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Abstract

Agronomic decisions abound in the life of cassava farmers, yet research on agricultural technologies tend to focus on single practices individually. This study analyzed the interdependence and factors influencing the choice of 14 agronomic practices among 1,177 cassava farmers in 216 communities and 54 districts of major cassava-producing regions of Ghana. The multivariate probit model estimated using simulated maximum likelihood method with robust standard error estimates was used to capture the effects of correlated unobservables on farmers' decision-making processes. The prevalence of practices ranged from 27.4 percent of manure use to 67.6 percent of manual weed removal. Independence test indicated significant interdependence between the 14 equations. Residual correlation was greatest for fertilizer and manure use, manual and chemical weed control, and monoculture and proper plant spacing. Access to credit influenced positively 13 out of the 14 practices, while farmers based organization influenced positively 11 practices. Education, farm size, land tenure, living arrangements, household characteristics, experience of farmers and extension office distance showed different impacts on various practices. Land ownership showed conditional negative influence on some practices, while extension office distance had mixed impact across practices. These results reveal that cassava farmers construct portfolios of agronomic practices under heterogeneous financial, organizational, resources, tenure and information context. Technology dissemination must, therefore, be done through portfolio-based extension and identification of constraints of farmers to specific practices.

Keywords: cassava; agronomic practices; multivariate probit; technology adoption; credit access

1. Introduction

Cassava (*Manihot esculenta* Crantz) occupies a very important position in the food systems and rural economy of sub-Saharan Africa serving as food, income, planting material, and processing raw material as well as supporting increasing industrial applications. It performs fairly well in relatively harsh farming conditions and traditionally has emerged as an important food crop of smallholder farmers. One should however avoid confusing the production stress tolerance capacities of cassava with its non-reaction to management. Yield variations can be attributed to the quality of planting material, crop establishment, soil fertility management, weed competition, crop protection, and harvesting practices (Adiele et al., 2020; Amelework et al., 2021; Ekeleme et al., 2021; Mbanjo et al., 2021).

Traditionally, research in agricultural technology has examined adoption focusing either on specific technologies or adopter/non-adopter dichotomy providing valuable insights into the role of farmer characteristics, information, resources, risk, institutional environment, and technology attributes in the farmer decision-making process (Doss, 2006; Feder et al., 1985; Feder & Umali, 1993). The approach however proves restrictive in situations where farmers have to make several production decisions simultaneously. There are various types of agricultural technologies in terms of capital requirements, labour input, information needs, divisibility, timing, and expected returns perspectives. A farmer can choose to apply one recommended practice while refusing, postponing, or being unaware of the other.

This distinction is particularly relevant to cassava production as management is not confined to variety choice alone. The decisions that a cassava farmer is supposed to make include how to prepare the field, where to get planting material, type and age of the cassava cutting to plant, cultivation system (monoculture or mixed) and spacing. They can include soil amelioration regime and options, pests and disease control, weed management, field monitoring and harvesting time and methods. While these decisions may share some input and information sources, they may be constrained differently. Kondo et al. (2020) report that demonstrations, planting material supply, peer communications, media exposure and farmer-based organizations membership were crucial in the diffusion of improved cassava varieties. Farmers' knowledge and institutional environment that exposes them to such knowledge is crucial in their choice of a package of agronomic practices. Subsequently, Acheampong et al. (2022) find that awareness, farm size, extension contacts and extension visits influence improved variety adoption. Adoption is correlated with increased yields.

The problem of adoption is however not only one that involves the adoption of improved varieties. Baffour-Ata et al. (2024) find that knowledge, technological assistance, land tenure, pests, diseases and production conditions influence the application of climate-smart practices by cassava farmers. Similarly, Nsiah Frimpong et al. (2025) highlight the deficiencies in farmers' knowledge about cassava disease causes, spread and management and variations of their agroecological environment. These raise the issue of an agricultural management problem where knowledge, resources, institutional environment, and field conditions interplay across several practices rather than affect only one adoption decision.

Agricultural practices may be interdependent but interdependence usually arises due to the fact that technologies share labor force, finances, information, equipment, production risks or unobservable managerial capabilities. Ehiakpor et al. (2021), using the multivariate probit model, find that farmers' sustainable agriculture choices are interrelated and that institutional and farm-specific factors influence different practices differently. A similar study in the area of digital agricultural services highlights joint demand for multiple services and combinations of practices rather than isolated practices (Antwi-Agyei & Amanor, 2023; Miine et al., 2023). Multivariate probit model is an appropriate tool for analysis of such problem because it estimates the binary choice simultaneously but allows correlation between the unobserved determinants (Cappellari & Jenkins, 2003). Multivariate models have already been used to analyze various agricultural technologies in Ghana and elsewhere. This paper, therefore, focused on application of the multivariate model in examining the relatively scarce empirical evidence on a portfolio of routine cassava agronomic and crop-management practices in Ghana. The latter includes planting-material management, crop establishment, fertility, disease management, weed management, field monitoring, and harvesting.

This study fills this empirical gap by pursuing these specific objectives, namely (a) identifying the prevalence rate of the chosen agronomic practices; (b) investigating whether the underlying unobserved influences affecting the farmers' decision are correlated and (c) identifying the socioeconomic, farm-level, tenure, financial and institutional factors influencing individual practices. The main contribution of this study is in demonstrating simultaneously the areas where the cassava management choices have similar unobserved influences, and where their observable correlates diverge beyond just being an adopter and non-adopter of the agricultural technology.

2. Conceptual and empirical framework

2.1. Agronomic practice choice

The analytical framework draws on random-utility reasoning. Farmer i is assumed to use agronomic practice j where the expected utility from using that practice exceeds the expected utility associated with not using it. Since the underlying utility difference is not directly observed, the decision can be represented by a latent variable:

$$Y_{ij}^* = X_i \beta_j + \varepsilon_{ij}$$

where Y_{ij}^* is the latent propensity of farmer i to use practice j , X_i is a vector of observable farmer, household, farm, tenure, financial, and institutional characteristics, β_j contains practice-specific parameters, and ε_{ij} represents unobserved influences.

The binary choice is observed:

$$Y_{ij} = \begin{cases} 1 & \text{if } Y_{ij}^* > 0 \\ 0 & \text{otherwise.} \end{cases}$$

The explanatory variables represent different dimensions of the decision environment for the farmer. The demographic characteristics consist of such variables as gender, residency, household size and marital status. Education and farming experience represent the human capital dimension. The number of farms and farm size represent the operational resources dimension. Ownership of land represents a broad tenure dimension, while participation in farmer-based organizations, access to credit and distance to an extension office represent the institutional, financial and informational dimensions.

It is not necessarily true that these variables should influence all practices in the same way. Heterogeneous benefits from the agricultural technologies and different cost of adoption are well-established in the literature (Suri, 2011). The information can also spread both through formal institutions and social networks (Bandiera & Rasul, 2006; Conley & Udry, 2010). Awareness and exposure are also considered as prerequisites of certain agricultural decisions, which means that non-adoption of a particular technology may be the result of lack of exposure rather than the fully-informed decision (Diagne & Demont, 2007).

2.2. Interdependence of practice choices

The 14 agronomic choices are not mutually exclusive. A farmer may make such choices as using healthy planting material, applying the proper spacing, fertilizing, using manure, carrying out weed control manually, using weedicide, monitoring the field and harvesting on time.

For two practices j and k , the multivariate model permits:

$$\text{Corr}(\varepsilon_{ij}, \varepsilon_{ik}) = \rho_{jk}.$$

If $\rho_{jk} \neq 0$, unobserved determinants of one practice are statistically associated with unobserved determinants of another. Estimation of the practices separately would constrain these correlations to zero.

The interpretation of ρ is deliberately bounded. A positive residual correlation shows that unobserved influences increasing the latent propensity for one practice tend to move in the same direction as unobserved influences affecting another practice. It does **not** demonstrate agronomic complementarity, economic synergy, or causal interaction between the technologies themselves.

3. Materials and methods

3.1. Study area

This survey entailed the collection of data from important cassava-growing regions of Ghana. It involved nine regions within the administrative structure as described in the original survey, namely: Ashanti, Brong Ahafo, Eastern, Western, Greater Accra, Central, Volta, Northern, and Upper West Regions. The exclusion was that of the Upper East Region. Fifty-four districts in the forest zone, forest-savannah transitional zone, coastal savannah zone, and Guinea savannah zone agroecologies were selected for the survey.

The southern regions involved in this study experience primarily bimodal rainfall. Rainfall as stated in the original survey document ranges between approximately 800 mm and 2,200 mm with annual temperatures of approximately 24–30°C. However, Northern and Upper West Regions experience unimodal rainfall, having a mean annual rainfall of approximately 1,100 mm and mean annual temperature of 25°C. Selection of the districts took into account not only the production volume but also the experience of intervention. Districts with a minimum of 5,000 ha under cassava and with an annual production of at least 10,000 tonnes along with having either WAAPP or Root and Tuber Improvement and Marketing Programme demonstrations done within them since 2011 were considered, with more weight being given to those with larger cassava area and production.

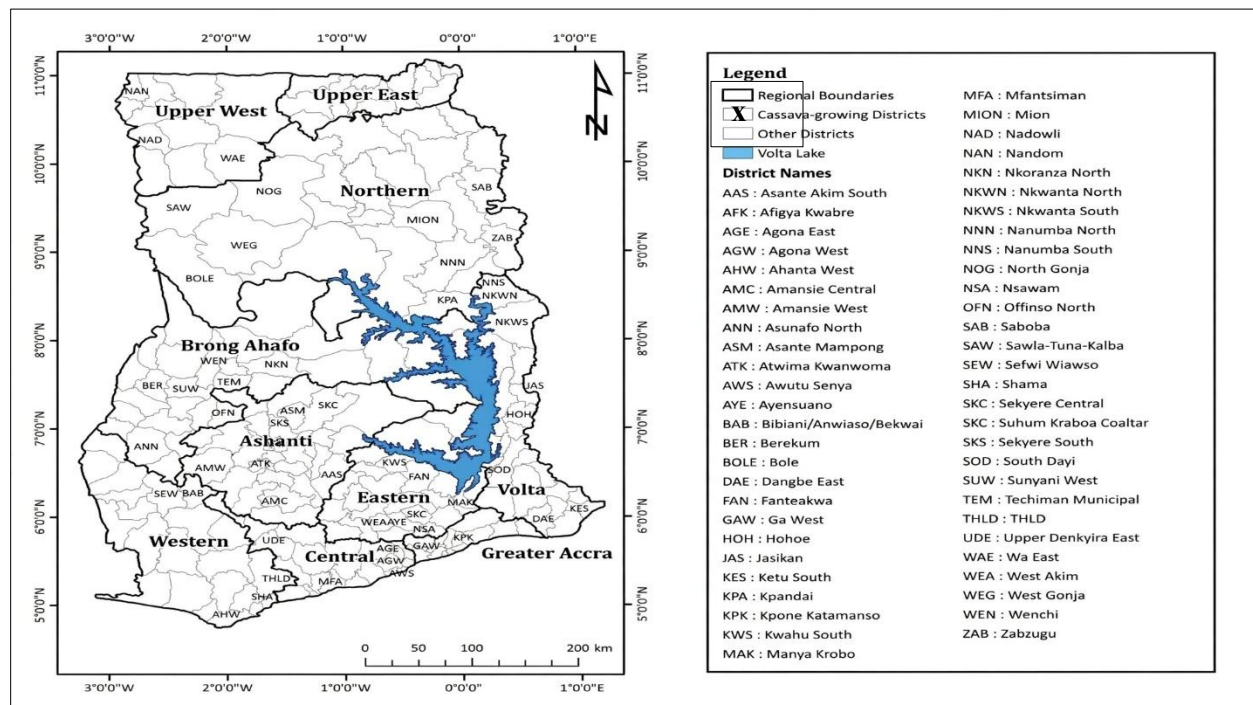


Figure 1. Location of sampled cassava-producing districts in Ghana
Source: Modified from (Acheampong et al.,2017)

3.2. Sampling procedure

Multistage sampling, a combination of purposive and random sampling methods, was used. Important cassava producing environment regions were purposively selected. Similar considerations were made for district selection as well. Randomly selected communities were then chosen from which farmer data was gathered through random sampling method. The total sample of cassava farmers analyzed is 1,177 from 216 villages and 54 districts. This is the official analytical sample used across all sections of the current paper. The sample is considered to be a geographically extensive coverage of main cassava-growing regions due to the use of purposive criteria in higher stages of sampling procedure.

3.3. Data collection

The structured questionnaires were administered using trained enumerators. Prior to the primary survey, the questionnaire was pretested in non-sampled communities. Pretesting examined the suitability of questions and ability of enumerators to apply them consistently. The data on farmer/household characteristics, farm characteristics, social network and association membership, livestock ownership, saving and credit, agricultural extension, knowledge and perception, food security, and household decision-making were obtained using structured questionnaire. The dataset used in the present analysis was obtained from the CSIR–Crops Research Institute in 2024. The ethical clearance for the survey was obtained. Consent of farmers was asked prior to the interview, while participant identifiers but not the names and locations of the respondents are included in the analytical dataset. The provided project materials do not include the details of the ethics committee and reference number; these have to be retrieved from the original project files.

3.4. Variables and measurement

Table 1 provides the list of explanatory variables. More than 73.0% of respondents were male, while 70.5% of them were native residents. The respondents that are married account for 86.2%. The average household size was 7.56 persons, the education was 6.30 years, and farming experience was 22.49 years. Respondents managed an average of 2.50 farms, and the average farm size was 2.14 acres. Land ownership, farmer organization membership, and credit access were recorded in 69.7%, 59.3%, and 38.9% of cases, respectively. The average distance from the respondent's homestead to an extension office was 4.69 km. Distance to extension office has been used as the variable name in place of extension access because the former measures geographical distance to the extension office as opposed to extension contact.

Table 1: Definition and descriptive statistics of explanatory variables

Variable	Measurement	Mean	SD
Sex	1 = Male; 0 = Female	0.730	0.444
Number of farms	Count	2.502	1.986
Farm size	Acres	2.135	2.131
Land ownership	1 = Owned; 0 = Not owned	0.697	0.460
Education	Years of schooling	6.295	4.951
Residential status	1 = Native; 0 = Settler	0.705	0.456
Household size	Number of household members	7.560	4.168
Married	1 = Yes; 0 = No	0.862	0.346
Farming experience	Years	22.489	12.398
FBO membership	1 = Yes; 0 = No	0.593	0.491
Credit access	1 = Yes; 0 = No	0.389	0.488
Distance to extension office	Kilometres	4.694	6.983

Source: Study data.

The dependent variables include 14 binary agronomic/crop management practices. "Planting-material selection" involves selecting healthy plants for cutting to serve as planting material in the

next growing season. "Good cutting" involves the use of cuttings with a single node as in the questionnaire. "Fresh-cutting use" involves the use of planting material within seven days of cutting. Disease control involves the removal of diseased plants upon identification whereas plant spacing involves the use of recommended spacing.

Table 2: Prevalence of cassava agronomic practices

Practice	Prevalence (%)
Minimum tillage	52.6
Planting-material selection	44.1
Good cutting	48.3
Monoculture	51.7
Recommended plant spacing	48.5
Fresh-cutting use	59.8
Fertilizer application	31.1
Manure application	27.4
Disease control	31.5
Manual weed control	67.6
Weedicide application	65.3
Farm monitoring	56.9
Timely harvesting	66.8
Row planting	53.4

Source: Study data.

3.5. Multivariate probit estimation

The joint estimation of the 14 binary choice equations was done using multivariate probit (MVP). The raw model was estimated in Stata 17 through simulated maximum likelihood (SML) with robust standard errors. Five draws of the simulation were supplied. The model converged at the log pseudo-likelihood value of -8500.924. The explanatory variables had a statistically significant effect jointly, Wald $\chi^2(168) = 690.36$, $p < 0.001$. MVP coefficients are latent index coefficients. Therefore, a coefficient is not an indicator of percentage point change in the probability that a farmer uses the practice. Hypothesis about independence of choice behavior was tested using the joint test of equality of all 91 cross-equations residual correlations to zero:

$$H_0: \rho_{jk} = 0 \forall j \neq k.$$

Rejection confirms the need for employing the multivariate specification.

4. Results

4.1. Prevalence of agronomic practices

Table 2 provides information about the prevalence of agronomic practices. Usage of different practices significantly varied across the data set. The most popular practice was manual weed removal with 67.6% of users, followed by timely harvesting (66.8%) and weedicide use (65.3%). Next came fresh-cutting (59.8%), farm observation (56.9%), row planting (53.4%), and minimum tillage (52.6%). Monoculture was observed in 51.7% of observations, proper plant spacing in 48.5%, proper cutting in 48.3%, and choosing appropriate planting material in 44.1%. Much less popular were fertilizer usage (31.1%), disease control (31.5%), and manure use (27.4%). The distribution shows that the practices were not used in a package. Many weed removal and timing practices were used quite frequently, while soil fertility and disease control practices were not used by one third or less of respondents.

4.2. Interdependence among agronomic practices

Table 3 provides information on the correlation between the dependent variables. The likelihood ratio test rejected the null hypothesis of all 91 error correlations being jointly equal to zero, $\chi^2(91) = 3306.83$, $p < 0.001$. Thus, the assumption of independence required by estimation of the 14 decisions separately is incompatible with the estimated residuals structure. All 91 estimated correlations between the residuals were positive and significant. The strongest correlation was between fertilizer application and manure application ($\rho = 0.662$); the next largest was between manual weed control and weedicide application ($\rho = 0.607$), monoculture and recommended spacing ($\rho = 0.594$), monoculture and manual weed control ($\rho = 0.575$), plant spacing and manual weed control ($\rho = 0.570$), and weedicide application and farm monitoring ($\rho = 0.564$).

Table 3: Residual correlation matrix from the multivariate probit model

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Minimum Tillage	1													
Seed selection	0.429*** (0.047)	1												
Good cutting	0.156*** (0.046)	0.384*** (0.042)	1											
Monoculture	0.293*** (0.042)	0.346*** (0.041)	0.462*** (0.039)	1										
Plant spacing	0.322*** (0.046)	0.456*** (0.041)	0.505*** (0.037)	0.594*** (0.035)	1									
Fresh cutting use	0.361*** (0.046)	0.397*** (0.041)	0.305*** (0.043)	0.419*** (0.039)	0.420*** (0.040)	1								
Fertilizer Application	0.315*** (0.049)	0.519*** (0.041)	0.362*** (0.042)	0.450*** (0.040)	0.444*** (0.042)	0.391*** (0.041)	1							
Manure Application	0.375*** (0.046)	0.373*** (0.045)	0.399*** (0.046)	0.463*** (0.043)	0.419*** (0.044)	0.424*** (0.045)	0.662*** (0.035)	1						
Disease Control	0.163*** (0.055)	0.546*** (0.040)	0.441*** (0.041)	0.430*** (0.044)	0.519*** (0.040)	0.440*** (0.041)	0.535*** (0.039)	0.408*** (0.042)	1					
Manual Weed Control	0.402*** (0.044)	0.489*** (0.040)	0.461*** (0.040)	0.575*** (0.035)	0.570*** (0.039)	0.464*** (0.042)	0.554*** (0.037)	0.501*** (0.043)	0.511*** (0.038)	1				
Weedicide Application	0.309*** (0.050)	0.517*** (0.037)	0.406*** (0.041)	0.370*** (0.040)	0.550*** (0.036)	0.402*** (0.041)	0.539*** (0.038)	0.476*** (0.040)	0.516*** (0.038)	0.607*** (0.032)	1			
Farm Monitoring	0.410*** (0.048)	0.366*** (0.047)	0.298*** (0.046)	0.309*** (0.043)	0.475*** (0.039)	0.443*** (0.042)	0.457*** (0.043)	0.452*** (0.043)	0.372*** (0.043)	0.540*** (0.037)	0.564*** (0.034)	1		
Timely Harvest	0.209*** (0.049)	0.514*** (0.039)	0.456*** (0.039)	0.316*** (0.043)	0.533*** (0.037)	0.310*** (0.042)	0.491*** (0.038)	0.454*** (0.041)	0.404*** (0.041)	0.461*** (0.038)	0.481*** (0.037)	0.343*** (0.042)	1	
Row Planting	0.225*** (0.045)	0.312*** (0.044)	0.183*** (0.046)	0.276*** (0.043)	0.263*** (0.044)	0.304*** (0.043)	0.439*** (0.041)	0.324*** (0.044)	0.301*** (0.043)	0.410*** (0.040)	0.329*** (0.042)	0.274*** (0.043)	0.233*** (0.045)	1

Likelihood-ratio test: $\chi^2(91) = 3306.83, p < 0.001$.

4.3. Determinants of agronomic practices

Table 4A and 4B provides information about the determinants of the use for the agronomic practices from the MVP model. The analysis revealed a lot of heterogeneity in effects on different practices. Education, FBO membership, credit, size of the farm, land ownership, residential status, size of the household, farming experience, number of farms, and distance to extension office were related to the practices in different ways. Credit access exhibited the widest set of significant relationships. In 13 out of 14 equations, it had a positive coefficient. FBO membership had positive coefficients in 11 equations. Education had positive coefficients in 10 equations. Land ownership had negative coefficients significant at 10% significance level or higher in 12 equations.

Table 4A: Multivariate probit estimates: establishment and fertility practices

Variable	Minimum tillage	Material selection	Good cutting	Monoculture	Spacing	Fresh cutting	Fertilizer
Sex	0.017 (0.018)	-0.019 (0.017)	0.015 (0.017)	-0.013 (0.019)	-0.011 (0.020)	-0.005 (0.018)	-0.004 (0.018)
Number of farms	-0.149 (0.093)	0.019 (0.095)	0.078 (0.093)	0.132 (0.092)	0.158* (0.091)	0.250*** (0.092)	0.079 (0.096)
Farm size	0.145*** (0.033)	0.099*** (0.024)	0.004 (0.025)	-0.009 (0.028)	0.040 (0.031)	0.056** (0.028)	0.025 (0.028)
Land ownership	-0.212** (0.087)	-0.236*** (0.087)	-0.192** (0.087)	-0.199** (0.086)	-0.320*** (0.089)	0.013 (0.089)	-0.171* (0.092)
Education	0.017** (0.008)	0.043*** (0.008)	0.027*** (0.008)	0.019** (0.008)	0.028*** (0.008)	0.007 (0.008)	0.039*** (0.008)
Residential status	-0.026 (0.086)	-0.192** (0.088)	-0.119 (0.089)	-0.211** (0.088)	-0.107 (0.090)	-0.092 (0.089)	-0.341*** (0.092)
Household size	-0.027** (0.011)	-0.030*** (0.010)	-0.006 (0.009)	0.000 (0.010)	-0.009 (0.010)	-0.006 (0.009)	0.002 (0.010)
Married	0.054 (0.116)	-0.061 (0.119)	0.045 (0.120)	-0.012 (0.114)	0.006 (0.112)	0.017 (0.117)	-0.131 (0.119)
Farming experience	0.002 (0.003)	0.005 (0.003)	-0.002 (0.003)	0.000 (0.003)	0.001 (0.003)	-0.001 (0.003)	0.004 (0.003)
FBO membership	0.058 (0.080)	0.188** (0.082)	0.343*** (0.080)	0.225*** (0.079)	0.200** (0.079)	0.235*** (0.081)	0.368*** (0.084)
Credit access	0.533*** (0.082)	0.320*** (0.081)	0.385*** (0.080)	0.396*** (0.081)	0.319*** (0.081)	0.167** (0.083)	0.322*** (0.085)
Extension distance	-0.014*** (0.005)	0.004 (0.006)	0.013** (0.005)	0.006 (0.006)	0.001 (0.006)	0.012** (0.005)	-0.013** (0.006)

Robust standard errors are in parentheses. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.10$.

Table 4B: Multivariate probit estimates: crop protection, monitoring and harvesting

Variable	Manure	Disease control	Manual weed	Weedicide	Monitoring	Timely harvest	Row planting
Sex	-0.010 (0.018)	-0.023 (0.020)	0.015 (0.024)	-0.022 (0.019)	0.009 (0.019)	0.011 (0.018)	0.003 (0.020)
Number of farms	0.173* (0.100)	0.104 (0.096)	0.117 (0.092)	0.104 (0.089)	0.130 (0.098)	0.107 (0.094)	0.272*** (0.093)
Farm size	0.062* (0.035)	0.050*** (0.018)	0.063** (0.030)	0.034* (0.018)	0.050 (0.045)	0.063*** (0.024)	0.017 (0.018)
Land ownership	-0.403*** (0.092)	-0.127 (0.093)	-0.233** (0.094)	-0.171* (0.090)	-0.274*** (0.096)	-0.311*** (0.090)	-0.533*** (0.094)
Education	0.023*** (0.009)	0.031*** (0.008)	0.011 (0.008)	0.020** (0.008)	0.008 (0.008)	0.045*** (0.008)	-0.001 (0.008)
Residential status	-0.107 (0.093)	-0.210** (0.092)	-0.136 (0.092)	-0.213** (0.089)	-0.078 (0.094)	-0.176* (0.091)	0.030 (0.090)
Household size	-0.002 (0.010)	-0.018* (0.010)	-0.002 (0.009)	-0.008 (0.009)	-0.014 (0.010)	-0.007 (0.009)	0.004 (0.009)
Married	-0.205 (0.125)	-0.193 (0.126)	-0.075 (0.118)	-0.226* (0.117)	0.136 (0.120)	-0.069 (0.118)	-0.107 (0.120)
Farming experience	-0.001 (0.003)	0.009*** (0.003)	-0.001 (0.003)	0.006** (0.003)	-0.001 (0.003)	0.001 (0.003)	-0.002 (0.003)
FBO membership	0.395*** (0.088)	0.267*** (0.086)	0.177** (0.080)	0.383*** (0.080)	0.119 (0.084)	0.114 (0.082)	0.278*** (0.082)
Credit access	0.507*** (0.085)	0.394*** (0.084)	-0.055 (0.083)	0.284*** (0.082)	0.271*** (0.087)	0.449*** (0.083)	0.333*** (0.086)
Extension distance	-0.002 (0.006)	0.012** (0.006)	0.006 (0.006)	0.007 (0.006)	-0.000 (0.005)	0.009 (0.006)	0.007 (0.006)

Robust standard errors are in parentheses. *** $p < 0.01$. ** $p < 0.05$. * $p < 0.10$.

5. Discussion

5.1. Interdependence of cassava agronomic choices

The probability of likelihood ratio is an important indicator that cassava-management decisions are not of each other. The fact that independence cannot be established between all 14 equations indicates that there are certain unseen factors related to one agronomic decision that are linked to factors seen in other decisions. This is important because the conception of how farmers behave in terms of management has been altered as a consequence of it.

Ehiakpor et al. (2021) found interdependence between sustainable agricultural practices in Ghana and the fact that farm, institutional and resource attributes have different effects on individual choice. Miine et al. (2023) made a similar inference regarding digital agricultural services where they found joint demand among various services as well as FBO membership, credit and agronomic education playing a role. Antwi-Agyei & Amanor (2023) have also found that farmers in Ghana often practice clusters of climate-smart agricultural practices as opposed to practicing one particular practice. There is empirical evidence in recent studies in Ghana on cocoa rehabilitation which shows that even different management choices may have correlated unobservables (Agbolosoo et al., 2026).

The correlation of 0.662 for the fertilizer-manure residual is the highest relationship identified in the analysis. However, this does not imply that there exists evidence of agronomic complementarity of inorganic fertilizer and manure from this analysis. This implies that there are some unobservable farmer propensities toward investment in fertility that result in them using both fertilizers. These propensities may include soil characteristics, business orientation, availability of inputs, financial capabilities, and agronomic information. Similarly, Ehiakpor et al. (2021) discovered the existence of relationships within soil management practices, while studies on bundling climate smart technologies in Ghana showed that farmers bundle nutrient, planting, and information practices based on the circumstances surrounding their farms.

This interpretation also holds true in the case of the 0.607 correlation coefficient of manual weed elimination and weedicide spraying. Farmers who face intense or continuous weed problem situations can still spray herbicides while continuing to implement manual weed control measures. Ekeleme et al. (2021) showed that weed competition continues to be one of the main problems in cassava farming, while showing that integrated weed management strategies can perform better than untimely manual weed control methods. The correlation in question is therefore agriculturally logical but cannot prove that combining both approaches of weed control is the best approach for all farmers. The import is that, extension agencies should embrace agronomic clusters without packaging them. While the statistical results support joint decision-making environments, they do not prove that every practice in a cluster needs to be promoted jointly.

5.2. Credit access

Credit access was positive and statistically significantly associated with all of the 14 management practices except for manual weed management. This implies that liquidity affects cassava production management much more broadly than through financing fertilizer and agrochemical purchases alone. Production of cassava creates costs at different stages of production process. A farmer may need to acquire or transport planting material, hire labour for plant establishment and weed removal, buy soil or pest/fertility/crop protection amendments, inspect fields, and mobilize labour and transportation for harvesting. A farmer thus can know about the correct management of cassava but be unable to undertake it at the right moment because of lack of the needed money. Missiame et al. (2021), who found that access to rural and community bank credit was positively correlated with technical efficiency of Ghanaian cassava farmers. In this case, credit access itself was influenced by institutions, thus reflecting the close link between finance, organizations and agriculture. Ehiakpor et al. (2021) found agricultural credit to be relevant for both adoption and intensity of sustainable practices in Northern Ghana, while Miine et al. (2023) found credit access a predictor of adoption and intensity of digital agriculture services. Karlan et al. (2026) using experimental design for digital credit provision, observed increased farm input expenditures but not uniform higher output, sales or profits. The problem was timing since the loan came later than the moment when the agricultural investment opportunity window closed. The wide relationship between access to credit and agronomic practices cannot be interpreted as the assumption that the “more credit”, the better result will be achieved. Credit should be provided timely and in coordination with farmers' decisions. Similarly, Sirin et al. (2026) found that access to credit was simultaneously associated with productivity and farmer welfare, confirming the relevance of

looking at credit provision not in isolation, but within a larger production system. However, MVP estimates in the current work are still conditional associations. Those farmers who are able to obtain credit may be differentiated from other farmers by their business orientation, asset holdings, management skills, risk attitudes, market participation. The model does not reveal any exogenous impact of credit on agronomic practices. This implies that liquidity seems to function as a cross-cutting constraint in cassava management. Agriculture finance should thus be combined with extension and agricultural calendar considerations, but a causal statement on the impact of credit must be based on a design that addresses issues of selection and timing.

5.3. Farmer-based organizations

The analysis reveals that membership in FBO is positive and statistically significantly associated with selection of planting materials, cutting good cutting, monoculture, recommendation of space between plants, using fresh cutting, fertilization, manuring, disease management, manual weed management, weedicide application, and row planting. The wide association has significance since farmer organizations provide a mechanism through which multiple streams of information and services are channeled at once. An organization member attends an organizational meeting and receives information on planting materials, participates in demonstration, meets an input provider, gets to know credit opportunities, and engages extension officers. FBO membership can thus affect decisions on a number of technologies without necessitating the creation of dissemination channels for each one. In line with the discussion, Kondo et al. (2020) noted that farmer organizations played a role in disseminating improved cassava varieties in Ghana along with demonstrations, provision of planting materials, inter-farm communication, and media. Similarly, Addai et al. (2022) noted a positive link between FBO participation and machinery and row-planting technology adoption among rice farmers in Ghana despite controlling for selectivity into farmer organizations. Also, in line with the discussion, Adams et al. (2021) suggested that improving farmer organizations and extension institutions could encourage technology adoption. In another empirical illustration of the role of institutional arrangements in technology adoption, Konja and Abdulai (2024) reported outgrower scheme participation to be correlated with fertilizer and weedicide use and farm productivity. In addition, FBO membership was among the institutional arrangements linked to outgrower scheme participation. However, it should not be assumed that belonging per se is responsible for improved agronomic practices. Organizations differ in terms of functionality, leadership, meeting frequency, links with external organizations, and delivery of services. Membership may also be endogenous in nature. That is commercially oriented and information seeking farmers might be more willing to become members. It is however clear that FBOs play a key role in the cassava innovation system and need to be considered when disseminating technologies.

5.4. Education and farming experience

Education had positive and statistically significant relationship with minimal tilling, selection of planting material, proper cutting, monoculture, recommended plant spacing, application of fertilizer, application of manure, disease prevention, weedicide application, and timely harvesting. This results suggest that formal education is an important component in facilitating farmers' skills at acquiring and interpreting technical information. Practices such as selection of appropriate

planting material, knowledge about recommended spacing, external soil amendment, disease identification, and application of agrochemicals are all information processing practices to various degrees. Thus, education may facilitate farmer's skills in translating technical recommendations into practice. This study is consistent with recent multiple practice research, according to which human capital affects the adoption of each technology differently. Ehiakpor et al. (2021) revealed heterogeneous determinants of sustainable practices, while Antwi-Agyei and Amanor (2023) reported nuanced socioeconomic determinants of climate-smart-practice typologies. Omodara et al. (2023) working with cassava farmers in Nigeria came to similar conclusions where education, among other socioeconomic characteristics, affected specific adaptation practices. In contrast, farming experience generated a more narrow set of correlations. It correlated positively with the control of diseases and weedicide application. Thus, accumulated human capital may acquire particular significance in cases when farmers need to diagnose problems in the fields and decide upon the necessary measures. Nsiah Frimpong et al. (2025), however, illustrate that experience alone does not necessarily mean the possession of disease knowledge. This is to say that formal education and accumulated experience provide two different kinds of human capital. Neither of them can substitute for the targeted extension and training.

5.5. Farm size and number of farms

Farm size was positive and statistically significant with minimum tillage, selection of planting materials, cutting of fresh planting materials, manure application, control of diseases, weed removal by hand, weedicide application, and proper harvesting of crops. Number of farms also had a positive relation to the recommended spacing of planting materials, cutting of fresh planting materials, manure application, and row planting. Farm size may affect both the potential benefits and the costs associated with different agronomic management practices. Large farms, being more profitable due to larger returns on successful practices and the possibility to dedicate different parcels of their land to various practices, are more costly in terms of needed labour and total cash required for inputs. That is why farm size is not always positively related to all practices. Acheampong et al. (2022) established farm size as one of the main correlates of the improved variety adoption in Ghana. Similar relations between farm characteristics and choice of adaptations among cassava farmers were reported by Omodara et al. (2023). These emphasize the importance of operational scale, conditional upon the nature of resource requirements and expected returns for each particular practice.

5.6. Land ownership and tenure complexity

Land ownership had a statistically significantly relationship with minimum tillage, planting material choice, good cutting, monoculture, plant spacing, fertilizer use, manure application, weeding manually, applying weedicides, crop monitoring, harvest timing, and row planting. A straightforward conclusion to draw would be that ownership reduces the willingness to make investments in agronomy. That would be hard to justify since the ownership variable does not reflect tenure security properly. While it distinguishes land classified as owned and non-owned, it fails to identify land used as family property, customary rights, rental agreements, sharecropping, borrowing, length of use, title ownership, disputes, or subjective perception of security of tenure. According to Asaaga et al. (2020), the connection between tenure security and investment in

sustainable land management in cocoa systems in Ghana is complicated and influenced by multiple factors other than legal ownership of the land. Donkor et al. (2023) also demonstrated that various tenure arrangements involve different levels of investment in production and have different characteristics, namely family lands and sharecropping arrangements differ from titled lands in terms of investment behavior. Also, Alhola and Gwaindepi (2024) proved that titles and customary rights can provide a sense of tenure security and even though the perception of security varies depending on institutional settings and regions. Abdallah et al. (2024) showed that land arrangements and exposure to large-scale land acquisitions are associated with different types of short- and long-term investments on the farms in Northern Ghana, showing that land ownership is not enough to ensure secure tenure. Consequently, the negative coefficients obtained in the current research can be a result of unobservable differences between owner-operators and farmers growing cassavas in different conditions. Non-owner farmers may be more commercially minded, grow crops on different pieces of land, have a different incentive to grow, get land under different agreements and production technology among others. The result should be viewed as the evidence that tenant status is an indicator that distinguishes agronomic behavior but not that insecurity contributes to better farm management.

5.7. Extension-office distance and information access

The distance between the extension office and the farmer's homestead was negative and statistically significant with minimum tillage and fertilizer application and positively with good cutting, fresh-cutting usage, and disease control. One would notice that it refers to the geographical distance between the office and the farmer rather than the extent of extension. Kondo et al. (2020) stated that the dissemination of cassava technologies in Ghana is performed by demonstration, planting material distribution, communication among the farmers, media, and organizations apart from extension services. In their study of the West Africa Agricultural Productivity Programme in Ghana, Senegal, and Mali, Bambio et al. (2022) found that exposure to activities aimed at disseminating the technology was associated with its usage and positively related with productivity and income. Such results prove that farmers may receive agricultural information via program activities and decentralized channels regardless of the distance to formal offices. Moreover, digital channels are an additional means to transmit the information. According to Mohammed and Abdulai (2022), ICT-based extension among farmers correlated with knowledge acquisition, technology adoption, and farm performance. But as Nyarko and Kozári (2021) found in their research, the use of ICTs by extension officers does not guarantee intensive ICT-based advisory delivery as such. The difference is that ICT availability and utilization are distinct concepts. Weather and climate-information services have the impact on some climate-smart practices as well. The positive effects of distance for certain practices might thus be due to farmers who are far from offices getting their information through FBOs, demonstrations, peer groups, projects, input dealers, processors, and mobile information.

5.8. Weed management

Manual weed control and weedicide application were two of the most common practices, with 67.6% and 65.3% of the respondents using them, respectively. The residual correlation of 0.607 for them was also one of the highest of the model. The high levels of both practices indicate that weed control via chemicals and manually should not necessarily be seen as alternative options. A farmer might apply weedicide at the start of the production process and perform manual weed removal in places where there are regrowth of weeds, where chemicals are not sufficient to kill certain types of weeds, or when the stage of the crop requires it. Ekeleme et al. (2021) have provided direct evidence from West African cassava farmers demonstrating that weed control is very influential to cassava output and farm profits. In their experiments, integrated weed management systems involving proper agronomy and herbicides proved to be superior to poor manual weed control, and also reduced the need for labour. Most importantly, the authors stressed the importance of training farmers in proper and safe herbicide use. The association between credit access and the use of weedicide application in this study was significant but not with manual weed control. The reason behind this is that weedicide use needs purchased inputs, but manual weed control can use household or locally hired labor in place of money. On the contrary, FBO membership is significant for the use of both methods. The implication is that organizations influence information and management practices regardless of the nature of the practice being cash or labor intensive. This does not imply that weedicide use must replace manual weeding. The issue here is that the process of weed management must be done as a series of decisions depending on weed pressure, the stage of growth, labor supply, chemical availability, knowledge about safety and profitability.

5.9. Disease management

There was a positive statistically significant relationship between disease management and the farm size, level of education, experience in farming, membership in FBOs, credit access, and distance to the extension office, whereas residential status and household size showed a negative relationship with the practice. According to the findings of Nsiah Frimpong et al. (2021), farmers' knowledge on cassava pests is much higher than cassava diseases, with some significant shortcomings on disease causation and management. They found that there are persistent knowledge gaps and differences in management practices in agroecological zones (Nsiah Frimpong et al., 2025). Positive associations between FBO and education, are also reasonable because disease management requires information. The credit association could be due to the higher overall costs in replacing planting material, labor or other disease-related activities. Nonetheless, the present model is unable to distinguish such mechanisms individually.

5.10. Residential and household characteristics

Residence was negatively associated with planting material choice, monoculture, fertilizer use, disease management, weeding and, more mildly, harvesting in time. Natives have less latent propensity, taking into consideration the other explanatory variables, of engaging in such practices.

It implies that residence could also be associated with something beyond the settlement. Native and settler farmers might have different arrangement with regards to land, commercial orientation, network, production area or reliance on agriculture. Literature on land tenure in Ghana also reveals that residence status could be correlated with land tenure and investment environment (Donkor et al., 2023).

The number of household members had a negative relationship with minimum tillage, choice of planting material, and disease control. This suggests that household size is not an automatic source of excess labour for carrying out agronomic activities. Whether this will be the case depends on the composition of the household, dependency ratio, off-farm labour involvement of household members, and whether particular practices need labour, money, or technical know-how. For example, Anang (2018) found that the size of a household made the adoption of improved rice varieties and mechanization less likely among smallholder farmers in northern Ghana, indicating that high consumption needs may nullify any benefits that accrue from family labour. Additionally, Ehiakpor et al. (2021) found that the determinants of interdependent sustainable agricultural practices in Ghana are different from practice to practice, thus making it clear that there is a need to have a practice-specific analysis and not a generalized one. In a related study, Antwi-Agyei and Amanor (2023) showed the existence of socioeconomic variation in rural Ghana depending on the type of climate-smart practices. In a different study carried out in Nigeria by Omodara et al. (2023), household and socioeconomic factors affect the choice of adaptation practices by cassava farmers. All the above studies show that there may be competing needs of the family, which makes it difficult to undertake practices requiring money or information, despite being able to use family labour.

6.0 Conclusion

This study suggest two levels of cassava agronomic decision-making. Firstly, the level of similar decision-making environment. Significant residual correlations indicate that some unobservable financial, managerial, information, field, institutional, or market conditions simultaneously influence more than one choice. Secondly, the level of choice-specific constraints. Credit availability is an issue for the majority of the technologies, except for manual weeding. Membership in FBOs is important for many, but not all, decisions. Education influences ten choices, but not all. Resources are relevant for the choice in a selective manner. The same applies to tenure status and its role is evident, but the exact channel is not identified. Extension distance varies across practices. Cassava farmer are best seen as a portfolio manager rather than a single adopter or non-adopter. The portfolio approach does not imply bundling of technologies together but implies that agricultural policy recognizes the connection between decisions and diagnoses the reasons why a particular technology is or is not applicable for a particular farmer. Therefore, it is necessary to acknowledge two facts in technology dissemination, namely farmers' management choices are interlinked but constraints for individual practices are distinct. Portfolio-based approach to extension services combined with practice-specific analysis makes a stronger case for cassava production support than a single technology package.

6.1 Policy Implications

- Recommendations based on agronomy can be grouped around consistent management domains (planting material and crop establishment, soil fertility, crop health, weed management, field monitoring, and harvesting) rather than communicated as independent messages.
- Financial means could be more helpful in cases where lending is synchronized with the calendar of agriculture investments, needs for inputs, and technical information.
- FBOs could serve as a platform for dissemination to decrease costs of communication about demonstrations, planting material, agronomical information, and connections with suppliers and extension workers. Programme development should still leave other ways open for farmers who are not members of such organizations.
- Demonstrations, FBO-based education, mobile advisory services, farmer-to-farmer communications, agro-dealers, processors, and other decentralized extension service providers can complement formal public extension.

7. Study limitations

- The empirical approach rests upon cross-section data. It is thus reasonable to treat the observed associations as conditional rather than causal effects.
- The MVP framework allows accounting for the interdependence among the unobservables of the determinants of 14 practices. Yet, endogeneity problem remains relevant for the explanatory variables. For example credit access and FBO membership can be driven by some unobservables affecting both farmers' behavior and these variables.
- Agronomic practices are defined through the use of binary self-assessed indicators. Such indicators do not reflect the frequency of use, application rates, implementation intensity and quality. For instance, two farmers who were identified as users of the same practice can apply it in different ways.
- Ownership of land is a crude measure of tenure and does not capture the various forms of land access that exist within Ghana. The distance to the extension office also measures physical distance but not whether or not the advice was actually sought.

Declarations

Ethics approval

Prior to the original survey ethical clearance was acquired from CSIR-Crops Research Institute Administration. The CSIR-Crops Research Institute administration approved the project and all its activities before the project was implemented. Though the Institute has not yet put in place an ethical standing committee, the project met all the institute's expectations, guidelines and ethics. The study was conducted in line with Ghana's Council for Scientific and Industrial Research Act, 1996 (Act 521) and the Data Protection Act, 2012 (Act 843).

Consent to Participate

Consent was obtained from participants prior to the interview process in two stages. First stage was at the start of the interview to determine whether the respondents was the right person to speak to. If yes, they were asked if they were willing to participate in the survey. It was only upon a “Yes” response that the interview was conducted. Anonymous identification codes were used for each participant rather than respondent's names or exact location in the analytical data set.

Clinical trial number: Not applicable.

Consent for publication

The manuscript presents aggregated results and does not include any personal participant data.

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Data availability

Ownership of the data used in this research is attributed to the Council for Scientific and Industrial Research–Crops Research Institute (CSIR-CRI), Ghana. Data could be made available upon request and in accordance with relevant data governance guidelines.

Competing interests

Authors declare there are no competing interests

Author contributions

NEA analyzed, interpreted, discussed and produced the first draft of this paper; AAA, BNF and JOA contributed to the analysis and discussion of the paper; LB contributed to data collection, cleaning provision of data summaries and PPA was team lead for the cassava data collection and source of the survey instrument

AI-assisted manuscript preparation

OpenAI ChatGPT was employed to assist with manuscript organization and language refinement. The authors have reviewed and are solely responsible for the empirical analysis, findings, references, conclusion and final manuscript.

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