^{ns}	0.47
Erosion	0.59^{ns}	0.58	0.58^{ns}	0.58
Low organic matter	0.59**	0.45	0.68**	0.49
Heat stress	0.43**	0.31	0.61***	0.29
Familiarity_AC	2.43***	1.57	2.36***	1.83

[i] 1 acre = 0.4047 ha.

ns, *, **, *** Nonsignificant or significant at $P \leq 0.10$, 0.05, or 0.01, respectively.

AC_WTA = willingness to adopt alley cropping; ACS_WTA = willingness to adopt alley cropping with black locus trees; Familiarity_AC = familiarity with alley cropping.

with black locust trees and economic incentives for adoption, were more familiar with the concept of alley cropping than those not willing to adopt it or uncertain about adoption (P = 0.000 for familiarity with alley cropping systems' comparison, and P = 0.0019 for familiarity with alley cropping systems' comparison, when the black locust scenario with payment for adoption is presented to respondents).

Similar to previous studies' findings, farmers' environmental motivations for farming, captured here by the environmentally friendly production practice variable, explain farmers' interest in adopting alley cropping (Arbuckle et al. 2009; Kronenberg et al. 2023). Also, the results presented above suggest that familiarity with alley cropping may be correlated with the adoption of alley cropping systems. The complexity of a production practice that combines trees and crops in the same system could explain the importance of education to increase farmer familiarity with the system and, therefore, help them make informed decisions regarding the adoption of this practice (Adesina et al. 2000; Alemayehu and Simeneh 2024; Arbuckle et al. 2009; Arimi and Omoare 2021; Kronenberg et al. 2023; Pattanayak et al. 2003; Valdivia and Poulos 2009; Wilson and Lovell 2016).

Our findings suggesting a potential correlation between respondents' perceptions of heat stress and low organic matter as important production challenges and willingness to adopt alley cropping are consistent with previous studies' findings of a correlation between farmers' perceptions of farmland problems and the adoption of alley cropping (Adesina et al. 2000; Valdivia and Poulos 2009). This result is also consistent with Beer and Theuvsen's (2020) findings, which suggest that farms with better location conditions in terms of biophysical characteristics might be less likely to adopt alley cropping.

Willingness to adopt alley cropping by payment scenario and reasons for being willing and not willing to adopt this production system. As stated in the Materials and Methods section, we explored survey respondents' willingness to adopt the black locust tree alley cropping system given different payment levels (i.e., \$270/acre, \$330/acre, \$390/acre, and \$450/acre). Among the 37 respondents who received the \$270 per acre payment option, which covered the cost of trees only, 19% indicated they would be willing to adopt the specific alley cropping system (Fig. 3). When the payment increased from \$270 to \$330 per acre, the percentage of respondents willing to adopt alley cropping systems increased to 29% of the 45 respondents who received the \$330 per acre payment option. Nonetheless, contrary to what we expected, for payments above \$330, the proportion of respondents willing to adopt the alley cropping system decreased. Among the 41 respondents who received the \$390 per acre option, 22% indicated they would be willing to adopt the alley cropping system scenario. Among the 40 respondents who received the \$450 per acre payment option, 18% indicated they would be willing to adopt the alley cropping system presented to them. It is important to note that results from the pairwise comparison of means test suggest that the percentage of respondents willing to adopt alley cropping across all payment scenarios is not statistically significantly different (Fig. 3). Findings from Borremans et al. (2016) and Otter and Deutsch (2023) suggest that payments need to cover investment, potential crop losses, tree maintenance costs, and potential environmental services offered by the farmers when adopting agroforestry practices to have a positive impact on adoption. None of the payment scenarios presented to respondents compensated farmers for environmental services offered by the farmer after adoption. Therefore, our results might suggest that although payment may influence adoption, the level of payment might not make a difference in adoption rates unless it compensates farmers for environmental services offered by the farmer after adoption.

To better understand the results presented above, we investigate the reasons provided by respondents for their willingness to adopt or not adopt the specific alley cropping system. We asked respondents to rate alternative reasons that may explain their responses using a 4-point Likert scale, where 1 represents not important at all, and 4 represents very important. Among the reasons for not willing to adopt the black locust alley cropping system explicitly presented to respondents in the survey question, the reason with the highest ratings in terms of importance (i.e., above 2.90) was the negative impact on the farm's economic viability of taking the land out of production to implement the alley cropping system. The reason with the second-highest rating was the lack of labor to implement this production system (Table 5).

We allowed respondents to write other reasons for not adopting the black locust alley cropping system aside from the ones presented to them and rate those other reasons in terms of importance. We grouped responses from the "other reasons" category into three additional categories: 1) I do not have enough land to implement this production system, 2) I'm too old to implement a new production system on the farm, and 3) I do not like the type of tree in this production system, or I would prefer a tree that generates income in the short run (Table 5). In each of these categories, we only had 8, 3, and 12 observations, respectively.

The type of tree (black locust) as a reason for not adopting was rated high in terms of importance for not adopting (i.e., average 3.92). We suspect that although that type of tree as a reason for not being willing to adopt the alley cropping systems was not an option explicitly presented in the survey to respondents, the selection of black locust trees for the alley cropping scenario could have affected respondents' willingness to adopt this production system. For example, at the end of the survey, we provided respondents with the opportunity to provide additional comments, and we received the following comments: 1) "If there are grants or programs for other types of trees or plants or digging of water retaining ponds or swales would be very interested!" 2) "My only concern is the locust trees with all of the thorns. Thorns cause flat tires . . . lots of them. Isn't there another tree that could be used instead? Just spent tons of funds removing locust trees from the fields . . . not sure it would be wise to plant more." 3) "This idea could work but the cost share should be able to cover the cost of fruit trees, currently it would not. In general the cost share isn't going to be adequate in its current form and there will be a higher level of maintenance required after implementation that growers should

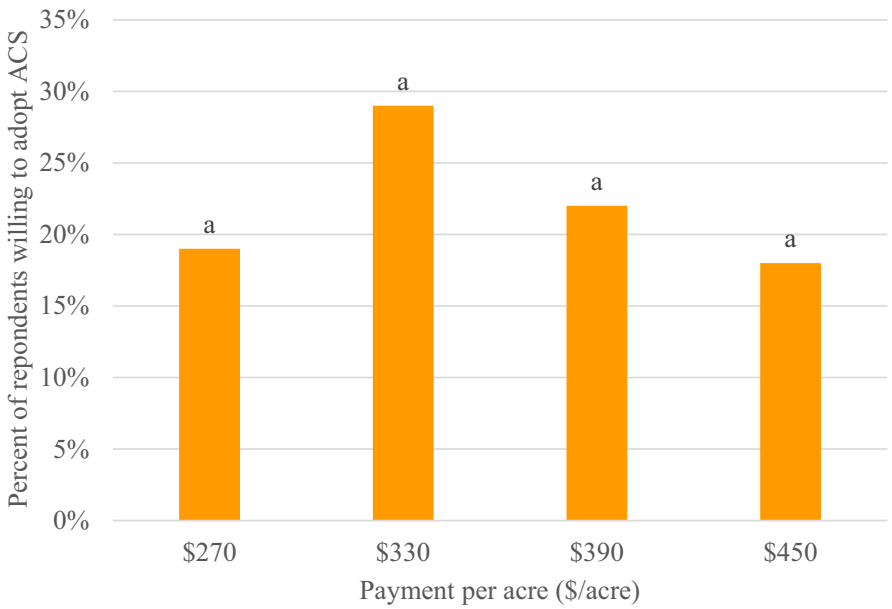

Fig. 3. Percentage of respondents willing to adopt the alley cropping black locust scenario at various payments per acre levels. The same letters on top of the bars indicate that percentages are not statistically significantly different. ACS = alley cropping with black locus trees.

be informed of." 4) "Can alley cropping be done with fruit trees and are they available through this program?"

Table 6 presents reasons for adopting alley cropping provided by those respondents who indicated they would be willing to adopt the black locust alley cropping system. The reasons to adopt with the highest ratings (i.e., average rating above 3.5) included benefits related to increased organic matter, increased productivity, and restoration of soil structure and reduced compaction. Other reasons explaining respondents' willingness to adopt alley cropping with high ratings (e.g., average ratings above 3.4) include benefits related to reduced fertilizer use, less runoff with increased water infiltration, modified microclimate conditions favorable for vegetable crop growth and quality, and comfort for agricultural workers (Table 6).

Conclusions

Using data from a Tennessee fruit and vegetable survey conducted in 2024, we evaluated farmers' willingness to adopt alley-cropping systems. The results from this study suggest that about half of the survey respondents (46%) were interested in adopting alley cropping. Nonetheless, the percentage of respondents willing to adopt alley cropping decreased to 22% when they were presented with an alley cropping system that included a tree not preferred by some of the farmers and that does not generate income in the short run.

Additionally, results suggest that production challenges faced by respondents related to low organic matter and heat stress differentiated those respondents willing to adopt alley cropping from those not willing to adopt or uncertain about the adoption of this production practice. These results might suggest that farmers who are facing production challenges that alley cropping systems could help to address might be looking for alternatives to alleviate those challenges. Hence, these farmers are more willing to adopt alley cropping. In contrast, those who do not perceive those challenges might

Table 5. Average rating (where 1 = not important at all to 4 = very important) of reasons for not being willing to adopt or being uncertain about the adoption of ACS black locust system scenario.

	Payment per acre ($/acre)				
Reasons for unwillingness or uncertainty	$270 (n = 30)	$330 (n = 32)	$390 (n = 32)	$450 (n = 33)	All payments (n = 127)
I do not have enough information about alley cropping.	2.54	2.52	2.64	2.58	2.57
Taking land out of production to plant trees will hurt the economic viability of my farm.	3.12	2.96	2.93	2.81	2.95
I do not have experience producing and maintaining trees.	2.04	2.48	2.28	2.07	2.21
Recurring costs (maintenance, inputs)	2.50	2.48	2.70	2.41	2.53
I do not have the additional labor necessary to manage trees on my farm.	2.89	2.70	3.39	2.77	2.94
Increased complexity in the production system	2.46	2.67	3.03	2.46	2.67
Other reasons written by respondents					
I do not have enough land to implement this production system.	4.00	4.00	3.33	4.00	3.75
I'm too old to implement a new production system on the farm.	4.00	4.00	—	4.00	4.00
I do not like the type of tree in this production system, or I would prefer a tree that generates income in the short run.	3.67	4.00	4.00	4.00	3.92

ACS = alley cropping with black locus trees.

Table 6. Average rating (where 1 = not important at all to 4 = very important) of factors that explain the decision to be willing to adopt the ACS black locust system scenario.

Decision factors	Payment per acre ($/acre)				
	$270 (n = 30)	$330 (n = 32)	$390 (n = 32)	$450 (n = 33)	All payments (n = 127)
Reduced sheet, rill, wind, and gulley erosion	3.17	2.75	3.25	2.57	2.91
Increased soil organic matter	3.83	3.64	3.75	3.83	3.74
Receiving payment for adoption	3.17	2.64	3.17	2.67	2.86
Reduced fertilizer use	3.83	3.09	3.29	3.67	3.40
Restoration of soil structure and reduced compaction	3.83	3.36	3.29	3.67	3.50
Less runoff with increased water infiltration	3.17	3.45	3.57	3.71	3.48
Reduced nutrient leaching to groundwater	3.33	3.27	2.67	3.57	3.23
Trees intercept pesticide drift	3.67	2.64	2.57	2.86	2.87
Trees provide windbreak	3.50	2.91	3.38	3.43	3.25
Crop productivity could increase	3.83	3.30	3,57	3.71	3.57
Plant diversity improves wildlife habitat	3.33	3.45	2.71	3.71	3.32
Increased carbon sequestration	3.17	3.36	3.00	3.14	3.19
Pest and disease control	3.83	3.64	3.25	3.57	3.56
Modified microclimate conditions favorable for vegetable crop growth and quality, and comfort of agricultural workers	3.33	3.36	3.29	3.57	3.39
Other	4.00	3.33	2.50	—	3.17

ACS = alley cropping with black locus trees.

delay adoption or might not be willing to consider alley cropping until they are faced with those challenges. Whether this result is related to the perception of not being affected by these production challenges or not being aware that they are affected by these challenges is uncertain.

Familiarity with alley cropping seems to strongly differentiate those who are willing to adopt alley cropping from those who are not willing to adopt or are uncertain about the adoption of this production system. This result has implications for extension professionals and other information providers. Previous studies suggest that information availability and technical assistance on agroforestry, including alley cropping, through extension or other natural resource professionals such as NRCS officers could positively affect adoption, given the complexity of adopting a production practice that combines trees and crops in the same system (Adesina et al. 2000; Alemayehu and Simeneh 2024; Arbuckle et al. 2009; Arimi and Omoare 2021; Kronenberg et al. 2023; Pattanayak et al. 2003; Valdivia and Poulos 2009; Wilson and Lovell 2016).

Finally, the results related to one-time payments to partially or fully cover the costs of implementing alley cropping suggest that although payment may influence adoption, it is unclear what the optimal payment level would be to maximize adoption rates. Future research should explore scenarios of alley cropping that include various types of trees and payments that better reflect the costs associated with implementing this practice. Specifically, payments that cover costs associated with tree management and compensate farmers for potential income losses and environmental benefits provided by them when adopting this system in the short to medium term.

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