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Ranchers' Attitudes toward Managing for Vegetation and Landscape Heterogeneity

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Abstract

Grasslands are imperiled due to land conversion, fragmentation, woody encroachment, population growth, and global warming. What remains of intact grasslands are vital for the ecosystem services they provide. Wildlife species native to the North American Great Plains evolved in response to very specific and differing habitats. Without variation in vegetation structure and composition (heterogeneity) the number of species that can thrive is minimized, as are the interconnected ecosystem services. Landowners' assistance in the maintenance of grassland ecosystems is essential because Great Plains grasslands are primarily privately managed. Thus, increasing heterogeneity on working rangelands is a partial solution to balancing the needs of wildlife with that of cattle production. This study tested a predictive model of factors influencing attitudes toward heterogeneous and landscape-scale ranch management. An online survey was sent to ranchers within prescribed-burn and grazing groups in the Great Plains. Predictors of landscape-scale management were spirituality, stewardship, social descriptive norms, consideration of future consequences, and participation in grassland activities. The lone predictor of attitudes toward heterogeneous grassland management was consideration of future consequences. Even though the survey targeted groups that were more likely to be higher in heterogeneous attitudes, a vast majority are still following the "manage to the middle" paradigm. It appears these ranchers are unaware of the benefits of a heterogeneous landscape and the compatibility of its associated management techniques with their cattle production goals. To improve the adoption of techniques that promote vegetation heterogeneity, more resources should be devoted to demonstrating how these practices benefit ranchers' cattle business alongside the larger landscape.

Keywords: grazing, grasslands, vegetation heterogeneity, biodiversity, conservation

1. Introduction

1.1 The Need for Heterogeneous Grasslands

Grasslands provide vital ecosystem services to human populations including providing critical wildlife habitat, yet they are the most threatened and least protected biome (Scholtz & Twidwell, 2022). Increasing pressure to convert grass to row-crop agriculture (Gage, Olimb, & Nelson, 2016) and encroaching trees and shrubs (Briggs et al., 2005; Ratajczak, Nippert, & Collins, 2012) jeopardize the services provided. Grasslands, particularly in the United States Great Plains, are primarily in private ownership, so it is imperative to reconcile the need for working rangelands with the need for functioning grasslands. This appears possible as researchers continue to explore how cattle grazing can be used to sustainably manage grasslands.

As a result of the decreasing volume of grasslands, the quality of those remaining is of growing importance. Attention is therefore being placed on vegetation heterogeneity. Heterogeneity, in rangeland science parlance, is a term illustrative of grassland health. According to Fuhlendorf and Engel (2001, p. 626), "heterogeneity is defined as variability in vegetation stature, composition, density, and biomass", and serves as the foundation of biodiversity, ecosystem resilience, and multifunctionality (Kolasa & Pickett, 1991; Ostfeld, Pickett, Shachak, & Likens, 1997). More simply put, borrowing a phrase from Diacon-Bolli, Holdereger, and Burgi (2012), "heterogeneity fosters biodiversity." Grassland species require very specific habitats which in turn requires plant diversity across the landscape, and without the variation in vegetation (heterogeneity) the number of species that can thrive on the land is minimized, as are the interconnected ecosystem services. To balance the needs of conservation with that of cattle production, a partial solution to preserving the vital ecosystem services provided by grasslands is increasing heterogeneity on working rangelands.

1.2 How Cattle Can Promote Heterogeneity

Blair, Nippert, and Briggs (2014) found that "grazers [domesticated and wild] promote heterogeneity in grasslands by selectively consuming some species while leaving others, through trampling, soil compaction, soil tunneling, and redistribution of nutrients" (p. 412). Freese, Fuhlendorf, and Kunkel (2014) also suggest that cattle grazing can be utilized to create vegetation heterogeneity, particularly when combined with patch fires. In their 11-year study comparing traditional fire and grazing management with "conservation-based management" (pyric-herbivory applied through patch burning), Limb, Fuhlendorf, Engle, Weir, and Elmore (2011) illustrated that pyric-herbivory does not require reduced stocking rate, deferment, or rest. In addition, the increase in forage quality after fire reduced feed costs. Other studies on this topic have found similar results. Concluding their study of grazing preferences and vegetation feedbacks, Powell, Martin, Dreitz, and Allreda (2018, p. 45) argue "… mixed-grass prairies are resilient to fire-grazing interactions and that rest from grazing following fire is likely ecologically unnecessary." They further assert pyric herbivory (fire-grazing interaction) as a suitable strategy for increasing the heterogeneity of grassland habitat. Similarly, Spiess et al. (2020) examined patch-burn grazing as a drought-resilient management tool and found that despite drought conditions, the "…burned patches maintained grazer attraction and that animal performance was maintained or improved…" (p. 473). While pyric-herbivory is but one management technique used to bolster heterogeneity, it is arguably the most important ecologically and innocuous to cattle enterprise.

Ideally, heterogeneous landscapes would be managed in large units—several hundred thousand hectares, according to Freese et al. (2014). This would allow for large expanses of intact habitat for native herbivores and the predators that rely on them. However, this is beyond the scope of most landowners financially and in terms of management. The existence of private property boundaries also confounds obtaining unfragmented habitat and there is a lack of large-scale management planning, as neighbors do not often collaborate on management strategies (Freese et al., 2014). Yet, some ranchers do acknowledge their land's place in the greater landscape (Belin et al., 2005; Sliwinski, Burbach, Powell, & Schacht, 2018; Kennedy & Burbach, 2020) and take the ecosystem into management consideration. Measuring this landscape-scale perspective alongside rancher attitudes toward managing for heterogeneity will help uncover potential partnership solutions going forward.

1.3 Past Research on Vegetation Heterogeneity

Studies of conservation social science, particularly those exploring farmer conservation behaviors, have not traditionally examined practices that promote vegetation heterogeneity, but rather best management practices (BMPs). It is therefore of interest to include heterogeneity inquiry in the study of grassland management. A majority of the research conducted on heterogeneity has been conducted in the field of rangeland ecology, where studies have put forth its importance for ecosystem health. However, a few studies have utilized a social-science perspective, examining the human dimensions of adopting heterogeneity-promoting measures (Becerra, Engle, Elmore, & Fuhlendorf, 2013; Joshi, Becerra, Engle, Fuhlendorf, & Elmore, 2017; Sliwinski et al., 2018).

Fuhlendorf, Engle, Elmore, Limb, and Bidwell (2012) explored the history behind the mainstream rangeland paradigm and asserted the need for change. They put forth that rangeland management as a discipline has promoted good care of the grass, not heterogeneity. This means that rangeland management courses and professionals have taught ranchers the take-half, leave-half philosophy that maintains an even landscape, which is not how grasslands naturally function and thrive. The decline in biodiversity then has been the result of teachings that put cattle production gains over the health of the ecosystem.

Fuhlendorf and Engle (2001) explained that grassland birds are in decline even with the *improvement* of rangeland conditions, which suggests that current management techniques may not be enough to ensure and maintain biological diversity. Along these lines, the definition of poor range condition is similar to what is needed for heterogeneity. Fuhlendorf et al. (2012) argue that this confirms the lack of importance of biodiversity within the profession and that the current approach to defining rangeland condition is insufficient in determining ecosystem health. They propose a paradigm that promotes the potential heterogeneity of landscapes through an alternate approach to managing rangelands—linking the goals of conservation biologists, ecologists, and rangeland managers. A more collaborative approach, such as this, takes biodiversity *and* productivity into consideration. This alternative paradigm aims to avoid equal distribution and disturbance on the range using fire and grazing to create some patchiness rather than the uniform outcome of "managing to the middle." However, alternative management paradigms such as this have not been adopted by producers en masse (Fuhlendorf et al., 2017; McGranahan et al., 2018; Sliwinski et al., 2018).

1.4 Study Purpose

This study aims to better understand sustainable rangeland management and beef production by testing a research-based model explaining attitudes toward heterogeneous and landscape-scale grassland management. An improved understanding of attitudes toward practices that promote heterogeneity can assist in overcoming barriers to their use by informing education measures and reshaping policies.

2. Methodology

2.1 Study Context

Research focusing on the human dimensions of heterogeneity has predominantly examined landscape preference (Becerra et al., 2013; Becerra et al., 2017; Joshi et al., 2017). While preference is beneficial in understanding some of the underlying factors regarding grassland management, this study delves into attitudes as they pertain to specific management techniques: those that promote heterogeneity.

2.2 Hypothesized Model

2.2.1 Dependent Variables

Regarding the management of heterogeneous landscapes, an article by Freese et al. (2014) put forth a framework of ten major ecological drivers for restoring and conserving biodiversity on Great Plains rangelands. They outline ten tenets to aid in this transition, calling them biodiversity-centered management practices (BCM). These practices include: maintaining or restoring diverse plant communities; allowing for patchiness; using prescribed fires and pyric herbivory; managing for natural stream flows; accepting high temporal ecological variability; allowing other grazing animals and predators on the land; minimizing fragmentation; and creating relatively large management units.

The caveat to this framework is that it was proposed for those whose primary land goal is conservation, while much of the remaining grasslands are working rangelands. Many of the tenets of the BCM framework are challenging to operationalize because of ranch size and the necessity of income generated from cattle production. As Kennedy and Burbach (2020) demonstrated, managing for biodiversity and cattle can be complementary, maybe just not at the scales put forth in the Freese et al. (2014) framework. To operationalize the BCM practices at the individual ranch scale, we reorganized the framework. Freese et al. (2014) state: *"*Of the ten BCM practices, we believe that five—managing for native vegetation and topographic conditions, heterogeneous grazing, patch fires, contiguous landscapes, and larger management units—will often have modest effects (negative or positive) on production and income for the livestock enterprise" (p. 363).

For this reason, we took the practices complementary to cattle production using the above suggestions of Freese et al. (2014) in addition to the alternative paradigm suggested by Fuhlendorf et al. (2012) and condensed the BCM tenets into the following categories:

1. Intact Grasslands with Native Vegetation
2. Grazing and Fire
3. Wildlife

As attitude is a moderator for behavior (Kraus, 1995; Glasman & Albarracín, 2006), if we are interested in the adoption of BCM practices, we must first ask: *how do those whose main goal is production, feel about BCM tenets?*

The second dependent variable in this model is attitude toward landscape-scale management. In their study of rural woodland landowners and their attitudes toward an ecosystem-based approach, Rickenbach et al. (1998) deconstructed the broad ideas of ecosystem-based management, dividing it into three measurable components. One component, landscape-scale, is the focus here. Landscape-scale perspective pertains to landowners' attitudes toward management at spatial scales larger than the individual parcel—or their view of how their property fits into the larger ecosystem. The authors reported that "several items indicated that respondents believed their land was part of something larger and their actions had impacts elsewhere" (Rickenbach et al., 1998, p. 21). Belin et al. (2005) replicated the use of these variables with a larger population of rural woodland landowners and found similar results. Similarly, Sliwinski et al. (2018) found that ranchers' attitude toward cross-boundary management (landscape-scale) was generally positive, which confirmed that ranchers realize they are not isolated on the landscape and that their management practices impact neighboring lands and vice versa.

Regarding measuring attitude, Belin et al. (2005) expressed that while favorable attitudes do not guarantee a behavioral outcome, they do imply uncertainty. This means that if the attitudes were unfavorable, adoption of the behavior (i.e. recommended management practice) would be unlikely. Belin et al. assert, "an improved understanding of these attitudes can assist managers in addressing landowner concerns and policymakers in reshaping programs to appeal to owners" (2005, p. 28).

This study surveyed ranchers regarding their attitudes toward practices that promote vegetation heterogeneity and landscape-scale management and specifically asked: are there factors that are predictive of heterogeneous landscape-scale grassland management?

2.3 Independent Variables

The following concepts have been gleaned from the literature as showing potential in the study of rancher conservation decisions and have been included as independent variables in the hypothesized model.

2.3.1 Sociodemographic and Grassland Management

Studies of conservation social science, particularly those exploring farmer conservation behaviors, have not traditionally examined the management of vegetation heterogeneity, but rather what motivates farmers to use BMPs. Several studies illustrate that there are few to no universal determinants of conservation behaviors among farmers (Prokopy, Floress, Klotthor-Weinkauf, & Baumgart-Getz, 2008; Knowler & Bradshaw, 2007; Barr & Cary, 2000). Reimer et al. (2014) noted that past studies on farmers' conservation adoption have observed a great deal of unexplained variation due to ignoring the broader context. Accordingly, questions of interest were added such as number of generations ranching, whether there was a succession plan in place, and inquired about additional sources of ranch income.

2.3.2 Consideration of Future Consequences

Strathman, Gleicher, Boninger, and Edwards' (1994) research focused on consideration of future consequences, examining the extent to which people take into consideration distant versus immediate consequences of their behaviors. Consideration of future consequences captures how much a person is driven by short-term rewards or how much an individual focuses on long-term goals (Bruderer Enzler, 2013). While most of the consideration of future consequences literature examines its relationship to various health-related decisions, research has found it can help predict people's pro-environmental behavior (Bruderer Enzler, 2013; Joireman, Lasane, Bennett, Richards, & Solaimani, 2001).

Studies of rancher conservation behaviors have not directly measured consideration of future consequences but have examined similar variables. In their study of conservation program participation and adaptive rangeland decision-making, Lubell et al. (2013) found that orientation toward the future (time horizon) was a significant factor in participation in conservation programs. Similarly, although not rancher specific, in their meta-analysis of time perspective and environmental engagement, Milfont, Wilson, and Diniz (2012) found that future time perspective appears to play an important role in influencing attitudes and behaviors towards the environment.

2.3.3 Stewardship and Spirituality

Along with studies by Didier and Brunson (2004) and Greiner et al. (2009), in their interview of Great Plains ranchers, Sliwinski et al. (2018) found that being viewed as a "good rancher" by their peers was important because they want to be considered good stewards. Similarly, research by Kennedy, Burbach, and Sliwinski (2016) and Kennedy and Burbach (2020) revealed that ranchers desire continuous management improvement to ensure future generations remain on the land. Some mention "doing as the Good Book says" or that "this land belongs to our Creator," thus one must take good care of it. Stewardship and spirituality will thus be included in this study.

2.3.4 Property Rights Orientation and Social Responsibility

Agricultural production and consequent environmental problems have gained increasing regulatory attention. According to Jackson-Smith, Kreuter, and Krannich, "The extension of habitat protection efforts under the federal Endangered Species Act has led to considerable controversy among private landowning constituencies throughout the country" (2005, p. 588). The idea of overstepping regulation can be seen as a threat to individual property rights. Jackson-Smith et al. (2005) surveyed ranchers in Texas and Utah to gain some insight into how ranchers viewed their property rights. Their study explored the impact different demographic variables had on property rights orientation. They found that property rights are multifaceted and inclusive of three dimensions: protection of *individual rights*, recognition of *social responsibility*, and *stewardship* obligations.

Another study by Kreuter, Nair, Jackson-Smith, Conner, and Johnston (2006) found mixed results in the correlation between willingness to adopt socially desirable rangeland management objectives such as noxious weed control, protecting water quality, protecting endangered species habitat, among others, and property rights orientation. Most of those surveyed felt obligated to be good stewards, but not because of social responsibility. This is similar to findings from Jackson-Smith et al. (2005) who found ranchers support environmental stewardship when it aligns with their moral values, rather than proper land management benefitting all of society. Research by Greiner et al. (2009) also found conservation adoption to align with values and attitudes.

2.3.5 Social and Personal Norms

Like the idea of social responsibility is that of social norms. Descriptive social norms describe what behaviors are 'normal' to a social group, while injunctive social norms are the perception of how others are expected to act (Cialdini, Reno, & Kallgren, 1990). So, to avoid social stigma, individuals act in a way that is seen as 'normal' to their social group or in ways that they assume others want them to act. Personal norms, on the other hand, are self-expectations, based upon feelings of moral obligation (Thogersen, 2006). Sliwinski et al. (2018) found social norms to be important predictors of attitudes toward prairie dogs in their study of rancher attitudes toward vegetation heterogeneity. Similarly, in a survey of beef cattle ranchers, Willcox, Giuliano, and Monroe (2012) examined intentions to consider wildlife management in routine cattle management activities and found that attitudes and subjective norms best explained rancher intentions.

2.3.6 Innovativeness

Kennedy et al. (2016) and Kennedy and Burbach (2020) illustrate that producers often look for ways to improve, including trying new things. They view ranching as an experiment, which takes a certain amount of innovativeness. Adoption of innovation in range management has been used as a dependent variable in research, such as the study of livestock operators by Didier and Brunson (2004), who found that innovation was related to ranching full-time, dependence on ranch income, anticipated future of the ranch, the extent of social networks, and a desire to illustrate stewardship. Or, it can be used as an independent variable like in the study of variables that influence the grazing strategy preference (Roche et al., 2015). Roche et al. (2015) found that variables associated with ranchers' grazing preferences included a combination of human dimensions (goal setting, views on experiment and risk tolerance, information networks). Whether used as an independent or dependent variable, the focus of innovativeness is the adoption of better range management practices.

2.3.7 Ranching Operation Activities Affecting Land Management

In a study of attitudes toward heterogeneity, Joshi et al. (2017) explored attitudinal and socio-demographic determinants impacting landscape preferences among the general population. The authors defined 'activity' as a level of engagement in prairie or grassland area activities. They hypothesize, "Since active involvement in educational, outreach, and other activities might help a respondent to know more about benefits associated with heterogeneous landscapes, we expected to have a positive relationship of this variable" (p. 927). This study, framed with Random Utility Theory, found population groups involved in local activities leaned toward heterogeneous landscapes (significant at the 5% level). However, contrary to expectations, those with higher levels of activity did not prefer the most heterogeneous landscape.

2.4 Questionnaire Design

Questions related to independent variables were pulled from existing instruments, which allowed minimal room for editing, whereas questions of dependent variables were original and had not yet been tested. The Bureau of Sociological Research (BOSR) assisted with improving the latter and demographic questions with adherence to principles of questionnaire design without altering the substantive content.

The final questionnaire retained 9 questions for independent variables, 46 questions for dependent variables, and 11 questions asking for demographics and other information of interest. Dependent variables were specific to attitudes toward BCM management practices (i.e., questions about grassland conversion, use of fire, use of fire in conjunction with grazing, other grazers, predators, etc.) and landscape-scale management. The independent variable questions measured 11 constructs including spirituality (Delaney, 2005), social and personal norms (Weir, 2012), property rights orientation (Jackson-Smith et al., 2005), consideration of future consequences (Joireman et al., 2001), innovativeness (Goldsmith, 1995), motivation (Greiner et al., 2009), and activities (Joshi et al., 2017).

2.5 Data Collection Process

In the early phase of data collection, ranchers, over 19 years old, of the National Grazinglands Coalition were invited to participate in this 15-minute-long online survey using Qualtrics. The National Grazinglands Coalition was selected due to the organization's mission to "Provide voluntary ecologically and economically sound management of all grazing lands for their adaptive uses and multiple benefits to the environment and society through science-based technical assistance, research and education". Ranchers, specifically those working toward ecologically sound management, were expected to have more favorable attitudes toward heterogeneous landscape-scale management. The first email invitation with a link to the online survey was sent to two listserv administrators of the National Grazinglands Coalition to help distribute this survey to their listserv. An email reminder was sent to the same two administrators two weeks later to ask for help with distributing the reminder email to the listserv. Due to the low response rate, a second email reminder was added and was sent to the listserv administrators two weeks after the first reminder email. Due to the lack of autonomic manipulation over the distribution of these recruitment communications where pre-planned times of distribution could not be guaranteed, and the shortage of sufficient responses, more rancher groups suspected of having members with favorable attitudes toward heterogeneous grassland and landscape-scale management were recruited. Eight more rancher groups agreed to participate including Independent Cattlemen, Centennial Valley Association, East Kansas Prescribed Burning Association, Tri-County Prescribed Burning Association, Sandhills Prescribed Burn Association, Oklahoma Grazinglands coalition, Mid-Missouri River Prescribed Burn Association, and Nebraska Prescribed Fire Council. These groups were selected because the use of fire is essential in creating a heterogeneous landscape. In addition, four potential respondents who had taken part in a prior case study as part of this project were contacted to participate in this survey. The original survey invitation along with the reminders was tailored to recruit the additional groups mentioned above on a rolling basis. All distributions of these recruiting materials were handled by their respective group administrator who oversaw their members' contact information. The researchers maintained contact with these distributors during the period of data collection (~6 weeks) to remind them to send out each recruitment material at the pre-scheduled time point.

2.5.1 Response Rate

Information regarding the exact number of ranchers on each group's contact list was not provided to either the researcher or BOSR and there was also no guarantee that all survey invitations and reminders had been sent out to each group by those distributors, therefore, it was not possible to calculate the final overall response rate because of a lack of key information. However, demographic data illustrates that study participants are representative of the ranching population. Among those who answered the age question, the average age was 57.6 years, and over four-fifths of the respondents were male (81.9%). According to the USDA Census of Agriculture (2012), the average age of a beef cattle rancher is 58 years. Eleven percent of ranches are operated by women.

2.5.2 Data Cleaning

BOSR deleted IP addresses from the dataset. Respondents that started the survey but did not answer all questions were removed from the dataset, ending up with a total of 189 responses including responses from two sources; the rancher groups managed by their "gatekeeper" who helped distribute the surveys and the case study participants. Frequency distributions were run on each of the variables in the survey. Out-of-range values on all survey items were checked. One invalid zip code was coded as a missing value.

2.5.3 Data Management

Eleven constructs, "spirituality", "social injunctive norms", "social norms", "personal norms", "rights", "stewardship", "social responsibility", "future consideration", "motivation", participation in grassland activities, and "innovativeness", used questions from existing instruments, but were placed in a grid using the same response scales. To ensure consistent statistical findings, variables in the model were standardized. According to Kwan and Chan (2011, p. 730), "Standardized data are affected less by the scales of measurement and can be used to compare the relative impact of variables that are incommensurable (i.e., measured in different units on the same/different scales)". This is a common practice in multiple regression analysis and SEM modeling. A mean score was then calculated for each observation. Questions for the other two constructs, "heterogeneous grassland management" and "landscape-scale management", were written by the researchers and went through internal pilot testing for face validity. These questions did not share the same response scales, which, therefore, made a summated score irrelevant. Principal axis factoring was conducted on all the items for each of these two constructs to identify items that had a low correlation with the factor. For "heterogeneous grassland management", four rounds of principal axis factoring were done to remove the clutter of low correlations (any correlations below 0.3) that were not likely to be meaningful. Eighteen items that had a less than 0.3 correlation with the factor were removed, leaving 26 items for the factor of "heterogeneous grassland management". The total amount of variance explained by this factor was 22.43%.

Likewise, a principal axis factoring was conducted with the eight items for "landscape-scale management" which singled out one item that had a less than 0.3 correlation with the factor. The total variance explained by this factor was 34.62%.

2.6 Model

Structural equation modeling was employed to test the regression equations simultaneously. In the original model (Figure 1), "norms" and "property rights" variables were set as latent variables. Based on the theory detailed in the literature review, given that social norms and property rights each is an umbrella consisting of three facets, the variable "norms" is assumed to cause the scores observed on the measured variables "personal norms", "social injunctive norms", and "descriptive norms". The variable "property rights" is assumed to cause the scores observed on the measured variables "rights," "stewardship," and "social responsibility." Factor loading of "social norms" on "personal norms" was fixed to 1, and the factor loading of "property rights" on "rights" was also fixed to 1. Variables "heterogeneous grassland management" and "landscape-scale management" were allowed to covary and were regressed on "spirituality", "norms", "property rights", "consideration of future consequence", "innovativeness", "motivation", and "activity". Cases with missing data were excluded from the statistical analysis through listwise deletion of cases.

Mplus output indicated that a negative error covariance estimate for measured variables was obtained where the high correlation (r=.645) between "personal norms" and "social injunctive norms" was found to be the cause.

According to Hu and Bentler (1999), RMSEA values below .06 and Tucker-Lewis Index values of .95 or higher are recommended. The chi-square statistic of absolute model fit along with various descriptive model fit indices indicated that the model did not fit the data well: $\chi^2(57)$ =223.997, p<.0001; CFI = .379, TLI = .260, RMSEA = .145, p<.001. A model modification was needed to obtain a better-fitting model.

2.7 Model Modification

In the modified model (Figure 2), the latent variable "norms" and "property rights" were removed from the model while the six facets "personal norm," "social injunctive norm," "descriptive norm," "rights," "stewardship," and "social responsibility" were treated as exogenous variables. Thus, all endogenous and exogenous variables were assumed to be observed variables.

Since the models in question are nested models where a chi-square difference test is meaningful, altering the structural component of the model resulted in a significant increase in model fit, with a difference of 183.772 ($\chi^2{}_{diff} = \chi^2{}_{old} - \chi^2{}_{modified}$), degree of freedom =23 ($df_{diff} = df_{old} - df_{modified}$), p<.01. After making the modifications mentioned above, the chi-square value of 40.225 with 34 degrees of freedom is non-significant at the .05 level: its p-value is .214. This finding suggests the model fits the data acceptably in the population from which the researchers drew their sample. Corroborating evidence is provided by the RMSEA fit statistic – the obtained value of .036 is well below the desired .06 cutoff. Similarly, the Tucker-Lewis Index result of .960 is above the .95 threshold denoting a satisfactory model fit.

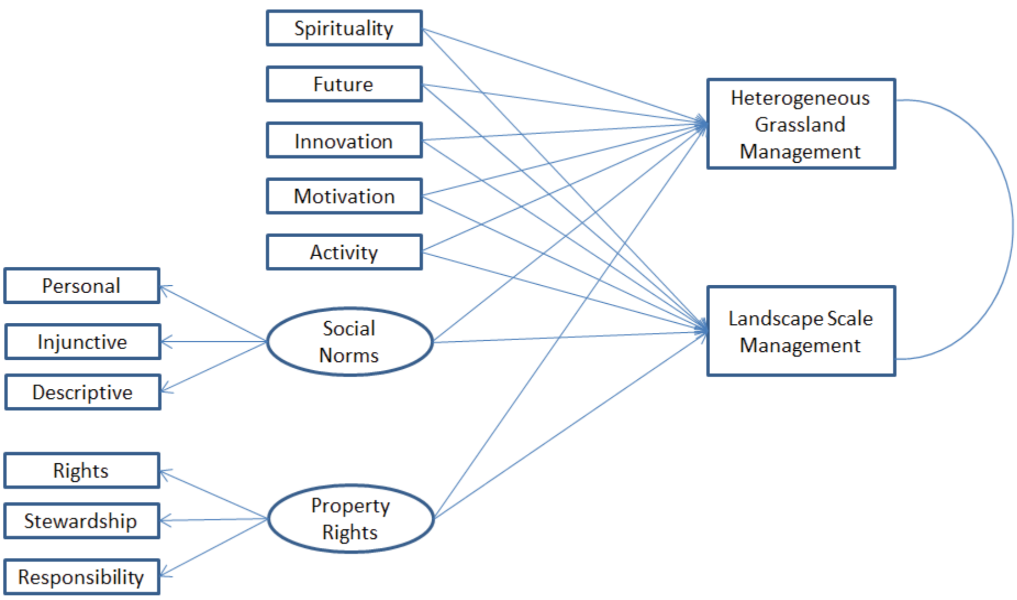

Figure 1. SEM model with latent variables

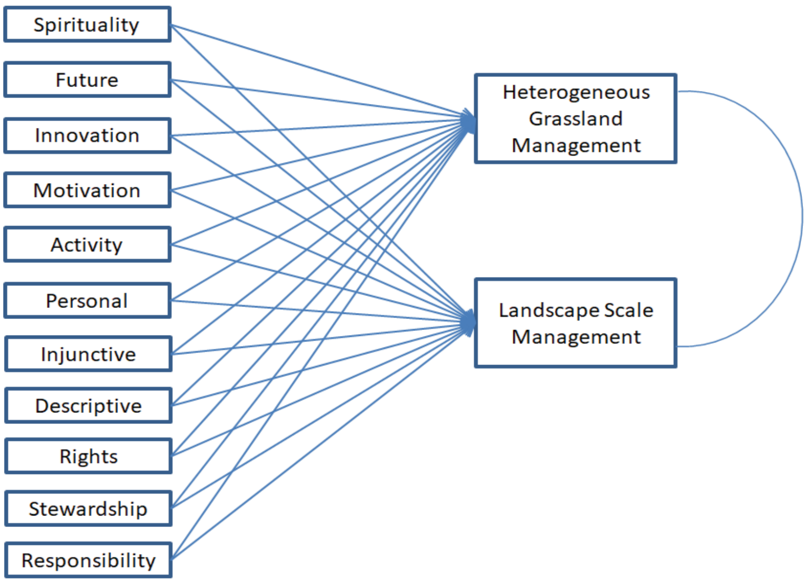

Figure 2. Modified model – multivariate multiple regression

3. Results

3.1 Demographic Information

More than half of the participating ranchers strongly agreed or agreed that they are dependent on the ranch as a source of income (55.1%). About two-fifths (38.2%) of ranchers indicated their great-grandparents were ranchers; one-fifth (20.6%) had great-great-grandparents as ranchers, and a similar rate are first-generation ranchers (18.4%). Three-quarters (77%) either have a succession plan in place or in progress. The majority of ranchers who answered this set of questions have extractive recreation businesses, such as hunting or fishing, that affect land management (64.7%), with other agricultural production enterprises (58.1%) as the second most common facet in their ranching operation (Figure 3). Over four-fifths of the ranchers were male (81.9%). There was an equal number of respondents aged 46 to 64 years old and 65-80 years old (38.5% each).

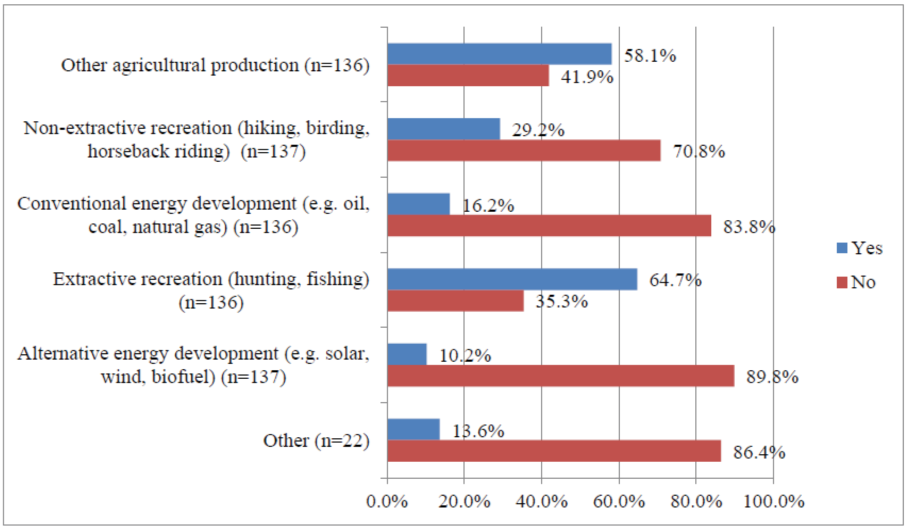

Figure 3. Activities as part of the ranching operation that affect land management

3.2 Other Questions of Interest

While fire was the BCM practice highlighted throughout this study, an important first step in grassland conservation is to leave them intact. Therefore, we asked about respondents' perception of converting grazinglands (grasslands) to croplands. More than two-thirds (68.5%) of ranchers who answered this question perceived converting their grazinglands to croplands for agricultural profits as detrimental or very detrimental

(Figure 4). We also asked if they feel financial pressure to convert grazingland to cropland and if financial incentives are important in that decision. While a vast majority of ranchers reported not feeling pressured (80.5%) to convert their grazinglands to croplands, one-fifth (19.5%) were pressured "a little" to "a lot" (Figure 5). About three-quarters of respondents (74.8%) considered financial incentives (e.g., crop insurance, subsidies) as somewhat unimportant or very unimportant in making decisions to convert grazinglands to croplands.

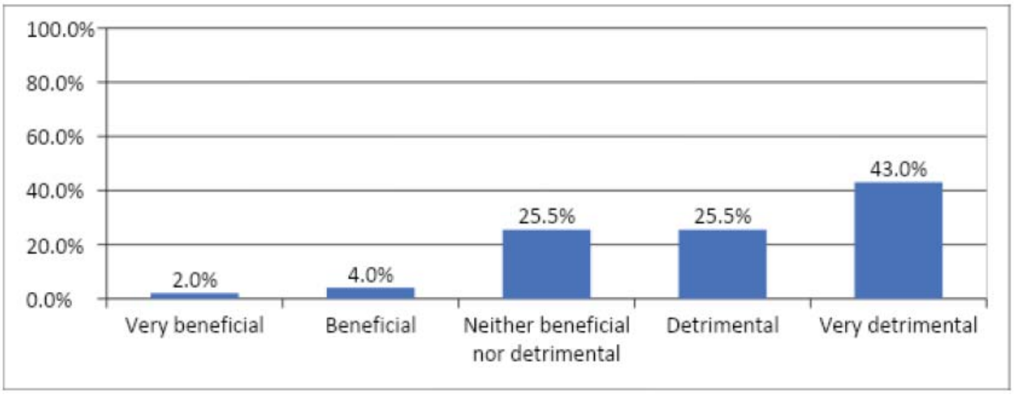

Figure 4. Perception of converting grazinglands to croplands (n = 149)

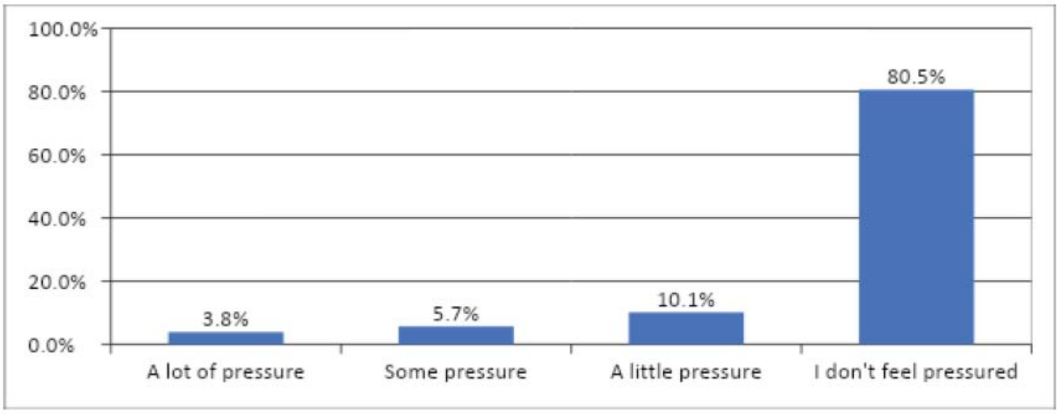

Figure 5. Financial pressure to convert grazinglands to croplands (n = 159)

Descriptive statistics and correlations

Descriptive statistics and Pearson correlations provided the initial basis of analysis for the variables. Results are presented in Table 1.

Table 1. Descriptive statistics and correlations among variables

Variable	Mn	SD	1	2	3	4	5	6	7	8	9	10	11	12
1. Heterogeneous grassland management	86.83	12.05												
2. Landscape-scale management	14.46	3.87	0.539**											
3. Spirituality	20.53	8.59	0.135	0.468**										
4. Social injunctive norm	6.67	2.73	0.028	0.10	0.213*									
5. Social descriptive norm	8.11	2.39	-0.153	-0.127	0.156	0.276**								
6. Personal norm	5.62		0.081	0.117	0.094	0.643**	-0.071							
7. Rights	5.46	1.42	0.278**	0.182*	0.176*	0.008	-0.061	0.040						
8. Stewardship	3.43	1.44	0.258**	0.277**	0.207*	0.097	0.021	0.036	0.364**					
9. Social responsibility	6.36	2.72	-0.243**	-0.156	-0.023	0.115	0.180*	0.014	-0.338**	-0.129				
10. Future consideration	16.22	5.79	0.315**	0.489**	0.47**	0.033	-0.011	0.059	0.146	0.025	-0.078			
11. Motivation	20.35	5.82	0.175	0.404**	0.410**	0.066	0.055	0.037	-0.09	0.287**	0.034	0.326**		
12.Innovativeness	26.01	4.87	0.216	0.425**	0.381**	0.116	0.108	-0.087	0.025	0.014	-0.028	0.467**	0.305**	
13. Activity affecting management	1.67	0.85	0.202	0.312**	0.046	0.251**	0.031	0.079	0.077	0.119	0.010	0.075	0.134	0.266**

*p < 0.05; **p < 0.01. Note: Smaller means suggest higher levels in each variable.

3.3 Predictor Variables and Heterogeneous Grassland Management

Consistent with expectations, ranchers with a stronger tendency to "consider future consequences" (B=.214, Z=.105) are likely to have a positive attitude regarding heterogeneous grassland management, which is significant at $p<.05$ (Table 2). The were no other significant relationships between the predictor variables and heterogenous grassland management.

3.4 Predictor Variables and Landscape-scale Management

Ranchers with a higher level of "spirituality" (B=.234, Z=.078) are likely to hold a positive attitude towards landscape-scale management (significant at $p < .01$) (Table 2). Ranchers with a higher level of "stewardship" (B=.170, Z=.070) are likely to have a positive attitude towards landscape-scale management (significant at $p < .05$). Those with a higher level of "social descriptive norm" (B=-.161, Z=.070) are significantly more likely to have a negative opinion on landscape-scale management ($p < .05$).

In addition, ranchers who have more "consideration for future consequences" (B=.237, Z=.080) are significantly more likely to have a positive opinion on landscape-scale management ($p < .01$). Those who are more actively involved in activities on grassland or prairie (B=.232, Z=.069) are significantly more likely to have a positive opinion on landscape-scale management ($p < .01$). Ranchers who are more open to innovation (B=.172, Z=.076) are significantly more likely to have a positive opinion ($p < .05$).

Table 2. Results of Multivariate Multiple Regression

Heterogeneous grassland management on	Estimate (Standardized)	SE (Standardized)
Spirituality	-0.063	0.109
Personal norm	0.064	0.125
Social injunctive norm	-0.012	0.140
Social descriptive norm	-0.115	0.095
Consideration for future consequence	0.214*	0.105
Innovativeness	0.119	0.106
Activity	0.085	0.109
Motivation	0.017	0.108
Rights	0.124	0.094
Stewardship	0.159	0.099
Social responsibility	-0.097	0.090
Landscape-scale management on	Estimate (Standardized)	SE (Standardized)
Spirituality	0.234**	0.078
Personal norm	0.114	0.091
Social injunctive norm	-0.090	0.099
Social descriptive norm	-0.161*	0.070
Consideration for future consequence	0.237**	0.080
Innovativeness	0.172*	0.076
Activity	0.232**	0.069
Motivation	0.101	0.075
Rights	-0.020	0.070
Stewardship	0.170*	0.070
Social responsibility	-0.063	0.067
Factor covariance		
Heterogeneous grassland management with landscape-scale management	0.397***	0.079
Model fit indices		
X2	32.362	
AIC	4559.575 (df=34)	
BIC	4774.399	
R-Squared		
Heterogeneous grassland management	0.176**	0.058
Landscape-scale management	0.472***	0.058

Note. SE = standard error. *p < .05; ** p < .01; ***p < .001

4. Discussion

While the model fit is satisfactory for the population, there are some interesting things to note. Contrary to what was expected, those with a higher level of "social responsibility" are likely to have a negative opinion of landscape-scale management. While this seems counterintuitive, it corresponds with previous studies of property rights orientation (Kreuter et al., 2006; Jackson-Smith et al., 2005), where most of those ranchers surveyed felt obligated to be good stewards not because of social responsibility (benefit to society), but because it aligns with their moral values. Similarly, those with a higher level of "social injunctive norm" are more likely to have a negative opinion of landscape-scale management. This may relate to the idea that they manage their rangelands in specific ways not because others do it, but because it ought to be that way. Those with a higher level of "descriptive norm" were also significantly more likely to have a negative opinion of landscape-scale management. The less their neighbors, friends, and family act in the rangelands' best interests the lower their attitude toward landscape-scale management. Ranchers' attitudes toward landscape-scale management not only reflected a concern with their ranches and the more extensive natural system, but also the importance that their land has relative to other ranches—providing important habitat and benefiting society. This illustrates the complexity of rancher ideals.

One of the most noteworthy findings from this study is the general lack of acceptance of BCM techniques. While predictors accounted for approximately 47% of the variation found within attitudes toward landscape-scale management, they accounted for only 17.6% of the variation in attitudes toward heterogeneous grassland management. Interestingly, even though the survey targeted prescribed burn associations, only half (49.5%) of those who responded currently manage their grazinglands using prescribed fire. However, three-quarters of participants responded that they are very—or somewhat likely to use prescribed fire in the future. This was similar to the percentage of respondents that considered the use of fire on their grazinglands as beneficial (77.7%). Pyric herbivory—grazing within a few weeks after fire—was *not* utilized by a majority of those who responded (67.3%). Approximately half (49.4%) of those surveyed were likely to consider grazing within a few weeks after fire in the future, while only 30% considered pyric-herbivory as beneficial to their grazinglands.

There appears to be many ranchers who still follow the "manage to the middle" paradigm. Examining the descriptive data, it is the objective of 84.9% of those who responded to achieve an even distribution of grazing animals, and the objective of 80.7% to achieve even use of all grass plants. When asked how beneficial or detrimental they viewed patchy grazing on their grazinglands, the results were split: approximately 37% found it very beneficial or beneficial, 35% found it detrimental or very detrimental and 27% found it neither beneficial nor detrimental. However, approximately 81% of those who answered would consider managing for uneven use of grasses, if they wouldn't lose production per acre.

A majority of ranchers who participated in this survey currently manage their grazinglands to favor native grasses (92.6%), considering native forage species very important to their grazing operation (74.1%). Almost all of them control invasive species (92.5%), considering them detrimental to their operation (87%). A majority (95%) of ranchers who participated in this study have not converted any of their grassland to cropland in the last ten years and are not at all likely to do so in the future (70.4%). More than two-thirds (68.5%) of ranchers who answered this question considered converting their grazinglands to croplands for agricultural profits as detrimental or very detrimental. About three-quarters of respondents (74.8%) who answered this question considered financial incentives (e.g., crop insurance, subsidies) as somewhat unimportant or very unimportant in making decisions to convert grazinglands to croplands. Using all this information to paint a broad picture: ranchers are not interested in converting their grasslands to croplands and do not feel financially pressured to do so. They prefer native forage species and control for invasives.

This model is a starting point for the exploration of attitudes toward specific rangeland management practices. Other potentially important variables such as ranch size, production types, and management goals should be considered in future research to help further explain managing for vegetation and landscape heterogeneity.

5. Conclusion

It appears the ranchers who participated in this study are unaware of the benefits of a heterogeneous landscape and the compatibility of its associated management techniques with their cattle production goals, despite being members of progressive grazing and prescribed burn groups. This supports other studies, which note that the paradigm shift of rangeland ecology professionals to focus on heterogeneity has not made its way to producers (e.g., Fuhlendorf et al., 2017; McGranahan et al., 2018; Sliwinski et al., 2018). Those making management recommendations should consider these findings and plea to individual values and utilize trusted community leaders as exemplars. If one's neighbors are utilizing BCM practices and receiving positive results, the conversion of others may be easier.

While the great expanses of national parks and private conservation areas are an important part of conserving grassland ecosystems, the part of private landowners is also crucial. The balance of cattle production and grassland conservation must be considered when recommending management practices. Managing grass sustainably is understood to help the longevity and profitability of a ranch, especially with regard to running a multigenerational business (Kennedy & Burbach, 2020). Changing practices requires awareness and evaluation of available choices. To improve the adoption of techniques that promote vegetation heterogeneity, more resources should be devoted to demonstrating how these practices benefit ranchers' cattle business alongside the larger landscape.

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Epidemic Pressure of Cassava Mosaic and Brown Streak Diseases on Ten Exotic Cassava (*Manihot esculenta* Crantz) Cultivars in Kisangani, DRC

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Abstract

The crucial obstacle to cassava production in most of African countries is the diseases and pests. The present study assessed in field the epidemic pressure of Cassava mosaic disease (CMD) and Cassava brown streak disease (CBSD) on 10 exotic cassava genotypes in Kisangani. To assess the disease impact, trials were established in two sites in Kisangani, Tshopo Province in DRC. The experiment was laid out in randomized completed block design and thrice replicated. Sixty stem cuttings per variety were planted in a plot of 7 rows each measuring 25 m long. Results showed a relatively important CBSD pressure on all the ten exotic cassava genotypes tested (incidence close 60%, severity score 2 and 3.5 whiteflies/plant) and low CMD pressure (incidence 3.3%, severity score 2 and 3.5 whiteflies/plant). CMD remained relatively negligible depending on low symptom manifestation of the tested genotypes. Whitefly population varied according to the genotype and the crop age. The most abundant population was recorded on cultivar 'Mayombe' (17 whiteflies/plant). A negative relationship was statistically established between the abundance of whiteflies and the incidence and severity as well as for CBSD and for CMD. The production in terms of percentage of marketable tubers was (74.9%) for cultivar 'Mayombe', (70.3%) for 'Obama 1', (69.9%) for 'Obama 2' and (65.3%) for 'Ngandajika'. CBSD resulted in variable yield loss on all cultivars tested. The cultivar 'Butamu' (85%) recorded the highest loss rate, followed by the cultivar 'Mvuama' (70.8%) and 'Muzuri' (64.3%). The yield in cassava tubers was destroyed (< 5 t/ha) by large necrotic spots of the brown streak in the pulp. This loss is due to the depressive of viral pandemia pressure on the output of ten exotic cassava cultivars studied in Kisangani. Our study highlighted that the best moment of harvesting cassava in Kisangani is 9 MAP, this moment would be ideal to minimize harvesting losses due to CBSD root necrosis.

Keywords: epidemic pressure, Cassava brown streak disease, Cassava mosaic disease, Kisangani

1. Introduction

The importance of cassava (*Manihot esculenta* Crantz) in Africa cannot be underestimated as it is considered a resilient crop, urban and rural staple food and an industrial raw material (Nweke *et al*., 2002). Cassava roots provide 500 cal/day of food to over 70 million people (Chavez *et al*., 2005).

Cassava is widely consumed in Sub-Saharan Africa and parts of Asia. Nigeria is the world's largest producer of cassava with an estimated production of about 37 million tons (FAOSTAT, 2019). In Democratic Republic of Congo (DRC), the crop is grown on 50% of cultivated land with an output of 15 million tons (FAOSTAT, 2019). The crucial obstacle to cassava production in most of African countries is the diseases and pests. One of the most important is Cassava mosaic disease (CMD) caused by the single stranded DNA viruses in the family *Geminiviridae* , genus *Begomovirus* (Fauquet *et al*., 2005) and the Cassava brown streak disease (CBSD) caused by the single stranded RNA viruses in the family *Potyviridae*, genus *Ipomovirus* (Mbanzibwa *et al*., 2009; 2011).

These diseases severely attack local and improved cultivars of cassava causing characteristic severe distortion, leaf stunting almost on the entire plant and root necrosis (Bakelana *et al*. 2018; Sing'ombe *et al*., 2015). According to Otim-Nape *et al*. (1994); Thresh *et al*. (1994); Hahn *et al*. (1989), CMD caused losses of 20-95% of cassava production in various parts of the world.

In DRC, these viral pandemics affect production of cassava in the major cassava growing of Eastern region (Muhindo *et al*., 2020b; Casinga *et al*., 2018; Mulimbi *et al*., 2012; Monde *et al*., 2010). The characterized CMD viruses worldwide are nine with seven of them reported from Sub-Saharan Africa (Alabi *et al*., 2011). They include EACMV, ACMV, EACMCV (Fondong *et al*., 2000) EACMKV (Bull *et al*., 2006), EACMZV (Maruthi *et al*., 2004), EACMMV (Zhou *et al*., 1998), and the SACMV (Berrie *et al*., 1998).

For CBSD, two viruses have been characterized in East and Central Africa including CBSV and UCBSV (Mbanzibwa *et al*., 2009; Winter *et al*., 2010). It is known that Cassava mosaic begomoviruses (CMBs) and Cassava brown streak ipomoviruses (CBSIs) are vectored by whiteflies, *Bemisia tabaci* (Njoroge *et al*., 2017; Tocko-Marabena *et al*., 2017; Legg *et al*., 2011) and spread by infected cuttings that are routinely used by farmers (Sing'ombe *et al*., 2015). There are many methods of controlling plant pest and disease pathogens which include chemical application, use of biological control, phytosanitation and utilization of resistant varieties.

In DRC no studies have been done on the CBSD epidemic pressure of cassava improved cultivars under field conditions using sensitive diagnostic tools. The aim was to assess the impact of CMD and CBSD on exotic cassava cultivars while determining the density of whitefly vectors of the viruses. Thus, this study not only contributed knowledge on these issues but also is important for virus indexing to avail to breeders clean materials for further breeding efforts.

2. Materials and Methods

2.1 Experimental Site

Trials were established (from July 2017 to October 2018) in two sites in Kisangani Tshopo Province in DRC. One in Cimestan area (Latitude N 0°29'56.5", Longitude E 25°15'05.4", Altitude 408 m) and other in Lindi area (Latitude N 0°29'56.5", Longitude E 25°15'05.4", Altitude 405 m) in Kisangani. Kisangani is located at an altitude of 405 m above sea level (masl). It receives mean annual rainfall of 1500 mm and mean annual temperature of 27.6°C and the soil of Kisangani is a sandy-clay soil type (Lokinda *et al*., 2018).

2.2 Experimental Methods

The experiment (Figure 1) was laid out in randomized completed block design and thrice replicated. Sixty stem cuttings (two per place) per variety were planted (in horizontal position) in a plot of 7 rows each measuring 25 m long. There was a spacing of 1 m between rows and 1 m within rows. A plot of 105 plants represented one variety. Ten cassava exotic cultivars (Table 1) were indexed CMD and CBSD free by PCR. Plots were separated by 1.5 m and kept weed-free.

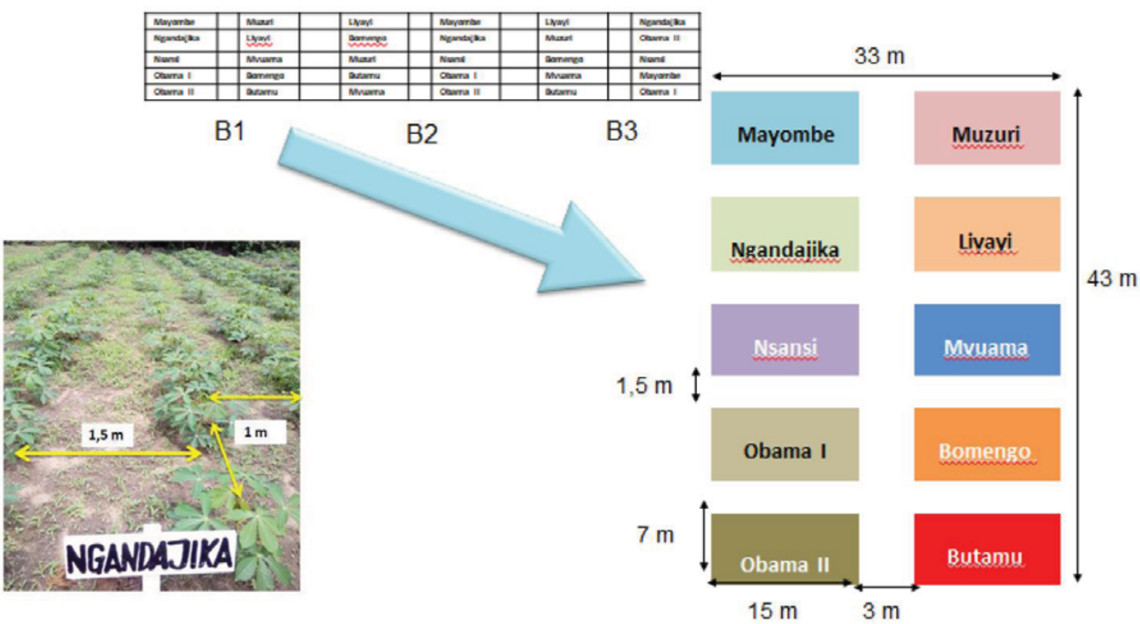

Figure 1. Representation of the experimental design by plot and bloc

Table 1. General characteristics of the ten exotic cassava cultivars (IITA, 2019)

No	Cultivars	Code	Resistance		Pulp	Yield (t/ha)	
			CBSD	CMD		On Station	Off station
1	Bomengo	M98/115	-	+	White	30-40	25-35
2	Butamu	MV 99/0395	-	+	Yellow	25-40	10-20
3	Liyayi	MM96/0287	-	+	Yellow	35	18
4	Mayombe	MM96/8353	-	+	Yellow	30-40	12-15
5	Muzuri	2006/073	-	+	Yellow	30-40	25-35
6	Mvuama	83/138	-	+	Yellow	25	15
7	Ngandajika	MV99/150	-	+	White	NA	NA
8	Nsansi	I95/0160	-	+	White	25-40	15-25
9	Obama1	TME419	-	+	White	45	20-30
10	Obama2	MV/2001/014	-	+	White	45	20-30

Legend: - : Susceptible to CBSD +: Resistant to CMD NA: Not applicable

2.2.1 Cassava Leaf Symptom Assessment

Three cassava plants from each variety were randomly selected within each plot and tagged for data collection. The CMD and CBSD leaf severity was recorded from 3 to 9 months after planting (MAP) using scale described in table 2.

Table 2. Diseases rating and corresponding symptom expression of Cassava mosaic disease (CMD) and Cassava brown streak disease (CBSD)

Rating	**CMD Symptoms** (Hahn *et al*., 1980)
1	No visible symptoms
2	Mild chlorotic pattern on entire leaflets or mild distortion at base of leaflets
3	Strong mosaic pattern on entire leaf, and narrowing cum distortion of one-third leaflet
4	Severe mosaic distortion of two-thirds of leaflets and general reduction in leaf size
5	Severe mosaic distortion of four fifths or more leaflets, twisted and misshapen leaves
	CBSD Foliar Symptoms (Alicai *et al*., 2016)
1	No visible symptoms
2	Slight symptoms on lower leaves, no lesion on the stem;
3	Foliar chlorosis, mean lesions, no Die-back;
4	Foliar chlorosis and marked lesions on the stem, no Die-back;
5	Defoliation with lesions on the stem and pronounced Die-back.
	CBSD Root Symptom (Bakelana *et al*., 2018)
1	No visible symptoms
2	Less than 5% necrotic tissue;
3	5-10% necrotic tissue;
4	10-50% necrotic tissue;
5	More than 50% necrotic tissue.

2.2.2 Disease Incidence

The CMD and CBSD incidence corresponds to the ratio of the number of plants displaying the disease symptoms on the total inspected plants (Toualy *et al*., 2014). This incidence is obtained by the following mathematical relation (Equation 1):

$$\text{Incidence (\%)} = \frac{\text{Total nomber of plants with disease symptoms}}{\text{Total nomber of observed plants}} \text{ x } 100 \quad (1)$$

2.2.3 Whitefly Survey

Adult whitefly populations in the tagged plants were counted on the five topmost leaves (Ariyo *et al*., 2005) of each plant of the various cassava genotypes from 3 to 9 MAP (Sseruwagi *et al*., 2004).

2.2.4 Cassava Root Symptom Assessment

To make sure of the presence or absence of CBSD root necrosis, three plants per genotype were uprooted. The entire roots were transversally dissected in five sections using a knife to determine the CBSD necrosis evolution. This cassava tubers CBSD severity was recorded from 12 to 14 MAP using the scoring scale of 1-5 (Table 2).

2.3 Evaluation of Yield and Root Loss

The roots of the three plants harvested per variety (Masinde *et al*., 2016) were weighed (kg) and the yield (t/ha) per variety computed using formula (Equations 2 and 3):

$$\text{Yield}\left(\frac{\text{t}}{\text{ha}}\right)\text{per variety} = \frac{Weight\ (kg)\text{x}\ 10{,}000\ m^2}{1m^2\text{x}\ 1{,}000\ kg} \quad (2)$$

The root loss (%) per variety was computed as shown below

$$\text{Loss (\%)per variety} = \frac{Total\ Root\ Weight\ (kg) - Weight\ of\ Marketable\ Root\ (kg)}{Total\ Root\ Weight\ (kg)}\text{X100} \quad (3)$$

2.4 Statistical Analyses

The data were entered into the Excel spreadsheet. Analysis of variance (ANOVA), frequencies, means, percentages, and Pearson correlations were performed using R software version 4.4.0 (R Core Team, 2020). Multiple comparisons of means by Tukey's test were performed.

3. Results

3.1 Diseases Incidence and Severity

Field incidence and severity of CBSD and CMD from 3 to 11 months after plantation (MAP) expressed by 10 exotic cassava cultivars are showed in table 3. With respect to CBSD, the cultivars 'Mayombe', 'Mvuama' and 'Nsansi', did not show symptoms on the leaves. Up to 5 MAP, no CBSD foliar symptom was visible on tested cassava plant. CBSD symptoms started to appear at 6 MAP and became severe from 7 MAP varied among cultivars. At 7 MAP, the incidence reached 100% for the cultivars 'Bomengo' and 'Muzuri' whereas it was null on cultivars 'Mvuama' and 'Nsansi' (Table 3).

Likewise, severity of CBSD foliar symptoms has significantly varied by cultivars from score 1 to 4 (F pr.<0.001). High severity rates started to be observed from 6 MAP and reached score 3 to 4 for cultivars 'Muzuri' and 'Obama 2' respectively, starting from 11 MAP. Whereas, for cultivars: 'Bomengo', 'Butamu', 'Liyayi', 'Ngandajika' and 'Obama 1', severity remained of level 2 (Table 3).

The incidence and severity of CMD was 3.3% and score 2 from two cultivars 'Obama 2' and 'Bomengo' at 6 MAP and 8 MAP respectively (Table 3).

3.2 Aleurodes Densities

The number of adult whitefly per plant has sensibly varied within cassava cultivars tested during the plant cycle. The cultivar 'Liyayi' has carried 11 whiteflies per plant at 3 MAP followed by cultivar 'Muzuri' (10 whiteflies per plant) and 'Ngandajika' and 'Nsansi' (8 whiteflies per plant). On the other hand, the cultivar 'Mvuama' did not attract any whitefly at 3 MAP. At 8 MAP, the cultivar 'Mayombe' carried 17 whiteflies per plant followed by cultivar 'Bomengo' (7 whiteflies). Globally, whiteflies abundance decreased with the age of cassava. From 9 MAP, whiteflies were not visible any more on the plants of all the cultivars (Table 4).

Regarding the number of whiteflies per plant (Table 4), it is noted that the cultivar 'Mayombe' the most attracted whiteflies (on average 6 whiteflies per plant) and followed by 'Nsansi' (3 whiteflies per plant) whereas the cultivar 'Mvuama' almost did not attract whiteflies during the culture.

3.3 CBSD Severity Effect on the Yield of Ten Cassava Cultivars

The production in terms of number of marketable tubers per cultivar show that the cultivar 'Mayombe' produced 11 and 12 marketable tubers (in Cimestan and Lindi respectively) followed by the cultivar 'Obama 2' (8.4 and 10.2 tubers in Cimestan and Lindi) and the cultivar 'Obama 1' (7.8 and 8 tubers) (Table 5).

Production expressed as a percentage of the marketable tubers was highest in cultivar 'Mayombe' (74.5 and 75.3%) followed by the cultivar 'Obama 1' (68.3 and 72.3%), cultivar 'Obama 2' (68.8 and 71.1%) and cultivar 'Ngandajika' (65.2 and 65.3%) in Lindi and Cimestan respectively (Table 5, Figure 3).

Concerning yield loss, cultivar 'Butamu' recorded the highest percentage loss (83.3 and 86.7%) followed the cultivar 'Mvuama' (66.7 and 75%) and the cultivar 'Muzuri' (61.8 and 66.7%) in Cimestan and Lindi respectively (Table 5).

3.4 Correlation between Diseases Incidence and Severity, Aleurodes Density and Yield Parameters

A positive correlation is recorded between the CBSD root necroses severity and the weight of one root in a tuft (WRt) (r = 0.21), the weight of one marketable root in a tuft (WMRt) (r = 0.20), the marketable root yield (MRY) (r = 0.18), the total root yield (TRY) (r = 0.17) and the percentage of the marketable roots (PMR) (r = 0.15) (Figure 2.A).

The CBSD necroses severity for major roots (marketable and non-marketable) has reached score 4 at 14 MAP (Figure 1.C) and significantly reduced the output (< 5t/ha) of these cultivar roots (marketable and nonmarketable) from 12 to 14 MAP (Figure 2.B and D, Figure 3).

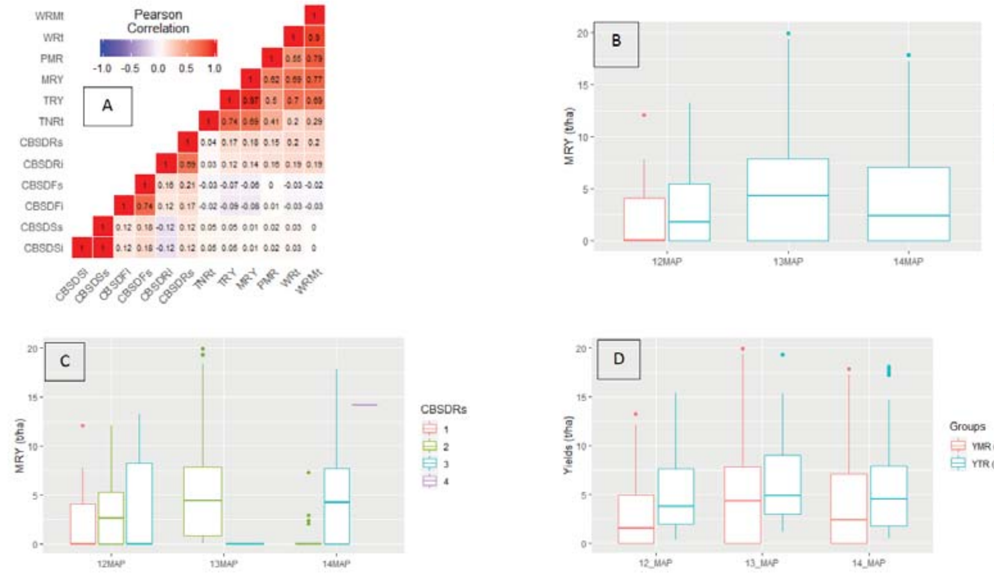

Figure 2. A= Pearson correlation between CBSD incidence, severity (foliar, stem, and root) of ten exotic cassava cultivars and B = Box-Plots of CBSD incidence from 12 MAP to 14 MAP and cassava tuber yield; C = Box-Plots of CBSD severity from 12 MAP to 14 MAP and cassava tuber yield; D = Box-Plot total yield and marketable roots from 12 MAP to 14 MAP

Note: Pearson correlation for CBSDfs: CBSD Foliar severity (1-5); CBSDfi: CBSD Foliar incidence (%); CBSDss: CBSD Stem severity (1-5); CBSDsi: CBSD Stem incidence (%); CBSDrs: CBSD root severity (1-5); CBSDri: CBSD Root incidence (%); TRY: Total Root Yield (tonne/ha); MRY: Marketable Root Yield (tonne/ha); PMR: Percentage of Marketable Root (%); WRt: Weight of one Root in a tuff (kg/tuff); WRMt: Weight of a Marketable Root in a tuff (kg/tuff); TNRt: Total number of root per tuff.

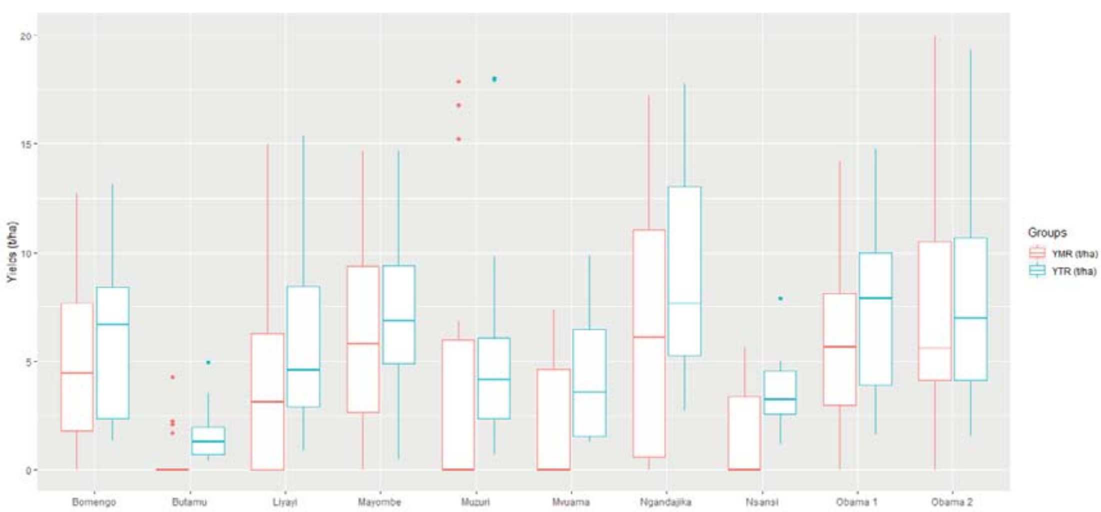

Figure 3. Box-Plot for total yield and marketable cassava roots per variety from 12 MAP to 14 MAP and cassava tuber yield

3.5 Discussion

Results from this study showed that all the ten cassava exotic cultivars displayed low visible CBSD symptoms (Incidence 53.4%, severity score 2) on leaves and tuberous roots. Major of these cultivars had foliar and root symptoms. Indeed, Casinga *et al.* (2018); Bigirimana *et al*. (2011); Mulimbi *et al*. (2012) showed in their work in the Great Lakes zones that low CBSD symptoms were observed on leaves.

CBSD leaf incidence and severity significantly varied with the ten tested cultivars (from 0.0% to 100% and from score 1 to 4, F pr.<0.001). The cultivar 'Bomengo' and 'Muzuri' reached 100% incidence at 6 MAP. However, the cultivar 'Mvuama' and 'Nsansi' remained < 10% incidence. The increase severity started from 5 MAP to reach score 3 or 4 for the cultivar 'Muzuri' and 'Obama 2' respectively. According to Abaca *et al*. (2012); Kanju *et al*. (2019), in their investigations in the East and the Center of Uganda, the manifestation of the CBSD symptoms on cassava leaves evolved/moved with the age of cassava plant. In general, it can be retained that during the experimentation in the area of Kisangani, the CBSD pressure on the ten exotic cultivars tested was of average (53%) incidence and average (score 2) severity.

It is retained that the cultivar 'Bomengo' presented a high CBSD foliar incidence (94.5%) and moderate severity (score 2). On the other hand, the cultivar 'Obama 2' displayed a high CBSD incidence (30%) and a high severity (score 3). It was also observed that all the exotic cassava cultivars displayed CBSD foliar symptoms presented CBSD root necrosis in various incidence and severity degrees (Table 3).

Indeed, the cultivar 'Mvuama' remained CBSD healthy regarding no foliar and root CBSD chlorosis and necrosis. However, for the cultivar 'Mayombe' and 'Nsansi', in the absence of CBSD foliar symptoms they expressed root necroses during harvests. This observation shows that some cultivars dissimulate CBSD symptoms on their shoot parts whereas they are sensitive to the CBSD.

Regarding the CMD symptoms, the disease incidence remained low from 0 to 3.3%. This low incidence occurred from 6 MAP for the cultivar 'Obama 2' and from 8 MAP for the cultivar 'Bomengo'. The fact of no CMD symptom observed on the other cultivars 'Butamu', 'Liyayi', 'Mayombe', 'Mvuama', 'Muzuri', 'Ngandajika', 'Nsansi' and 'Obama 1' confirms their CMD resistant character. It is noted that the CMD infection of the two cultivars might be relatively negligible owing to the fact that the CMD total incidence and severity remained low (3.3% and score 2). It can be understood that the two infected cultivars probably started to lose their on farm CMD-resistance character. Globally, these performed cultivars still better face to CMD in Kisangani (Table 3).

In Yangambi, RDC, Monde *et al*. (2013) noted a depressive effect of the CMD on the growth and the production of the fourteen improved and local cassava cultivars. The impact of the disease on the production was overall more significant for the local cultivars and was negligible for the resistant cultivars.

In Yaoundé, Cameroun, Ambang *et al*. (2007), studied the tolerance to the CMD of the three cassava cultivars (the local 'Alot-Bikon' and the two improved: 'IITA8034' and 'IITA8061'), they recorded a low level of CMD infection (17.2%) on plants of the wild species. This wild species was seemed to be more tolerant to CMD whereas the cultivar 'IITA8061' was fairly resistant to CMD incidence. While the cultivars 'IITA8034' and the local 'Alot-Bikon', were found more sensitive to CMD.

Table 3. CBSD and CMD foliar Incidence and severity on ten cassava cultivars at different growth stages

		3 MAP		4 MAP		5 MAP		6 MAP		7 MAP		8 MAP		9 MAP		10 MAP		11 MAP		Mean	
Disease	**Cultivar**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S(1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**	**I (%)**	**S (1-5)**
CBSD	Bomengo	0.0	1	0.0	1	0.0	1	66.7	2	100.0	2	100.0	2	100.0	2	100.0	2	100.0	2	94.5	2
	Butamu	0.0	1	0.0	1	0.0	1	0.0	1	43.3	2	43.3	2	43.3	2	43.3	2	43.3	2	43.3	2
	Liyayi	0.0	1	0.0	1	0.0	1	0.0	1	10.0	2	10.0	2	10.0	2	10.0	2	10.0	2	10.0	2
	Mayombe	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Muzuri	0.0	1	0.0	1	0.0	1	36.7	2	100.0	2	100.0	2	100.0	2	100.0	2	100.0	3	89.5	2
	Mvuama	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Ngandajika	0.0	1	0.0	1	0.0	1	0.0	1	60.0	2	60.0	2	60.0	2	60.0	2	60.0	2	60.0	2
	Nsansi	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Obama1	0.0	1	0.0	1	0.0	1	33.3	2	50.0	2	50.0	2	50.0	2	50.0	2	50.0	2	46.7	2
	Obama2	0.0	1	0.0	1	0.0	1	0.0	1	30.0	2	30.0	2	30.0	2	30.0	2	30.0	4	30.0	3
	Mean	**0.0**	**1.0**	**0.0**	**1.0**	**0.0**	**1.0**	**45.6**	**2.0**	**56.2**	**2.0**	**56.2**	**2.0**	**56.2**	**2.0**	**56.2**	**2.0**	**56.2**	**3.0**	**53.4**	**2.0**
	CV (%)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**51.9**	**24.2**	**68.9**	**24.2**	**68.9**	**24.2**	**68.9**	**24.2**	**68.9**	**24.2**	**68.9**	**31.4**	**67.3**	**31.6**
CMD	Bomengo	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	3.3	2	3.3	2	3.3	2	3.3	2	3.3	2
	Butamu	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Liyayi	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Mayombe	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Muzuri	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Mvuama	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Ngandajika	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Nsansi	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Obama1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1	0.0	1
	Obama2	0.0	1	0.0	1	0.0	1	3.3	2	3.3	2	3.3	2	3.3	2	3.3	2	3.3	2	3.3	2
	Mean	**0.0**	**1**	**0.0**	**1**	**0.0**	**1**	**3.3**	**2**	**3.3**	**2**	**3.3**	**2**	**3.3**	**2**	**3.3**	**2**	**3.3**	**2**	**3.3**	**2**
	CV (%)	**0.0**	**0**	**0.0**	**0**	**0.0**	**0**	**31.6**	**15.8**	**31.6**	**15.8**	**42.4**	**21.1**	**42.4**	**21.1**	**42.4**	**21.1**	**42.4**	**21.1**	**42.2**	**21.1**

MAP: Month After Plantation, I: Incidence, S: Severity, CV: Coefficient of variation

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The number of adult whitefly per plant varied with the ten cultivars tested and the plant growth stages. From 3 MAP, the cultivar 'Liyayi' was found with 11 whiteflies per plant followed by cultivar 'Muzuri' (10 whiteflies per plant) and 'Nsansi' (8 whiteflies per plant). However, the cultivar 'Mvuama' did not attract any (0) whitefly at 3 MAP. These cultivar 'Mvuama' and 'Nsansi' remained < 10% CBSD incidence. It is observed by Muhindo *et al*. (2020a) that the presence of whitefly does not indicate necessarily the presence of diseases (Table 4).

At 8 MAP, the cultivar 'Mayombe' recorded a high number of whiteflies (17 whiteflies per plant) followed by the cultivar 'Muzuri' (7 whiteflies per plant). From 9 MAP, adult whiteflies were not visible any more on the plants of all the ten cultivars. This disappearance of whiteflies would be explained by the low childhood of cassava leaves which does not attract any more whiteflies (Table 4).

Table 4. Whiteflies abundance per plant on 10 cassava exotic cultivars at different growth stages

No	Cultivar	3 MAP	4 MAP	5 MAP	6 MAP	7 MAP	8 MAP	9 MAP	$Mean_a$	CV (%)
1	Bomengo	2.0	0.0	1.0	1.8	1.3	6.6	0.0	2.5	91.7
2	Butamu	5.5	1.5	2.1	1.3	4.0	4.2	0.0	3.1	55.2
3	Liyayi	11.2	0.0	1.0	1.0	2.0	3.7	0.0	3.7	111.8
4	Mayombe	7.1	1.0	2.9	2.5	2.0	17.4	0.0	6.4	97.1
5	Muzuri	10.0	1.0	1.0	1.4	3.0	4.6	0.0	3.9	89.4
6	Mvuama	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.2	204.1
7	Ngandajika	8.1	1.0	1.7	1.8	1.0	5.1	0.0	3.5	82.5
8	Nsansi	8.4	1.0	1.4	1.5	2.0	5.4	0.0	3.7	80.6
9	Obama1	3.4	1.0	1.2	1.1	2.0	4.1	0.0	2.4	55.2
10	Obama2	5.1	0.0	0.0	1.8	2.0	4.4	0.0	2.7	79.5
	$Mean_b$	**6.8**	**1.5**	**1.5**	**1.6**	**2.0**	**6.2**	**0.0**	**3.5**	**72.0**
	CV (%)	**52.4**	**38.7**	**58.7**	**41.4**	**45.8**	**72.7**	**NA**	**44.4**	**28.6**

Our results show that CBSD and CMD incidences were highly ($p<0.0001$) positive ($R^2 = 0.83$ and $R^2 = 0.96$) correlated to CBSD and CMD severities on leaves. This relationship was also observed between CBSD incidence and CBSD severity ($R^2 = 0.83$) on roots. Whereas, fairly positive relationship was obtained between the CBSD incidence on roots and CBSD severity on leaves (r = 0.13 to r = 0.52). Moreover, negative correlations were obtained between the CBSD and CMD incidences and severities on leaves and the abundance of whitefly per plant (r = -0.13 and r = -0.19) and (r = -0.06 and r = -0.06) correspondingly (Figure 2 A).

Our observations corroborate results found by Muhindo *et al*. (2020a) which found that the abundance of whiteflies was not in direct relationship with the CBSD and CMD incidences. On the other hand, Njoroge *et al*. (2017) concluded that the higher density (20 to 25 individuals) of whiteflies led to the higher transmission of the diseases. This statement highlights that the origin of the plant infection of the ten exotic cultivars tested in our study does not come from whitefly transmission but from cultivar sensitivity.

The analysis of our results shows that the production in terms of percentage of marketable tubers was as ranged from cultivar 'Mayombe' (74.9%), 'Obama 1' (70.3%), 'Obama 2' (69.9%) and 'Ngandajika' (65.3%). The effect of the CBSD on this cassava yield of all the tested cultivars got output loss that varied by cultivars. The most leading of these improved cultivars that got great loss were the cultivars 'Butamu' (85%), 'Mvuama' (70.8%) and 'Muzuri' (64.3%) (Table 5).

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Table 5. CBSD foliar, stem and root incidences and severities (from 12 to 14 MAP) and root weight and yield and loss of ten cassava cultivars

Site	Cultivars	F	CBSD Incidence (%)			CBSD Severity (1-5)			TNR	Weight (Kg)			Yield (t/ha)			%Loss
			Foliar	Stem	Root	Foliar	Stem	Root		NMR	MR	TRW	TNR	MR	%MR	
Cimestan	Bomengo	3	1.0	0.0	0.0	2.0	1.0	2.1	4.6	0.22	0.16	0.38	5.2	4.0	65.3	57.9
	Butamu	3	0.9	0.0	0.0	1.9	1.0	2.0	2.3	0.15	0.03	0.18	1.6	0.5	14.1	83.3
	Liyayi	3	1.0	0.7	0.7	2.0	1.7	1.8	3.9	0.23	0.15	0.38	4.9	3.4	57.7	60.5
	Mayombe	3	0.9	0.0	0.0	1.9	1.0	2.2	6.5	0.33	0.28	0.61	13.0	11.7	74.5	54.1
	Muzuri	3	1.0	0.2	0.2	2.4	1.2	2.1	4.3	0.21	0.13	0.34	5.1	3.6	42.6	61.8
	Mvuama	3	0.9	0.0	0.0	1.9	1.0	1.7	4.4	0.18	0.06	0.24	4.2	2.1	28.9	75.0
	Ngandajika	3	0.7	0.0	0.0	1.7	1.0	2.2	5.1	0.32	0.22	0.54	8.6	6.7	65.3	59.3
	Nsansi	3	1.0	0.0	0.0	2.0	1.0	2.1	3.6	0.21	0.11	0.32	3.4	1.5	34.3	65.6
	Obama1	3	0.9	0.2	0.2	1.9	1.2	2.4	5.2	0.36	0.28	0.64	10.2	7.8	68.3	56.3
	Obama2	3	0.9	0.1	0.1	1.9	1.1	2.3	4.7	0.40	0.33	0.73	9.8	8.4	68.8	54.8
	Mean[b]		**0.9**	**0.1**	**0.1**	**1.9**	**1.1**	**2.1**	**4.5**	**0.26**	**0.18**	**0.44**	**6.6**	**5.0**	**52.0**	**59.1**
	CV (%)		**26.8**	**275.9**	**275.9**	**16.9**	**28.8**	**28.9**	**60.8**	**61.4**	**112.3**	**173.7**	**106.9**	**143.4**	**85.0**	**35.3**
Lindi	Bomengo	3	0.8	0.0	0.0	1.8	1.0	2.2	4.0	0.31	0.24	0.55	6.4	5.0	66.7	56.4
	Butamu	3	1.0	0.0	0.0	2.3	1.0	2.2	2.6	0.13	0.02	0.15	1.6	0.3	11.4	86.7
	Liyayi	3	1.0	0.7	0.7	2.1	1.7	2.1	4.3	0.31	0.21	0.52	6.6	4.4	58.9	59.6
	Mayombe	3	0.9	0.0	0.0	2.0	1.0	2.3	5.7	0.39	0.34	0.73	13.1	12.0	75.3	53.4
	Muzuri	3	1.0	0.2	0.2	2.6	1.2	2.5	4.1	0.24	0.12	0.36	5.6	3.6	37.7	66.7
	Mvuama	3	0.6	0.0	0.0	1.6	1.0	2.0	4.2	0.22	0.11	0.33	4.5	2.5	33.3	66.7
	Ngandajika	3	0.7	0.0	0.0	1.7	1.0	2.3	4.8	0.35	0.25	0.60	8.7	6.7	65.2	58.3
	Nsansi	3	1.0	0.0	0.0	2.0	1.0	2.4	3.6	0.21	0.12	0.33	3.7	2.1	47.6	63.6
	Obama1	3	0.9	0.3	0.3	2.1	1.3	2.5	5.5	0.38	0.28	0.66	11.1	8.0	72.3	57.6
	Obama2	3	0.9	0.1	0.1	2.1	1.1	2.3	4.9	0.47	0.39	0.86	12.1	10.2	71.1	54.7
	Mean[b]		**0.9**	**0.1**	**0.1**	**2.0**	**1.1**	**2.3**	**4.4**	**0.30**	**0.21**	**0.51**	**7.3**	**5.5**	**53.9**	**58.8**
	CV (%)		**37.4**	**262.0**	**262.0**	**25.6**	**29.7**	**28.3**	**50.0**	**65.1**	**106.0**	**171.1**	**97.3**	**129.8**	**78.0**	**38.0**

Notes: F= Frequency; TNR= Total Number of Root; NMR=Not Marketable Root; MR=Marketable Root, TRW=Total Root Weight, %MR=Percentage of Marketable Root, %Loss=Percentage of Loss; CV=Coefficient of Variation

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The marketable roots yield was then more reduced according to the presence of CBSD necrosis in the pulp of the tuberous roots of all the tested cultivars. This reduction is also linked to the fact that the marketable root yield was slightly positive correlated (r = 0.18) to the CBSD necrosis severity for all the cultivar roots that has attained severity score 4 at 14 MAP and reduced the output (< 5t/ha) of these cultivar tuberoses roots (Figure 2 and 3). The visible negative effect of the CBSD on this cassava yield of all the tested cultivars got important output loss because of the fact that these roots became nonedible and nonmarketable roots.

In determining of the moment of harvest of cassava in order to minimize losses due to CBSD, results from this work showed that from 9 to 14 MAP all the tested exotic cassava cultivars were infected. This root infection was characterized by a spot necrotic of 10-50% necrotic tissue of the cassava tuberous roots. Thus, these cultivars could be harvested by 9 MAP a favorable moment also identified by Muhindo *et al*, (2020a) in Yangambi, DRC. Results from this work agree with those found by Kanju *et al*. (2019) which found that the best moment (12 MAP) for harvesting cassava under the CBSD-infected conditions of Uganda.

Multi-local studies through the various agro-ecological zones are also recommended to determine the total response of these cassava genotypes for virus infections.

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Declaration

The authors declare that they have any conflicts of interest.

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Comparative Efficiency of Organic and Inorganic Fertilizers on Maize (*Zea mays* L.) Growth and Yield in the Rainforest Zone of Centre Cameroon

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Abstract

Maize is a major crop grown and consumed in the world and it requires a high fertilizer input. Although chemical fertilizers are an important input to get higher crop productivity, they have an impact on soil fertility, environment and human health. A field study was carried out to find alternatives to the mineral fertilization of maize. The aim of this study was to determine the influence of fertilizers on maize growth and yield while evaluating economic profitability. Four treatments (control, compost, poultry manure and mineral fertilizer NPK 20-10-10) and two maize varieties (local variety and improved variety CMS 8704) were used in a split-plot design with four replicates. Physicochemical analyses of soil and organic fertilizer were determined. Growth parameters, yield and acceptability index were evaluated. As results, poultry manure and compost are rich in nitrogen and phosphorus. At 9 weeks after sowing (WAS) the best stem diameter was obtained by the local variety in the plots fertilized with mineral fertilizer (2.83±0.31 cm). The yield of the CMS 8704 variety was significantly higher in the plots fertilized with poultry manure (2.23 t ha^{-1}) than the yield of the local variety in the control plots (1.16 t ha^{-1}). Principal component analysis (PCA) shows that compost and poultry manure were characterized by an increase in growth parameters as well as mineral fertilizer NPK. Poultry manure had the highest acceptability index of 1.25. In view of these results, it is clear that organic fertilizers; especially poultry manure, would have a positive impact on increasing maize production.

Keywords: *Zea mays*, compost, poultry manure, growth, yield, acceptability index

1. Introduction

As the world's population continues to grow and food needs increase, agricultural production must increase significantly (Baligar & Frageria, 1997). This situation predisposes the soil to mechanical erosion, the dissolving action of water, and the rapid depletion of nutrients, especially nitrogen and phosphorus (Yemefack et al., 2006; Kaho et al., 2011). The consequences are low yields for the main food crops, especially cereals.

Maize (*Zea mays* L.) is one of the most widely grown cereals in the world. It occupies more than 33 million ha each year (FAO, 2015). A bulk of 1.162 billion tons of maize grains was produced worldwide in 2020. While in Cameroon, maize is cultivated on about 1.18 thousand hectares with a yield production of about 2.09 thousand tons (FAO, 2022). It is the staple food for nearly 80% of the population. Nevertheless, as the third most important commodity after cassava and plantain, maize production in Cameroon remains very low. The improvement of food security, which implies, among other things, increasing maize production, faces production constraints such as declining soil fertility, low adaptability of genotypes to climates, irregular rainfall, diseases, pests (Kimuni et al., 2013), soil acidity and particularly alumina toxicity (Mapiemfu-Lamaré et al., 2011). Without forgetting the use of chemical fertilizers and their high cost (Olaniyi et al., 2010).

Moreover, numerous studies have concluded that the effectiveness of chemical fertilizers is only noticeable during the first years of continuous supply and after a few years, their use leads to considerable degradation of soil properties in addition to yield decreases and also pollutes groundwater (Kasongo et al., 2013; Mahmood et al., 2017). Conventional mineral fertilization remains expensive and inaccessible to small farmers (Useni et al., 2013). Moreover, the application of mineral fertilizer cannot guarantee long-term crop productivity in many soils since they are not effective to maintain and improve soil fertility (Sigaye et al., 2020). Faced with this controversy, viable alternative solutions both economically and environmentally are indispensable. Several studies point out that organic fertilization input by producers is an integrated crop management alternative aimed at reducing or eliminating synthetic fertilizers (Abawi & Widmer, 2000; Islam & Munda, 2012). These amendments improve the physical, chemical and biological properties of the soil reduce environmental pollution and increase harvest and yields (Li et al., 2012; Sikuzani et al., 2014; Berhe & Andargachew, 2020). In particular, composts are rich in nutrients and recent research has shown that inputs of these products increase soil organic matter levels, cation exchange capacity, the biomass of microorganisms and their activities. Also, poultry manure is an inexpensive fertilizer rich in nitrogen, phosphorus and potassium that could be used in combination with mineral fertilizer to improve soil quality and increase crop yields (Biekre et al., 2018). The acquisition of a high yield in maize production requires an adequate and balanced fertilizer supply, as declining soil fertility is a major constraint for maize production (Khan et al., 2016). Very high maize yields are achieved through the balanced use of high-quality organic inputs alone and in combination with inorganic fertilizers, compared to the single application of inorganic fertilizers (Barbieri et al., 2012; Verde et al., 2013). The study was conducted to determine the influence of fertilizers on maize growth and yield while evaluating economic profitability in the rainforest zone of Cameroon.

2. Materials and Methods

2.1 Study Site

This experiment was undertaken in Mars 2015 on a fallow farm (5 years old) in the locality of Akonolinga, Loum, (03° 48.136' N and 012° 15.518' E, altitude 663 m), in the Centre Region of Cameroon. Crops like groundnut, macabo and cassava are routinely been cultivated in this area. This locality belongs to the agroecological zone 5 of Cameroon (humid forest zone with bimodal rainfall). The site is characterized by a Congo-Guinean sub-equatorial climate, with two dry seasons alternating with two rainy seasons. The average rainfall is 1633 mm/year distributed in a small rainy season (March-June) and a long rainy season (September-November). The average annual temperature is relatively constant (around 23 to 27 °C). Relative and average humidity is above 80% (Moudingo, 2007). The soil is ferralitic and is characterized by outcrops of the indurated horizon in the form of slabs or gravel.

2.2 Experimental Design and Cultural Practices

A plot of land (31 x 11 m) was cleared and ploughed. The experimental design was a "split-plot" with four replicates. Seeds of two maize varieties constituting the main plots were randomly replication with two variants: local variety and improved CMS 8704. The local variety was characterized by the white color of grains obtained from local villagers and is the most locally cultivated by farmers. The improved variety CMS 8704 is characterized by the yellow color of the grains produced and yield of up to 4 to 6 t ha^{-1}, under the best growing conditions at the Institute of Agricultural Research for Development (IRAD) station. Treatments were randomized sub-plots of the main plot (control, compost, poultry manure and mineral fertilizer (N-P-K 20-10-10)). Compost from three-month-old household waste was obtained from an Association named “GIC le Vert” and poultry manure was provided by the poultry complex to both in Yaounde. The mineral fertilizer used was the complex fertilizer N-P-K (20-10-10) with the trade name YARA existing in granular form. Eight treatments resulting from the combination of the levels of the two factors were tested. Each combination that constitutes sub-plots uses 21 packets of 3 lines and 7 packets per line at intervals of 0.80 x 0.50 m. A total of 32 sub-plots measuring 4 m x 2 m were counted, and separated by 1 m paths and blocks were separated by 2 m paths. Weeding was done at 3, and 6 weeks after sowing (WAS) using a hand hoe.

2.3 Soil and Organic Fertilizer Analysis

In order to elaborate on the fertilization of the plants, the physicochemical properties of the soil and organic fertilizers were determined in the Laboratory of the Institute of Agricultural Research for Development (IRAD) Yaounde-Nkolbisson. The soil sample was collected at a depth of 15 cm in different locations in the experimental field. These soil samples were analyzed to determine the following characteristics: texture (sand, silt, and clay), pH, organic carbon, total nitrogen, exchangeable bases (Ca, Mg, K) and available phosphorus using the methods described by Anderson & Ingram (1993); Buondonno et al. (1995). The organic fertilizers (compost and poultry manure) were also analyzed to determine total nitrogen, potassium and phosphorus according to the NF ISO 11261; 31108 and 11263 standards respectively and calculated following the formula proposed by Pauwels et al.

(1992).

2.4 Treatment Applications

The organic fertilizers were mixed with soil at a depth of 5 cm and applied 1 week before seeding (Gomgnimbou et al., 2019) in the respective sub-plots at 0.12 kg per pots (Yerima et al., 2014). Mineral fertilizer was applied two weeks after seeding at a rate of 11.2 g per plant according to Ojetayo et al. (2011). The organic and inorganic fertilizers were applied only once during the experiment.

2.5 Data Collection

Emergence was observed from the 7th to 9th day after sowing (DAS). The ratio of the number of plantlets actually emerged to the total number of seeds sown made it possible to determine the emergence rate according to the formula used by Ngatsi et al. (2017)

$$ER\ (\%) = (n/N) \times 100$$

Where: ER (%) emergence rate, N = number of emerged plantlets and N = total number of sown seeds.

Data were recorded from a sample of 6 randomly selected plants labeled per sub-plot and the growth variables were observed over a period of 3 to 9 weeks after sowing (WAS) with 2 weeks interval. Stem diameter using a caliper, plant height per meter and leaves number were assessed. Maize grain yield (t ha^{-1}) was conducted 122 days after sowing (DAS) on 12 plants randomly harvested from each sub-plot in each block and calculated by the following formula.

$$\text{Yield (t ha}^{-1}\text{)} = \text{Grain weight (kg/m}^2\text{)} \times 10000\ \text{m}^2\text{/ha} \times 1\ \text{t/1000 kg.}$$

2.6 Economic Profitability of Fertilizer Types

To identify the best treatment that is easily adopted by farmers, gross income (GR) and acceptability index (AI) were calculated (Nyembo et al., 2014). The gross income is equal to the yield (kg ha^{-1}) multiplied by the market price per kilogram of grain maize (Pr).

$$GR = \text{yield} \times Pr.$$

The Acceptability Index (AI) compares the net profit of the new treatments (NPt) to the reference treatment (control) known by the farmers (NPc).

$$AI = NPt/NPc$$

According to Kaho et al. (2011); Useni et al. (2012), for a technology to be adopted, the Acceptability Index (AI) value must be equal to or greater than 2. Adoption is reluctant if this value is between 1.5 and 2; and below 1.5 there is rejection.

2.7 Statistical Analysis

The data collected were subjected to a one-way and two-way analysis of variance (ANOVA) and the Principal Components Analysis (PCA) using R software version 4.1.2 (R Development Core Team 2022). PCA was constructed with the growth parameters at all periods, yield and fertilizer types. The multiple comparisons of Duncan's test mean threshold follows the analysis of variance when significant differences ($P < 0.05$) for one of the factors are detected and before, the normality test (Shapiro-Wilk test $P > 0.05$) and homogeneity of variance (Levene's test $P > 0.05$) were verified.

3. Results

3.1 Physicochemical Characterization of Soil, Compost and Poultry Manure

Soil analysis results during this growing season show that the soil is acidic with a sandy and clay texture and silt (Table 1). Assimilable phosphorus is 0.3 g kg^{-1}, total nitrogen (0.18 g kg^{-1}) and exchangeable calcium (1.91 mol kg^{-1}). The organic matter content is 34.6 g kg^{-1}. The carbon and nitrogen ratio (C/N) is 10 and the cation exchange capacity (CEC) is 9.03 cmol kg^{-1}. Compost and poultry manure is rich in nitrogen (20.6 and 16.35 g kg^{-1} respectively). As regards phosphorus and potassium respectively, poultry manure contains 35.77- 49.75 g kg^{-1} and compost (16.35-33.32 g kg-^{1}). The soil locality pH is acidic (pH KCl: 4.5 and pH H_2O: 5.6) as opposed to the pH of compost (pH KCl: 7.59 and pH H_2O: 7.97) and poultry manure (pH KCl: 7.89 and pH H_2O: 8.03) which are basic.

Table 1. Physicochemical properties of soil, compost and poultry manure

Soil		Compost		Poultry manure	
Characteristics	Contents	Characteristics	Contents	Characteristics	Contents
Clay (%)	31.3	N g kg^{-1}	20.6	N g kg^{-1}	16.35
Silt (%)	5.3	P (P_2O_5) g kg^{-1}	16.35	P (P_2O_5) g kg^{-1}	35.77
Sand (%)	62.4	K (K_2O) g kg^{-1}	33.32	K (K_2O) g kg^{-1}	49.75
pH (KCl)	4.5	pH (KCl)	7.59	pH(KCl)	7.89
pH (H_2O)	5.6	pH (H_2O)	7.97	pH(H_2O)	8.03
OM (g kg^{-1})	34.6				
OC (g kg^{-1})	1.8				
Total nitrogen (g kg^{-1})	0.18				
C/N	10				
AP (mg kg^{-1})	0.3				
Ca^{2+} (mol kg^{-1})	1.91				
Mg^{2+} (mol kg^{-1})	0.10				
K^+ (mol kg^{-1})	0.10				
CEC (cmol kg^{-1})	9.03				

OM: Organic Matter; OC: Organic Carbon; C/N: Carbon/Nitrogen; AP: Assimilable Phosphorus; CEC: Cation Exchange Capacity; N: Nitrogen; P: Phosphorus; K: Potassium.

3.2 Effect of Fertilizers and Variety on Emergence Rate

The emergence rate of plants varies over time in all treatments used (Table 2). There are significant differences ($P < 0.05$) between treatments at 7, 8 and 9 days after sowing (DAS). At 9 DAS, the emergence rate was significantly low in the sub-plots treated with poultry manure (75.74%) and compost (76.94%) compared to the control (79.53%) and the plots that received the mineral fertilizer NPK (80.12%). No significant difference between varieties were observed at 7 DAS (F-value=2.039, df=1, P-value=0.167) compared at 8 DAS (F-value=6.152, df=1, P-value=0.0213) and 9 DAS (F-value=7.303, df=1, P-value=0.013) for the emergence rate.

Table 2. Effect of treatments and variety on maize seed emergence rate

Treatments	7 DAS	8 DAS	9 DAS
Control	74.28 ± 1.54a	76.79 ± 1.65a	79.53 ± 1.95a
Compost	71.08 ± 1.08b	73.57 ± 0.96b	76.94 ± 1.55b
Poultry manure	72.68 ± 2.09ab	73.77 ± 2.10b	75.74 ± 1.02b
Mineral fertilizer	74.26 ± 1.57a	77.02 ± 1.87a	80.12 ± 1.47a
F-value	5.385	7.247	10.31
Pr(>F)	0.0069**	0.0017**	<0.001***
Varieties			
Local variety	72.50 ± 2.07a	74.16 ± 2.04a	77.05 ± 1.92b
CMS 8704	73.65 ± 1.87a	76.41 ± 2.03b	79.17 ± 2.27a
F-value	2.039	7.303	6.152
Pr(>F)	0.167ns	0.013*	0.0213*

Values followed by the same letter are not significantly different according to Duncan's test at ($P < 0.05$).

3.3 Growth Parameters and Yield

3.3.1 Stem Collar Diameter

Plant stem diameter is reported in Table 3. From this table, no significant differences are recorded at 3 weeks after sowing (WAS). At 5 WAS, the treatment effect (F-value=3.92, df=3, *P*-value<0.001) and variety effect (F-value=11.22, df=1, *P*-value=0.036) are observed. The largest diameter is obtained by the local variety in the plots fertilized with mineral fertilizer NPK (2.40±0.26 cm) than the stem diameter of variety CMS 8704 in the control plots (1.54±0.13 cm). At 9 WAS, no significant difference was registered between treatments and variety*treatment interaction. Only the variety effect is recorded (F-value=8.62, df=1, *P*-value=0.008). The local variety has a larger diameter (2.62±0.43 cm) than the improved variety CMS 8704 (2.20±0.39 cm). The results show that during this period, the plots fertilized with mineral fertilizer NPK of the local variety obtained the best diameter (2.83±0.31 cm).

Table 3. Effect of treatments and variety on the stem diameter of maize plants

Varieties	Treatments	3 WAS	5 WAS	7 WAS	9 WAS
Local variety	Control	1.00±0.12a	1.70±0.34c	1.82±0.11bc	2.29±0.38ab
	Compost	1.29±0.28a	2.26±0.09ab	2.55±0.42a	2.68±0.42ab
	Poultry	1.05±0.38a	1.83±0.32bc	2.36±0.48ab	2.67±0.55ab
	NPK	1.02±0.49a	2.40±0.26a	2.58±0.15a	2.83±0.31a
Means V1		1.09±0.33a	2.05±0.39a	2.33±0.43a	2.62±0.43a
CMS 8704	Control	0.96±0.08a	1.54±0.13c	1.74±0.16c	2.12±0.24b
	Compost	1.15±0.26a	1.89±0.27bc	1.88±0.29bc	2.11±0.54b
	Poultry	1.17±0.12a	1.59±0.26bc	2.10±0.18abc	2.15±0.39ab
	NPK	1.09±0.19a	2.25±0.45ab	2.01±0.56bc	2.38±0.48ab
Means V2		1.08±0.17a	1.82±0.40b	1.93±0.34b	2.20±0.39b
Pr(>F) V		0.9706ns	0.0357*	0.0026**	0.008**
Pr(>F) T		0.3787ns	<0.001***	0.0207*	0.3465ns
Pr(>F) V x T		0.7649ns	0.8678ns	0.3001ns	0.7914ns

V1: local variety, V2: improved variety CMS 8704, V: varieties, T: treatments, V x T: interaction, WAS: week after sowing. Values followed by the same letter are not significantly different according to Duncan's test at ($P < 0.05$).

3.3.2 Plants Height

Plant growth was better in the treated plots compared to the control plots (Table 4). It was observed that during the periods of parameter sampling, the variety*treatment interaction was not significant ($P > 0.05$). Nevertheless, at 3 WAS (F-value=0.29, df=3, *P*-value=0.834), the highest height was observed in the plots receiving the compost (0.45±0.07 m) of the local variety. At 9 WAS (F-value=2.06, df=3, *P*-value=0.132), plots fertilized with poultry manure (2.14±0.08 m) of the local variety and plots fertilized with compost (2.14±0.11 m) of the CMS 8704 variety obtained the best heights compared to the control plots (1.90±0.19 m) of the CMS 8704 variety.

Table 4. Effect of treatments and variety on maize plant height

Varieties	Treatments	3 WAS	5 WAS	7 WAS	9 WAS
Local variety	Control	0.37±0.02bc	0.89±0.25c	1.44±0.63bc	1.99±0.10bc
	Compost	0.45±0.07a	0.99±0.25b	1.49±0.61ab	2.06±0.07ab
	Poultry	0.43±0.05ab	1.10±0.21a	1.59±0.56a	2.14±0.08a
	NPK	0.40±0.04ab	1.12±0.22a	1.51±0.54ab	2.09±0.12ab
Means V1		0.41±0.05a	1.03±0.23a	1.51±0.95a	2.07±0.08a
CMS 8704	Control	0.31±0.02d	0.82±0.25d	1.36±0.59c	1.90±0.19c
	Compost	0.41±0.03ab	0.86±0.28cd	1.58±0.54a	2.14±0.11a
	Poultry	0.39±0.02abc	1.00±0.26b	1.55±0.53ab	2.10±0.13ab
	NPK	0.34±0.01cd	1.01±0.25b	1.45±0.58bc	2.08±0.11ab
Means V2		0.36±0.04b	0.92±0.26b	1.49±0.56a	2.05±0.11a
Pr(>F) V		0.0007***	<0.001***	0.459ns	0.529ns
Pr(>F) T		0.0012**	<0.001***	0.0017**	0.0002***
Pr(>F) V x T		0.834ns	0.707ns	0.170ns	0.131ns

V1: local variety, V2: improved variety CMS 8704, V: varieties, T: treatments, V x T: interaction, WAS: week after sowing. Values followed by the same letter are not significantly different according to Duncan's test at ($P < 0.05$).

3.3.3 Leaf Number

The number of leaves of maize varieties varies in the different treatments and as a function of time (Table 5). The data in the table show a significant difference at 5 WAS (F-value=3.30, df=3, *P*-value=0.037) and 9 WAS (F-value=3.67, df=3, *P*-value=0.026) for variety*treatment interaction, as well as the treatment effect at 9 WAS (F-value=5.56, df=3, *P*-value=0.004). At 5 WAS, the plots receiving the mineral fertilizer NPK (10.75±0.50 leaves) of the variety CMS 8704 obtained the highest number of leaves than the control plots of the same variety

(9.25±0.96 leaves). At 9 WAS, the plots fertilized with mineral fertilizer NPK of the local variety (17.25±0.96) and the CMS 8704 variety (16.05±0.74) have the highest number of leaves.

Table 5. Effect of treatments and variety on the number of leaves of maize plants

Varieties	Treatments	3 WAS	5 WAS	7 WAS	9 WAS
Local variety	Control	8.50±0.10a	10.50±0.58ab	12.50±0.58ab	15.00±0.78c
	Compost	8.25±0.50a	10.54±1.00ab	13.00±0.82ab	16.25±0.54b
	Poultry	8.00±0.82a	10.50±0.58ab	13.25±0.96ab	16.25±0.96b
	NPK	8.25±0.40a	10.05±0.82abc	13.00±0.82ab	17.25±0.96a
Means V1		8.25±0.68a	10.40±0.72a	12.94±0.77a	16.19±1.05a
CMS 8704	Control	7.75±0.96a	9.25±0.96c	12.25±0.96b	16.00±0.82b
	Compost	8.00±0.61a	10.00±0.64abc	13.50±1.01ab	16.00±0.68b
	Poultry	8.50±0.58a	9.50±0.58bc	13.00±0.82ab	16.05±0.65b
	NPK	8.00±0.58a	10.75±0.50a	13.75±0.50a	17.25±0.74a
Means V2		8.06±0.57a	9.88±0.81a	13.13±0.96a	16.33±0.44a
Pr(>F) V		0.4251ns	0.0522ns	0.5253ns	0.5691ns
Pr(>F) T		0.9738ns	0.4705ns	0.0452*	0.0048**
Pr(>F) V x T		0.3158ns	0.0373*	0.5142ns	0.0263*

V1: local variety, V2: improved variety CMS 8704, V: varieties, T: treatments, V x T: interaction, WAS: week after sowing. Values followed by the same letter are not significantly different according to Duncan's test at ($P < 0.05$).

3.3.4 Grain Yield

Regarding yield, no significant difference to fertilization was observed with interaction variety*treatment (F-value=2.81, df=3, P-value=0.06). The control plot of the local variety (1.16±0.19 t ha^{-1}) and CMS 8704 variety (1.21±0.17 t ha^{-1}) has the lowest yield, followed by the local variety in plot treated with compost (1.69±0.13 t ha^{-1}) and mineral fertilizer NPK (1.69± 0.05 t ha^{-1}). On the other hand, the plots that received poultry manure (2.23±0.27 t ha^{-1}) and compost (2.16±0.21 t ha^{-1}) of the improved CMS 8704 variety had the highest yields.

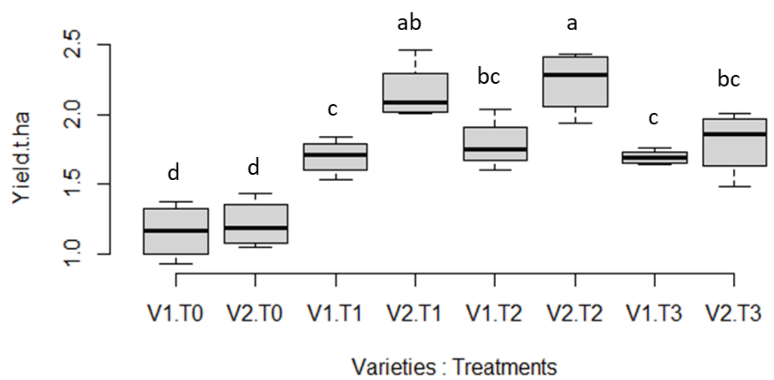

Figure 1. Effect of treatment and variety on maize yield; V1: local variety, V2: improved variety CMS 8704, T0: control, T1: compost, T2: poultry manure, T3: mineral fertilizer NPK (20-10-10)

3.4 Multivariate Analysis

Principal Component Analysis (PCA) was performed to show the relationship between agronomical parameters and treatments are presented in Figure 2. The two PCA explain 91.6% of the variance. The PCA1 represents 67.7% of the variation of the studied system; the variables are height (at 3, 5, 7 and 9 WAS), yield, number of leaves (at 5, 7 and 9 WAS), and stem diameter (at 7 WAS). The PCA2 contributed about 24% of the variability. Stem diameter at 5 WAS, number of leaves at 3 WAS and height at 5 WAS were the most representative variable. Poultry manure and compost were characterized by an increase in growth parameters as well as mineral fertilizer NPK. But poultry manure and compost yielded than mineral fertilizer NPK. Control is the opposite of the three techniques of fertilization and yields lower.

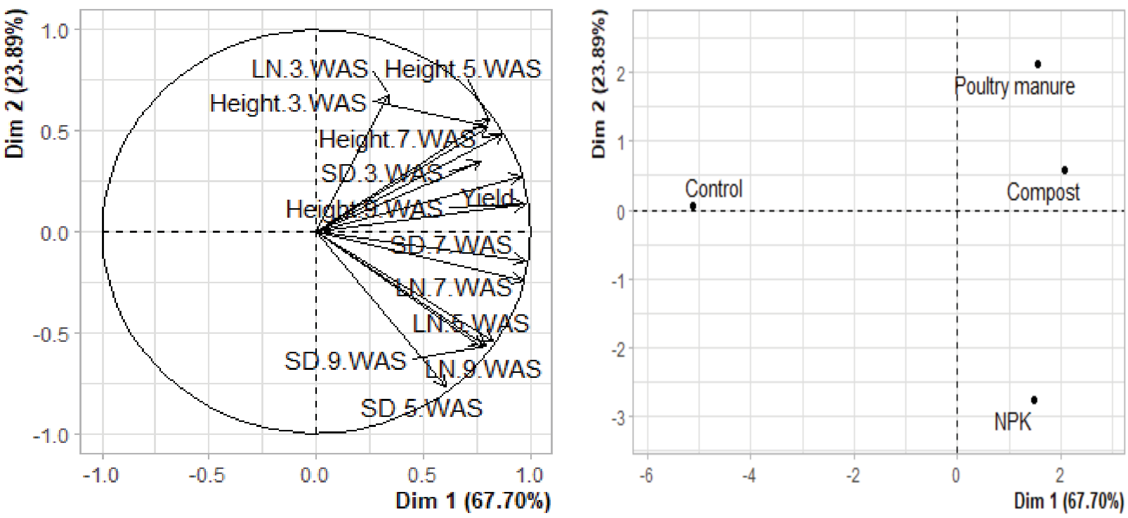

Figure 2. Principal components analysis (PCA) between the parameters studied. SD: stem diameter, LN: leaf number, WAS: week after sowing

3.5 Economic Profitability of the Use of Different Types of Fertilizers

The results of the economic profitability of the different types of fertilization are presented in Table 6. It appears that the acceptability index of NPK mineral fertilization is lower (1.04), contrary to that of organic fertilization. Fertilization with poultry manure gave the highest acceptability index of 1.25. Also, it can be seen that fertilization with compost is the most expensive.

Table 6. Economic profitability of the use of different types of fertilizers

Treatments	Quantities in 50 kg bags	FPP /ha (USD)	SpC (USD)	TC (USD)	Yield (kg ha^{-1})	GR (USD)	NP (USD)	AI
Control	0	0	0	0	1186.94	453.07	453.07	0
Compost	60	229.03	18.32	247.35	1925.19	734.87	487.52	1.08
Poultry	60	183.22	18.32	201.54	2009.16	766.92	565.38	1.25
NPK	6	178.64	18.32	196.96	1746.20	666.55	469.58	1.04

FPP: Fertilizer Purchase Price Yara 29.77 USD/bag of 50 kg; SpC: Spreading Cost; TC: Total Cost; GR: Gross Income (0.38 USD/kg selling price of grain maize); NP: Net Profit; AI: Acceptability Index. Price of compost purchase 3.82 USD/bag and poultry manure 3.05 USD/bag of 50 kg.

4. Discussion

In general, the best practice for maintaining soil fertility remains the use of organic fertilization (Lunze et al., 2007). In order to maintain this fertility in a sustainable way and to ensure the sustainability and durability of soil use, organic farming practices, which appear to be an alternative solution to mineral fertilization, could play a major role in promoting and maintaining soil fertility compared to conventional agriculture (Muyayabantu, 2010). The objective of the study is to determine the influence of fertilizers on maize growth and yield while evaluating economic profitability in the rainforest zone of Cameroon.

The different organic fertilizers used during the experiment had high levels of major nutrients (N, P and K). As demonstrated by Hassani & Presoon (1994), the nutrient content would depend in the case of compost, on the different organic elements involved during composting (the animal and/or plant organic matter composition of the household waste), the composting method and the storage method. In the case of poultry manure, it would depend on the quality of the feed consumed by the poultry, and the method of drying and storage. However, these organic fertilizers, in addition to providing the plant with the nutrients necessary for its growth and development (Saha et al., 2008), would also contribute to enhancing the fertility of nutrient-poor soils (Adelekan et al., 2010; Useni et al., 2012).

The effect of fertilizers on maize growth revealed significant differences ($P < 0.05$) in emergence rate at 7, 8 and 9 days after sowing (DAS). Significantly low mean emergence rates of 76.94 and 75.74% were recorded in the poultry manure and compost treatments, respectively. These results would be related to the depth of seed burial in the soil, or to the environmental conditions during the emergence phase and not to the nutrient supply, because at the germination stage, the seed's only nutrient source comes from the reserves contained in its cotyledons (Useni et al., 2013). Regarding the number of leaves and stem collar diameter, it was observed that during the first weeks of the plant's vegetative cycle, the effect of mineral fertilizer NPK (20-10-10) was clearly demonstrated at 5 WAS by significantly high values. However, it was only from the last weeks onwards that the application of organic fertilizers to the crop significantly influenced plant growth. The results obtained would be justified by the fact that chemical fertilizer, being obtained by synthesis, contains highly soluble mineral elements that have the advantage of being easily absorbed by the plant at the root level (Kimuni et al., 2013). Therefore, the nutrient supply (especially major nutrients) of the chemical fertilizer and the effect of the latter on plant growth and development would be direct and immediately observable from the first weeks of the plant growth phase (Galla et al., 2011). On the other hand, organic fertilizers applied to plants do not always make the nutrients they contain immediately available and easily accessible (Aliyu, 2000). These nutrients must first be mineralized by soil microorganisms before they are available (Vagstad et al., 2001; Giroux et al., 2007). These results are identical to those obtained by Adelekan et al. (2010) on maize cultivation in Nigeria. However, treatment with poultry manure and compost improved the height of maize plants of both varieties at 9 WAS. Ahmad et al. (2013) note that excess nitrogen stimulates exuberant growth of the aerial part, and promotes carbohydrate utilization as well as the export of mineral elements and plant growth. A significant effect ($P < 0.05$) between varieties is observed for stem collar diameter and height of maize plants. Indeed, the local variety recorded high values for these parameters compared to the improved variety which recorded low values. This would be only a consequence of the morphogenetic characteristic of the local variety, which over time has adapted to the local ecological conditions and which according to the local residents is likely to present an imposing morphology. Ngatsi et al. (2017) showed that the local variety most cultivated by the farmers of this locality presents a more imposing morphology (stem diameter and height) compared to the improved varieties used. Also, this difference might be due to the genetic potential difference between the varieties (Berhe & Andargachew, 2020).

Poultry manure and compost performed significantly better yields than the other treatments. This result confirms the results of Agyenim et al. (2012); Segnou et al. (2012) obtained after a study on mineral and organic fertilization of maize and pepper (*Capsicum annuum* L.). This result could be explained by the dual role played by poultry manure as an organic fertilizer (Effa et al., 2022). A role of nutrient supply, and a role of soil amendment by improving the physical (structural stability, erosion control, increase in water retention capacity, soil aeration and warming), chemical (supply of major nutrients, supply of trace elements, increase in CEC, increase in pH of acidic soils) and biological (stimulation of soil microbial activity) properties of the soil (Saha et al., 2008). This would contribute to plant growth and thus promote good yields. As for the control, the lack of fertilization and soil characteristics would be at the origin of the low yield (Kasongo et al., 2013). According to Kitabala et al. (2016); Sigaye et al. (2020), organic fertilization subsequently improved crop performance, and soil characteristics and increased yields. The improved variety is significantly more productive compared to the local variety According to Zaidi et al. (2003), improved cultivars in the tropics have shown that they can initiate better grain yield stability in maize.

Principal component analysis between fertilization types, growth parameters and yield shows that the addition of fertilizer increases the growth and yield of maize varieties compared to the control. Kouassi et al. (2019) in their work on the "effects of organic and organo-mineral fertilizers based on plant and animal wastes on soybean growth and yield (*Glycine max* L.)" show that mineral fertilizer application improves early soybean growth parameters. This author also shows that organic fertilization promotes better pod production by plants. The acceptability index of the different types of fertilization is below 1.5 and therefore all are rejected. This could be justified by the fact that organic fertilizers (compost and poultry manure) were probably applied at low doses (3 t ha^{-1}), and only once, as was the case with mineral fertilizer. This rate is lower than that applied in most cases (Olaniyi et al., 2010; Nyembo et al., 2014).

5. Conclusion

The organic fertilizers used during the experiment had high levels of major nutrients. During the vegetative period, compost from household waste and poultry manure had significant effects on maize plant growth only from the seventh week after sowing, as well as the chemical fertilizer used, which had effects on plant growth from the first weeks after sowing. The local variety recorded the highest values for stem diameter and height. Poultry manure is the most suitable organic fertilizer for obtaining better yields (2.23 t ha^{-1}) with CMS 8704 variety than the control plot (1.16 t ha^{-1}) with local variety. The variety effect results led to the conclusion that the improved variety is more suitable for obtaining better yields. Thus, organic fertilizers, especially poultry manure, give better value to maize compared to the control and chemical fertilizers.

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Competing interests

The authors declare that they have no conflict of interest.

Author Contributions

Bekolo Ndongo selected the scope of the work; Bekolo Ndongo and Zachée Ambang reviewed and edited the manuscript. Behly Tanekou Ndja'a conducted the field experiment, Patrice Zemko Ngatsi supervised the Fieldwork, analyzed data and writes the first draft of the manuscript. All authors have read and approved the final version of the manuscript.

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Effect of Dry and Flooded Rice as Cover Crops on Soil Health and Microbial Community on Histosols

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Abstract

Soil loss due to subsidence is a major concern in the Everglades Agricultural Area (EAA) of South Florida. Summer is typically the fallow season in the EAA, and soil loss due to oxidation and erosion is significant. Flooding and cover cropping are common practices being adopted to conserve soil, reduce weed pressure, and enhance soil health in the EAA. Cover crops also increase the microbial biomass which are the key drivers of soil function. The objective of this study was to determine the effect of (i) fallow, (ii) dry rice as a cover crop, (iii) flooded fallow, and (iv) flooded rice as a cover crop on soil health indicators and microbial community and diversity within the EAA. Baseline (pre-planting) soil samples were collected from all fields before the application of different treatments and post-harvest soil samples were collected after rice was cut and tilled into the soil surface. Microbial community composition was determined using 16S rRNA gene amplicon and fungal ITS gene amplicon sequencing. Soil bulk density decreased, and cation exchange capacity (CEC) increased in all farming practices including fallow fields. Results showed flooded fallow, flooded rice, and rice planting increased maximum water holding capacity (MWHC) and soil protein and decreased total potassium (TK). Bulk soil microbial communities responded surprisingly quickly to the applied treatments. Taxonomic composition of prokaryotic and fungal communities at the phylum level revealed visible shifts in microbial communities in response to the treatments. Instead of leaving field fallow, planting rice or flooding is a better strategy to improve soil health.

Keywords: soil health, organic matter, microbial community, prokaryotic, fungal community

1. Introduction

The Everglades Agriculture Area (EAA) of southern Florida, USA consists of Histosols, which have 80-90 % organic matter (OM) (Morris et al., 2004; Wright and Hanlon, 2009). In the early 1900s, this area was artificially drained for cultivation. The organic matter exposed to the surface continues to decompose at faster rate by heterotrophic aerobic microorganisms compared to anaerobic microbial decomposition in flooded soil (Tate and Tarry, 1980). This process of soil decaying is called subsidence (Wright and Hanlon, 2009). From 1924 to 2019, the rate of subsidence in the EAA has been examined and reported multiple times. The average rate of subsidence from 1924-1967, 1968- 2009, and 2010 to 2019 was reported to be an average of 2.8 cm yr^{-1}, 1.4 cm yr^{-1}, and 0.64 cm yr^{-1}, respectively (Bhadha et al., 2020). If an effective soil conservation method is not adopted soon EAA soil will be too shallow for agricultural use or without soil. Soil conservation is a major concern in EAA for sustainable agriculture. Several management practices such as flooding, increasing water table, crop rotation, and cover cropping can be adopted to slow down the subsidence rate and also to build up organic matter in the soil.

Flooding or raising the water table results in the reduction of aerobic decomposition of organic matter which slows down the subsidence rate (Bhadha and Schroeder, 2017). Besides the reduction of soil subsidence, flooding also reduces nutrient depletion, and insect pests' population (Cherry et al., 2015). Crop diversification including cover crop or crop rotation is another option to manage subsidence. Sugarcane, rice, and winter vegetables are commonly grown in the EAA. After harvesting sugarcane and winter vegetables in the summer, farms in EAA are either left fallow, flooded fallow, or planted with rice. Flooded rice after sugarcane harvest is a good crop rotation practice as it helps to reduce soil oxidation (Bhadha et al., 2021). Growing cover crops in the fallow season between sugarcane and winter vegetables not only retain soil nutrients but also add organic matter. Cover crops are becoming more popular during the fallow season because they sequester carbon, reduce soil erosion, and increase microbial community and diversity (Bacq-Labreuil et al., 2019). Planting leguminous cover crops may result in greater soil nitrogen (N) due to N_2-fixation (Gabriel et al., 2012). Nonlegume cover crops, on the other hand, maybe more successful in increasing soil organic matter and minimizing N leaching due to their higher biomass (Sainju et al, 2003). Previous research has found that cover crops boost the number of saprophytic and mycorrhizal fungi (Bacq-Labreuil et al., 2019). Muhammad et al (2021) showed that planting cover crops increased bacteria and fungi biomass by 7-13% compared to no cover crop. The larger fungal/bacteria ratio indicates that fungi were more influenced by cover crops than bacteria. Cover crop residue provides essential nutrients for microbial growth and development (Tao et al., 2017), whereas microbial communities decompose cover crop residue and add nutrients for main crops. Microbial compounds released following the decomposition of crop residue are the main antecedents of soil organic matter (Cotrufo et al., 2013). Soil organic matter enhances the soil absorption complex and nutrient retention, which is good for plant development (Drost et al., 2020). Besides enhancing soil health, the microbial community is capable of protecting host plants from pathogens and increasing tolerance to environmental stress (Rillig, 2004). Microbial community and activity are influenced by cover crop species and soil type (Muhammad et al., 2021). Integrative assessment of how soil's physical, chemical, biological properties and microbial community are affected by common land management practices in the EAA is essential to fully understand soil loss via subsidence. However, there is limited information available on the effect of flooding and growing rice as a cover crop on soil physical and chemical properties and microbial community and diversity in the EAA. Therefore, the objectives of this study were to: i) evaluate the impact of cultivating flooded rice and dry rice as a cover crop, leaving the field fallow and alternative practices such as flooded fallow on soil health of histosols; and ii) investigate the microbial community and diversity.

2. Materials and Method

2.1 Soil Sampling

This study was conducted on Histosols within the EAA during the summer of 2021. Four commonly used farming practices including fallow, dry rice as a cover crop, flooded fallow, and flooded rice as a cover crop were included in this study. Each farming practice was conducted on a separate field and soil samples were collected form each filed as randomized complete design. Diamond variety of rice was seeded at 100 kg ha^{-1}. Irrigation was not applied to dry rice whereas in flooded rice field, flooding was initiated 3 weeks after planting. Eight random baseline soil samples (referred to in this study as pre) were collected in May 2021 before planting rice or flooding from each field. The second set of eight soil samples (referred to post) were collected in September 2021 after rice was cut and tilled into the soil surface or the flooded field was drained out. Post soil samples were collected at the same spot or as close as possible to the pre-soil samples to minimize error due to variability in field conditions.

2.2 Soil Analyses

Air-dried pre-and post- soil samples of particle size less than 2 mm were analyzed for soil health indicators, including soil pH, bulk density (BD), maximum water holding capacity (MWHC), organic matter (OM), cation exchange capacity (CEC), active carbon (AC), soil protein (SP), Mehlich-3 phosphorus (M3P), Mehlich-3 potassium (M3K), total phosphorus (TP), total potassium (TK), and total Kjeldahl nitrogen (TKN). Soil pH was determined using Accumet AB250 pH meter with a 1:10 soil to water ratio. Bulk density was calculated by dividing soil mass by a fixed core volume. Maximum water holding capacity was determined based on the saturation procedure described in Jenkinson and Powlson (1976). Organic matter content was calculated based on the loss on ignition method. Soil samples were placed in a muffle furnace at 550 ˚C to combust organic material. The weight of ashed samples were measured after bringing to room temperature. Soil OM content was calculated as the difference between dry weight and ashed weight on a percentage basis (Amgain et al., 2021a). Cation exchange capacity was estimated using the ammonium acetate method (Sumner and Miller, 1996). Active carbon was determined based on potassium permanganate ($KMnO_4$) oxidizable carbon using 0.02 M $KMnO_4$ for mineral soils, in which approximately 2.5 g of soil was reacted with 20 ml of 0.02 M $KMnO_4$ for exactly two minutes, filtered and the supernatant solution was then analyzed using Thermo Scientific Genesys 30 spectrophotometer at 550 nm (Schindelbeck et al., 2016). Soil protein was determined by using a sodium citrate extraction method (Schindelbeck et al., 2016) under autoclaving with high temperature and pressure. The extracted protein was quantified by using the Thermo pierce colorimetric bicinchoninic acid assay (BCA) as calibrated against protein standards of known concentration. The color development was read by using Thermo Scientific Genesys 30 spectrophotometer at 550 nm. Soil available P and K were determined using Mehlich -3 extraction method and then analyzed using Agilent 5110 inductively coupled plasma-optical emission spectrometer (ICP-OES) (Santa Clara CA). Total P was determined by ashing samples for at least 5 hours (not to exceed 16 hours) at 550 ^{o}C in a muffle furnace followed by extraction with 6 M HCL and analyzed using ICP-OES. TKN was determined using the digestion method followed by colorimetric determination (EPA method 351.2).

2.3 DNA Extraction, 16S rRNA Gene Amplicon Library Preparation and Sequencing

Soil samples were placed on ice until returning to the lab and thereafter stored at -80 °C until further processing. Approximately 5 g soil samples were homogenized by grinding using mortar and pestle. DNA was then isolated from 0.25 g (wet weight) samples using the DN easy Power Soil kit (Qiagen, Germantown, MD) following manufacturer's instructions. Samples were treated by bead beating twice for 30 seconds at 4.0 m/s in a FastPrep-24 bead beater (MP Biomedical, Irvine, CA). DNA was dissolved in 50 µl molecular biology grade water and stored at -20 °C before use. Quality and quantity of DNA was assessed by UV/Vis spectroscopy using a NanoDrop ND-1000 (Thermo Scientific, Waltham, MA) and yielded DNA concentrations between 109.65 to 213.82 ng/µl with 260/280nm ratios > 1.7 from all samples. DNA samples were stored at -80 °C until use.

PCR amplifications, library preparations and DNA sequencing were conducted at the University of Illinois Chicago genome research core. PCR products for 16S rRNA gene amplicon libraries were generated following Earth Microbiome Project protocols (Thompson, 2017 #591). The V4-V5 region of the 16S rRNA gene was amplified using primers 515F-Y (Parada, 2016 #428) and 926R (Quince, 2011 #1542). Fungal ITS gene fragments were amplified using primers ITS1F and ITS2R (White et al., 1990). Barcoded libraries were prepared, pooled and sequenced on an Illumina MiniSeq instrument using the 250 cycle MiSeq Reagent kit v3 (Illumina, San Diego, Ca).

Amplicon sequences were demultiplexed on the instrument. Dada2 with default settings implemented in the QIIME 2 package was used to remove barcodes, quality filter ($Q \geq 30$), trim reads, merge reads, and screen for chimera (Callahan, 2016 #1283) (Bolyen, 2019 #1346). This yielded between 15,612 and 21,765, as well as 14,150 and 78,130 non-chimeric high-quality sequences per sample for 16SrRNA genes and fungal ITS genes, respectively. Amplicon sequence variants (ASV) table was generated with dada2 and taxonomic assignments were made with qiime feature-classifier using sklearn algorithm against the Silva database version 138 (Quast, 2012 #1284).

Data were rarefied to even depth of 15,000 (16S rRNA genes) and 14,000 (fungal ITS genes) sequences per sample. Bray-Curtis and weighted Unifrac distance matrices were calculated using "qiime diversity core-metrics-phylogenetic" command in Qiime 2. Shannon Index, Observed_OTUs, Chao1 alpha diversity metrics were calculated using phyloseq V1.30.0 (McMurdie, 2013 #2081) in R version 3.6.3 (R Core Team, 2020 #1579).

2.4 Statistical Analysis

Effects of different farming practices on soil health indicators were analyzed using the generalized linear mixed models (GLIMMIX) method (SAS version 9.4, SAS Institute Inc.) as a randomized complete design. Since each farming practice was conducted on a separate field, each farming practice was analyzed separately and compared pre vs post soil samples. Means were separated using Tukey–Kramer multiple-comparison procedure when the F test was significant at $p \leq .05$.

For microbial data, Principal coordinate analyses (PCoA) and distance-based redundancy analysis (dbRDA) were run by using the PCoA and capscale functions in vegan, respectively, using the vegan package (https://CRAN.R-project.org/package=vegan {Oksanen, 2019 #1577}) implemented in R. Significance of differences between treatments and time point were tested by the adonis function with 999 permutations in vegan. Pearson correlations and ANOVA comparison of means were conducted in base R.

3. Results

3.1 Impact on Soil Physical Properties

Soil BD ranged between 0.69 and 0.73 g cm^{-3} and 0.53 and 0.58 g cm^{-3} for pre and post soil samples, respectively (Figure 1 a). All farming practices showed a significant decrease in BD. The maximum water holding capacity of pre and post soil ranged from 173 to 183 % and 182 to 199 %, respectively (Figure 1 b). Maximum water holding capacity was higher in post-harvest soil samples compared to pre-planting/flooding soil samples in all farming practices except for the field that was left fallow. Fallow field was the only farming practice that showed a decrease in OM, all other farming practices remained statistically similar and showed no change between pre and post soil samples.

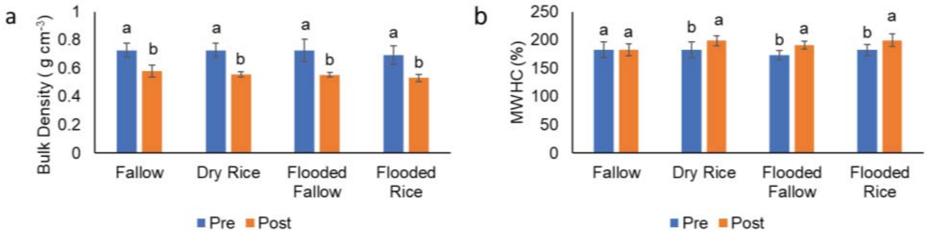

Figure 1. Effects of farming practices on physical soil health indicators. a. bulk density and b. maximum water holding capacity. Means sharing a common letter within each farming practice are not significantly different at $p = 0.05$ significance level

3.2 Impact on Soil Chemical Properties

All soil samples had neutral to alkaline soil pH (6.9 to 7.8). For flooded fallow, the pH of soil samples before and after flooding was statically identical. The pH of the soil increased significantly in fallow and dry rice but declined in flooded rice (Fig 2a). Organic matter content of pre-planting and post-harvest soil samples ranged from 75.7 to 77.6 and 71.1 to 80.6 %, respectively (Figure 2b). Cation exchange capacity of pre-planting soil samples ranged from 72 to 78 cmolc kg^{-1} and post-harvest soil samples ranged from 138 to 156 cmolc kg^{-1} (Figure 2c). All farming practices increased cation exchange capacity. Total Kjeldahl nitrogen (TKN) of pre and post soil samples ranged from 14611 to 18749 mg kg^{-1} and 12481 to 14993 mg kg^{-1}, respectively (Figure 2d). TKN concentration of flooded fallow and flooded rice farming was statically similar, whereas TKN concentration was reduced for fallow and dry rice. Total phosphorus ranged from 1706 to 2296 mg kg^{-1} and 1517 to 1923 mg kg^{-1} for pre and post soil samples (Figure 2e). The only farming practice that decreases TP was a fallow field. There was no significant difference in TP between pre and post soils for dry rice, flooded fallow, and flooded rice. Total potassium ranged from 540 to 606 mg kg^{-1} for pre soil samples and 303 to 653 mg kg^{-1} for post soil samples (Figure 2f). All farming practices significantly decreased TK except fallow. The field that had been kept fallow, there was no significant difference in TK between pre and post soil samples. Mehlich-3 phosphorus of pre and post soil samples ranged from 174 to 210 mg kg^{-1} and 168 to 201 mg kg^{-1}, respectively (Figure 2g). No significant difference in pre and post M3P was observed for dry rice and flooded rice fields, whereas M3P was increased in a fallow field and decreased in the flooded fallow field. Mehlich-3 potassium ranged from 307 to 386 mg kg^{-1} for pre soil samples and 180 to 476 mg kg^{-1} for post soil samples (Figure 2h). There was a significant decrease in M3P in the fallow field, whereas M3K increased in flooded fallow. Mehlich3 potassium remained statistically similar for dry rice and flooded rice.

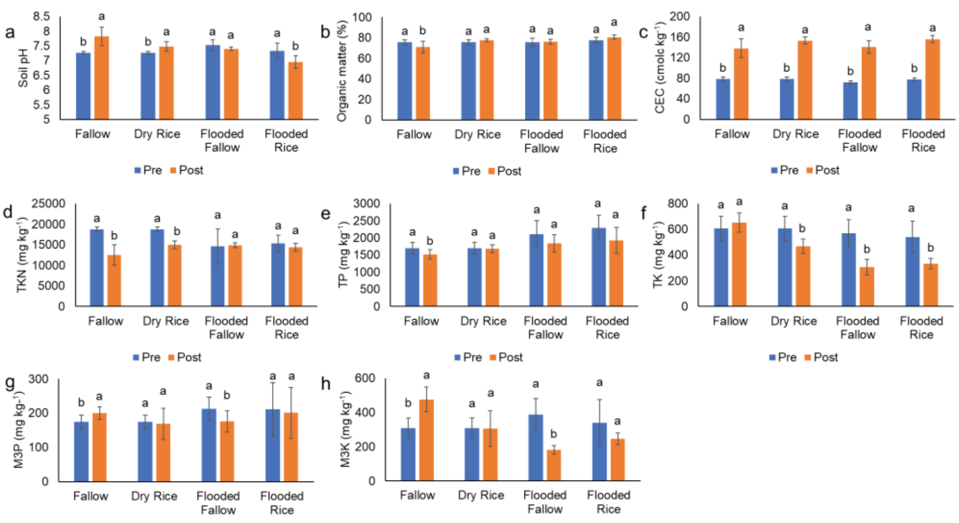

Figure 2. Effects of farming practices on chemical soil health indicators. a. soil pH, b. organic matter, c. cation exchange capacity (CEC), d. total Kjeldahl nitrogen (TKN), e. total phosphorus (TP), f. total potassium (TK), g. Mehlich-3 phosphorus (M3P), and h. Mehlich-3 potassium (M3K). Means sharing a common letter within each farming practice are not significantly different at $p = 0.05$ significance level

3.3 Impact on Soil Biological Properties

Active carbon ranged from 27909 to 29553 mg kg^{-1} and 28437 to 29004 mg kg^{-1} for pre and post soil samples, respectively (Figure 3a). Active carbon remained statistically similar for all farming practices. Although statistically similar, flooded rice and flooded fallow had increased AC, whereas fallow and dry rice had decreased AC. Soil protein ranged from 286 to 322 mg kg^{-1} for pre soil samples and 350 to 456 mg kg^{-1} for post soil samples (Figure 3b). Dry rice, flooded fallow, and flooded rice farming practices increased soil protein, whereas it remained statistically similar for fallow.

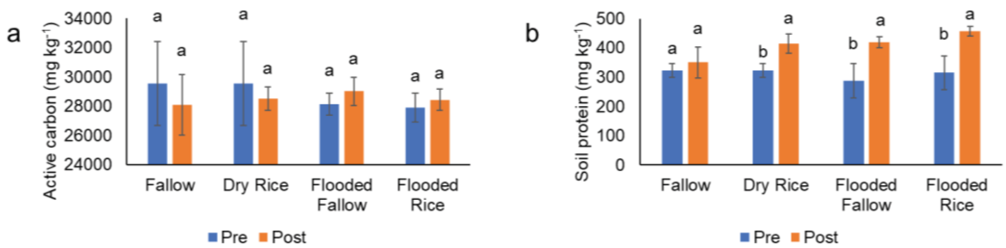

Figure 3. Effects of farming practices on biological soil health indicators. a. active carbon and b. soil protein. Means sharing a common letter within each farming practice are not significantly different at $p = 0.05$ significance level

3.4 Impact on Microbial Community and Diversity

To test if and how EAA soil microbial communities respond to the different treatments, prokaryotic and fungal communities were analyzed via amplicon sequencing of 16S rRNA- and fungal ITS genes, respectively. Surprisingly, principal Coordinate Analyses of weighted Unifrac distance matrices revealed significant differences between pre- and post-treatment in prokaryotic and fungal communities even within the relatively short timeframe (Figure 4). The same analysis based on Bray-Curtis distance matrices did not reveal significant differences (data not shown). Differences between weighted Unifrac and Bray-Curtis-based results suggest that the changes in both types of communities are predominantly caused by changes among closely related taxa.

Although the number of replicates was not sufficient to draw clear conclusions about the effects of each treatment on the microbial communities, alpha diversity measures indicated that the flooded fallow treatment could potentially reduce prokaryotic diversity (Figure 5). In contrast, Observed ASVs, Chao-1, and Shannon index all indicated a reduced fungal diversity in all but the flooded fallow treatment (Figure 5). Taken together, these data suggest that prokaryotic and fungal communities responded differently to the imposed treatments.

Taxonomic composition of prokaryotic and fungal communities at the phylum level revealed visible shifts in microbial communities in response to the treatments. In prokaryotic communities the combined relative abundance of taxa below 1.0% relative abundance, grouped as “Other”, increased in all but the fallow treatment from between 5.1% and 5.8% to 6.7% and 9.3% post-treatment. Conversely, Actinobacteriota decreased in all but the fallow treatment from 17.2% - 20.8% to 14.5% - 17.0%. The only other substantial pre-post difference appeared in the increased relative abundance of Chloroflexi in the fallow treatment from 14.0% to 19.3%. Pre-treatment fungal communities were highly dominated by Ascomycota ranging between 78.2% to 81.6%, accompanied by less than 15% combined other identified fungal phyla (Basidiomycota, Mortierellomycota, Rozellomycota, and other phyla below 1.0% relative abundance). Relative abundance of Ascomycota consistently decreased in all four treatments, with the fallow treatments showing the largest declines. Conversely, all treatments showed an increase of unidentified fungal taxa from between 9.9% to 16.2% pre-treatment to between 20.0% and 43.2%, likely representing poorly studied thus far uncultivated taxa. Notably, Rozellomycota increased in relative abundance in all four treatments from below 1.0% pre-treatment to 1.3% in the dry rice, 2.4% in the flooded rice, and 7.9% in the fallow treatment.

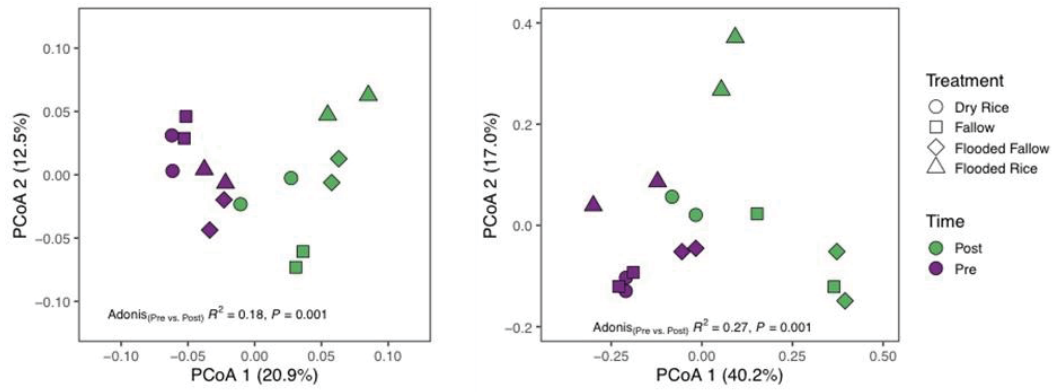

Figure 4. Principal coordinate analyses of prokaryotic (left) and fungal (right) microbial communities to study treatments based on weighted Unifrac distances of 16S rRNA genes and fungal ITS genes, respectively. Adonis test results for differences between communities before and after treatments are given

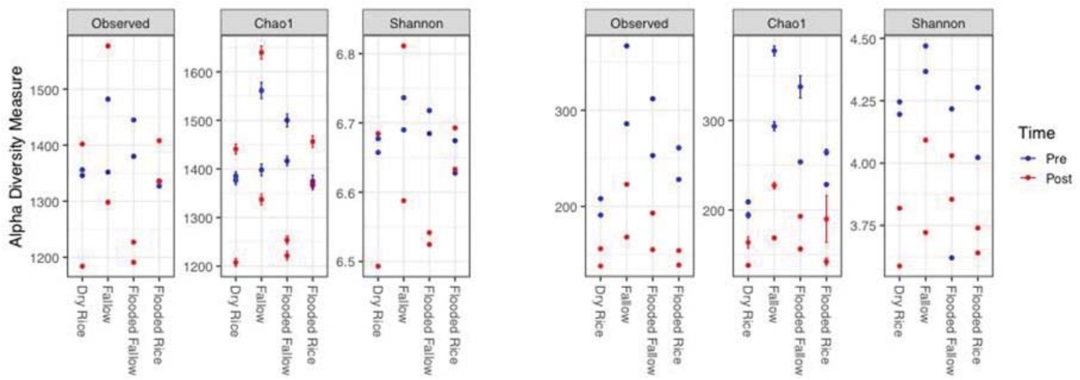

Figure 5. Responses of alpha diversity in prokaryotic (left) and fungal (right) communities depending on treatments

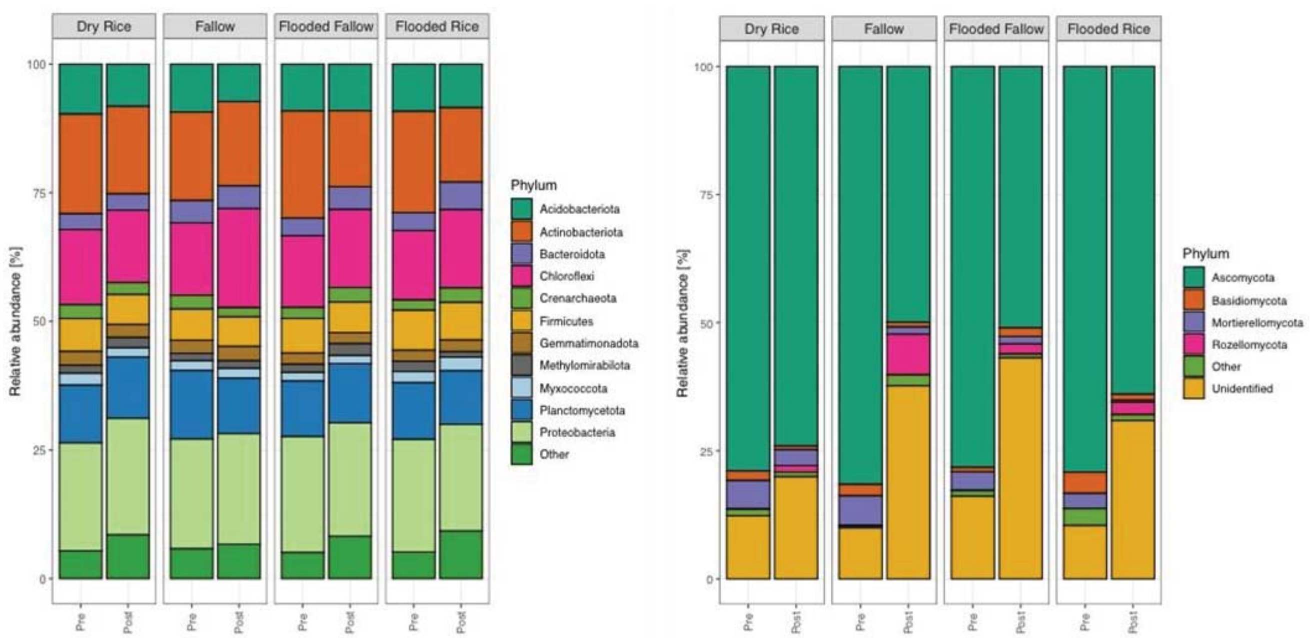

Figure 6. Phylum-level relative abundances of major prokaryotic (top) and fungal phyla (bottom) present in EAA soils pre- and post-treatment. Given are the relative abundances of phyla with relative abundances > 1.0%. All phyla with smaller relative abundances were grouped together as "Other". Fungal ITS sequences that were confidently identified as fungal ITS sequences but could not be further classified were labeled as "Unidentified"

4. Discussion

The high pH of EAA soil may be associated with the mixing of limestone bedrock with the topsoil. Increased soil pH is a serious problem for EAA producers because it has the potential to reduce the bioavailability of micronutrients from the soils (Sims and Patrick, 1978). The decrease in bulk density after all treatments is associated with the loosening of soil over time. Previously soil was compacted due to the use of a heavy machine for planting and harvesting vegetables. Over time these soils lose due to roots of rice plants and weeds. Lower soil BD is preferable since it improves aeration, tilth, and reduces root constriction. Increase in OM contributed to better nutrient cycling, aggregate stability, and water holding capacity (Lehman et al. 2015). The increase in MWHC of flooded field is most likely due to the increased delivery of finer-sized material in the form of silt and clay by irrigation water. Those fine particles high in the organic matter have a larger surface area which increases the water holding capacity. Increase in MWHC is also associated with increase in the OM content of the soil. Bhadha et al. (2017) reported every 1% increase in OM equates to a 2.3% increase in soil water holding capacity of sandy soils. Growers can enhance the MWHC of their soils by using farming techniques that increase soil OM. Soil CEC is influenced by carbon content and fraction clay sized particles (Parfitt et al., 1995). A higher CEC (72 cmolckg^{-1}) value of Histosols in EAA may be associated with high soil carbon content (> 70%). An increase in soil CEC is considered a beneficial improvement since it has the ability to hold fertilizer and pesticides in the soil matrix for a longer. The quantity of AC in soil quantifies the amount of C that can be easily mineralized to CO_2 in a short period of time under ambient circumstances. In the EAA, soil loss due to oxidation is a concern, therefore farming practices that increase AC is not always a beneficial practice. The deduction in TKN after dry rice is attributed to N uptake by rice. With no fertilizer application, rice cultivation in the EAA solely depends on the soils and irrigation water for its nutritional needs. Reduction in TKN in the fallow field is associated with leaching and other forms of N loss. Although TKN was not significantly different in a flooded field, it has decreased, which is due to N uptake by rice and some of the loss was compensated by irrigation water. Although TKN decreased after flooding and rice planting, soil protein level increased. Soil protein is the quantity of organically bound N in soil OM that can be mineralized by microbial communities. Our findings showed that flooding or growing cover crops in EAA helps to increase soil protein levels, which is beneficial because maintaining microbially degradable N helps to meet the nitrogen demands of subsequent cash crops. A decrease in TK in rice cultivated field might be due to uptake by rice plants. A decrease in TP in the fallow field is associated with soil loss due to wind erosion and leaching following rainfall. In the flooded field, no change in TP may be due to the addition of P from irrigation, whereas in a dry rice field, leaching loss and wind erosion of sediment is minimum. Tootoonchi et al (2018) reported TP of EAA canal water ranged from 0.033 to 0.066 mg L^{-1} in the 2014 and 2015 rice growing season. In another study, Amgain et al (2021b) observed TP of canal water ranged from 0.01 to 0.8 mg L^{-1} from July through August 2019. Increase in plant available potassium (M3K) and phosphorus (M3P) in a fallow field may be due to the breakdown of recalcitrant to readily available forms. From a nutrient perspective increase in M3P and M3K is a good sign as it indicates nutrient availability for the subsequent cash crop.

Bulk soil microbial communities responded surprisingly quickly to the applied treatments. Pre-treatment prokaryotic communities were composed similar to a previous report from the EAA (Huang et al., 2021). Notably, both, PCoA and phylum-level relative abundances showed distinct changes in microbial communities in different treatments in relatively short periods of time. Although no direct link could be observed between specific soil physical and chemical properties and soil microbial communities in this study, at least in part due to the limited replication, soil moisture and pH were previously shown to be the predominant drivers associated with differences in microbial communities in EAA soils (Huang et al., 2021). Although, soil moisture was not determined directly here, divergence of microbial communities between fallow and flooded treatments may be indicative of shifts towards facultative or strict anaerobic microbial communities in flooded treatments, as well as a sufficient turnover of microbial communities within the treatment times for such changes to become detectable.

5. Conclusions

From a soil conservation standpoint, cultivating rice as a cover crop or flooding the land had positive effects on the soil physical and chemical priorities. Rice as a cover crop or flooding had reduced bulk density and increased soil protein and water holding capacity. Soil with a lower bulk density and a higher maximum water holding capacity is desirable because it promotes root development and reserves water for the dry season. Within the EAA, planting rice in flooded field or flooding the field during the fallow period is a good management practice to enhance soil health as it helps to reduce soil loss via oxidation. Furthermore, detailed characterization of rice cultivation and flooding treatments on soil microbial communities and activates may be warranted to interrogate in more detail which roles the different microbial tax and activities play in the retention or degradation of soil organic matter and associated mineral nutrients.

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Farm Households Choices of Adaptation Strategies to Climate Variability Challenges in Benishangul Gumuz Regional State, Western Ethiopia

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Abstract

Climate variability and change are a serious threat to the livelihoods of rural communities because they are very sensitive to such changes. This study assesses the major adaptation strategies pursued by farm households to climate variability and change impact in Benishangul Gumuz regional state, western Ethiopia which is harshly affected by climate change stresses. The data were collected from a randomly selected 385 sample households through interview using field-based questionnaires and focus group discussions and analyzed using descriptive statistics. The results pointed out that the likelihood of households to adopt crop diversity, soil and water conservation practice, small scale irrigation, crop rotation, adjusting planting date and improved crop varieties were 54.2%, 49.8%, 47.3%, 45.3%, 44.4% and 43.5% respectively. Moreover, the results indicated that the joint likelihood of using all adaptation strategies was only 1.64% and the joint likelihood of failure to adopt all of the adaptation strategies was 2.92%. Therefore, future policy should focus on towards supporting improved extension service, offer climate related training and information especially to adaptation technologies to increase the farm households experience in adopting different strategies to the negative effects of climate variability which is a global problem of this century.

Keywords: adaptation strategies, choices, climate change, descriptive statistics

1. Introduction

Climate change is one of the swiftly spread phenomena across the globe since last century and livelihood of residents of the planet is at risk (He *et al*., 2020). One-third of the world population is directly or indirectly facing the heat of the climate change variations (Schattman *et al*., 2020). Increased temperature extremes affect agricultural productivity and increase the risk to global food security (Tai *et al*., 2014).

Adaptation to climate change has been recognized as a crucial response to climate change; even the mitigation strategies have been designed to stabilize earth's climate (IPCC 2001). Climate change refers to the changes in the mean and/or variability of climate state, and adaptation refers to adjustment, moderation, or changes to socio-economic and ecological systems in order to avoid and recover from the adverse impacts of climate change and to glean benefits from it (IPCC, 2007).

The Western part of Ethiopia is indicated with the most significant climate change impact due to drought and flood (Temesgen *et al.,* 2008). This initial potential together with the current global climate change aggravates the vulnerability of the community to climate change impacts.

To attain a sustainable level of output, farmers are expected to take adaptation measures to cope with risks posed by climate change on their productive activities (Ojo and Baiyegunhi, 2020). At farm level, there are several types of adaptation strategies available to different farmers, with the level of perception of climate change determining the type and extent to which the strategies are employed (Khan *et al*., 2020; Ojo and Baiyegunhi, 2020).

However, most climate change adaptation strategies are location specific. Therefore, there is the need to understand location-specific choices of adaptation to climate change among farm households is crucial.

Therefore, the objective of this study is to assess the choice of adaptation strategies pursued by farm households in the Benishangul Gumuz regional state of Western Ethiopia in order to guide policymakers and other stakeholders on ways to promote adaptation.

2. Methodology and Data

2.1 Description of the Study Area

Benishangul Gumuz Regional State which is the study area, is located in Western Ethiopia. According to the projected population of Ethiopian of 2019, the total population of the region is 1,125,999 of which 571,000 (50.7%) are male (CSA, 2019). The total area of the Region is estimated to be about 50,380Km^2. Mixed farming (crop production and livestock rearing) is the predominant sources of livelihood for the majority of the population in the area. The crop production is dominated by rain fed agriculture while irrigation is practiced on small-scale level (BGRANRB, 2021).

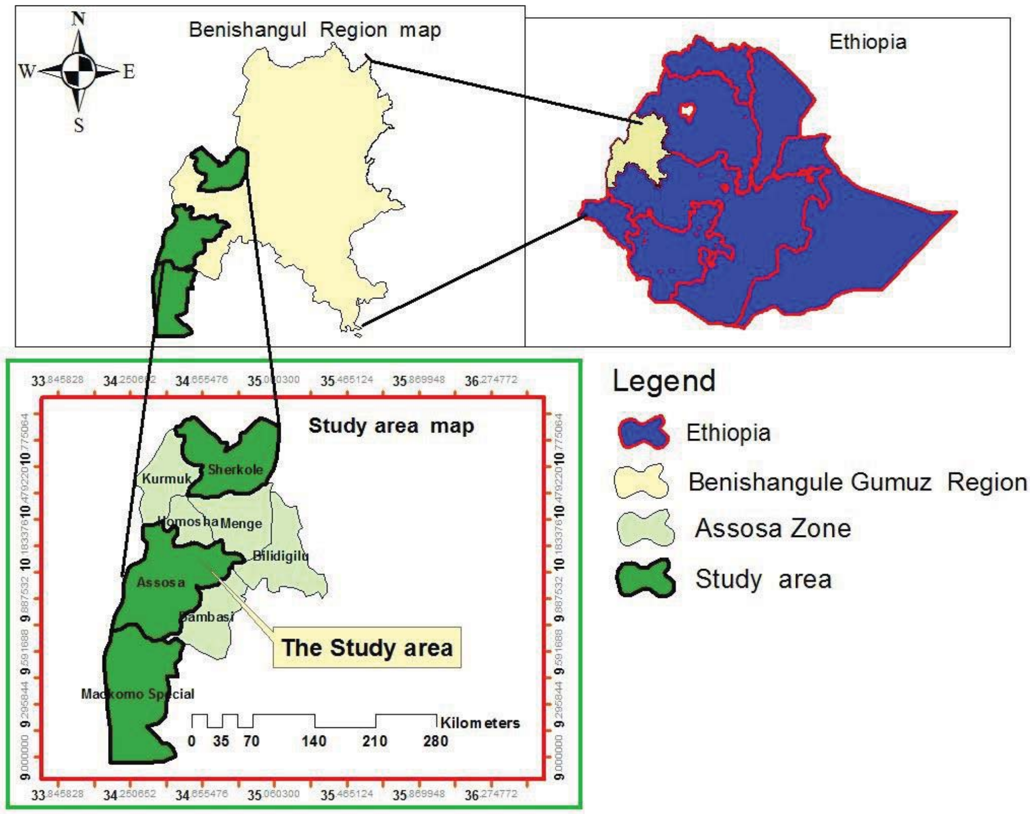

Figure 1. Geographical location of the study area

Source: GIS, 2022

2.2 Sampling Procedure and Method of Data Collection

The multistage sampling procedure was employed in selecting the sample households for this study. In the first stage, one zone (Assosa) and one special district (Mao Komo) were purposively selected based on main farming practices and socio-economic status. In the second stage, the districts were categorized based on agroecology and three districts (Mao Komo special district from the highland; Assosa district from midland and Sherkolle district from the low land climate zone were taken purposively based on agroecology of the districts. In the third stage, two kebeles were randomly selected to make a total of six kebeles. In the last stage, sample size of households at kebele level was determined based on probability proportion to size and the households were identified using simple random sampling technique.

For the household survey, sample size of respondents was determined following Kothari's (2004) formula given as:

$n = \frac{Z^2pqN}{e^2(N-1)+Z^2pq} = \frac{(1.96)^2(0.5)(0.5)226{,}966}{(0.05)^2(226{,}966-1)+(1.96)^2(0.5)(0.5)} = \frac{217{,}978.1464}{568.3729} = 383.5126 \approx 384$ + 10% compensate for more nonresponses and/or incomplete information = 422

Where n is the required sample size, Z is the inverse of the standard cumulative distribution that correspond to the level of confidence, e is the desired level of precision, p is population reliability (or frequency estimated for a sample of size n), which is 0.5 and p + q = 1. N is size of population which is the number of households in the region.

Both primary and secondary data were used for the study. Primary data were collected from a randomly selected sample households through interviewed using field-based questionnaires and focus group discussions.

Relevant secondary data were also obtained from Benishangul Gumuz region Agriculture and Natural resource Bureau, national meteorological agency and different reports and farmers' adaptation strategies to climate change were analyzed using descriptive statistics.

2.3 Data Analysis Method

The data collected were analyzed using descriptive statistics method using percentages, mean, standard deviation, and econometric model of multivariate probit of the joint probabilities for the success and failures of adapting different strategies to climate variability and change.

3. Results and Discussion

3.1 Descriptive Result

The distribution of adaptation strategies against climate variability and change pursued by farm households in the study area were given in table 1 as follow.

Table 1. Distributions of Adaptation Strategies Employed by Farm Households in Benishangul Gumuz Regional State, Western Ethiopia

Adaptation Strategies	Mean	Standard Error
Mulching	0.42	0.494
Soil conservation practices	0.50	0.501
Planting trees	0.39	0.489
Small scale irrigation	0.47	0.500
Crop diversification	0.54	0.499
Improved crop varieties	0.44	0.497
Applications of Agrochemicals	0.43	0.496
Crop rotations	0.45	0.499
Adjusting planting date	0.44	0.498
Switching to short maturing crops	0.41	0.493

Source: Own computation result based on survey data, 2021

Table 1 shows the distribution of adaptation strategies pursued by farm households sampled households. The result confirms that the most frequently adopted strategies includes crop diversification, soil conservation practice, small scale irrigation, crop rotation, improved crop varieties, and adjusting planting date and farm households respond to climate change stresses by using mutually inclusive adaptation strategies

Farm households in the study area from their indigenous knowledge adopted strategies such as changing planting dates and using different variety of seeds to make yields less susceptible to climate variability. Since climate variability may affect communities differently, they tend to possess different adaptive capabilities and strategies.

The author identified that choice of drought-resistant varieties, high-value crops, irrigation efficiency improvement and using better water technologies are methods that have been tried by smallholders as adaptation strategies to combat climate variability in some African countries. Different communities depending on their adaptive capacities developed their own coping strategies (Stephen, 2009) to reduce effect of climate variability. Previous studies argued that asset-holding improvement would be associated with better adaptation potential (Stephen *et al*., 2014). Farm households in the study area practiced crop rotation based on their traditional knowledge to adapt climate variability.

The data collected in 2021 showed that some households adopt two or more strategies in one season to acclimatize climate variability. Rainfall shortage in grain filling stage of crops was critical problem that resulted in serious damage as to households' response. Rainfall instability at the beginning time was also a threat to crop production and respond for late start of rain by changing sowing season and crop type. If there was no rain at the right time, most of the sample households shift sowing time, or change the crop.

3.2 Predicted and Joint Probability

Result of multivariate probit model showed that the predicted probabilities to adopt crop diversification (54.2%) the most frequently adopted strategies to climate variability challenged which is followed by soil conservation practice (49.8%). Small scale irrigation, crop rotation, improved crop varieties and adjusting planting date were 47.3%, 45.3%, 44.4% and 43.5%, respectively. Moreover, farmers of the study area can be succeeded in adapting all adaptation strategies and fail to adapt all strategies at a time is probably 2.13% and 2.82% respectively (Table2).

Table 2. The joint and predicted probability for adaptation strategies

SC Practice	**Crop Diversity**	**SS Irrigation**	**Improved Varieties**	**Agrochemical**	**AP Date**
Marginal probability to					
0.647	0.704	0.655	0.642	0.636	0.589
Joint probability (success) = 0.0162			Joint probability (failure) = 0.0296		

Source: Survey result, 2021

4. Conclusion and Policy Implications

Climate variability and change is a serious threat to the livelihoods of rural communities because they are very sensitive to such changes. It is, therefore, essential to understanding the various strategies used by farmers to mitigate the adverse impact of climate change.

Farm households adopt different kinds of adaptation strategies to reduce the negative consequences of climate change so as to maintain and/or to improve their livelihood.

Farm households in the study area from their indigenous knowledge adopted strategies such as changing planting dates and using different variety of seeds to make yields less susceptible to climate variability. Since climate variability may affect communities differently, they tend to possess different adaptive capabilities and strategies.

The data collected in 2021 showed that some households adopt two or more strategies in one season to acclimatize climate variability.

Result of the predicted probabilities to adopt shows that crop diversification (54.2%) is the most frequently adopted strategies to climate variability challenged which is followed by soil conservation practice (49.8%). The other strategies pursued by farm households in the study area includes small scale irrigation, crop rotation, improved crop varieties and adjusting planting date which contributed to 47.3%, 45.3%, 44.4% and 43.5% respectively. Moreover, farmers of the study area can be succeeded in adapting all adaptation strategies and fail to adapt all strategies at a time is probably 2.13% and 2.82% respectively.

Thus, future policy should focus on towards supporting improved extension service, offer climate related training and information especially to adaptation technologies to increase the farm households experience in adopting different strategies to the negative effects of climate variability which is global problem of this century.

Moreover, encouraging informal social net-works and environmental settings enhance the adaptive capacity of smallholder farmers to reduce the adverse effects of climate change and to help economic development and food security status.

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