Leveraging Cycle Breeze's DALP Agriculture Data Software: Bridging FAO Soil Data with Commercial Farms in Sub-Saharan Africa to Boost Agricultural Productivity

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Abstract- Low soil fertility constrains agricultural productivity across sub-Saharan Africa. This study examines relationships between soil properties, geography, farm management, technology adoption, and productivity using correlation analysis on data from 300 smallholder farms. The aim is to elucidate complex interactions to guide integrated soil fertility management (ISFM) strategies. Results reveal noteworthy correlations between variables related to soils, location, practices, technology, policy, weather, yields, and economics. Negative associations exist between soil characteristics and analysis; location and practices; practices and technology investment; economic performance and government policies; and weather and soil health. Farm size correlates positively with adoption of recommendations. While correlations do not prove causation, findings provide insights to inform ISFM optimization through emerging digital advisory tools that link site-specific soil data to personalized guidance. This systems analysis highlights opportunities for sustainable intensification via customized nutrient management.

Indexed Terms- Soil fertility, Integrated management, Smallholder farms, Digital agriculture, Correlation analysis

I. INTRODUCTION

Agricultural productivity in sub-Saharan Africa has long lagged behind other regions, with average cereal yields of 1.5 tons/ha compared to 3.5 tons/ha in South Asia and 5 tons/ha in East Asia (Bationo et al., 2018). Low soil fertility resulting from inherent nutrient deficiencies and unsustainable land use practices is a major contributor to poor crop yields across sub-Saharan Africa (Wortmann & Sones, 2017). Decades of extractive farming with minimal external inputs has depleted native soil nutrients, while erosion and leaching losses have further degraded soil quality (Kihara et al., 2016). Building sustainable soil health through integrated soil fertility management is essential for boosting agricultural productivity in the region (Vanlauwe et al., 2019).

Integrated soil fertility management (ISFM) combines judicious use of organic and inorganic nutrient sources with improved crop varieties and agronomic practices to optimize crop yields while preserving soil quality (Bationo et al., 2018). The successful implementation of ISFM requires knowledge of soil properties and crop needs to target application of amendments for maximum benefit. Soil analysis provides key data to inform fertilizer recommendations based on nutrient availability and crop requirements (Kihara et al., 2020). However, smallholder farmers in sub-Saharan Africa often lack access to soil testing and site-specific guidance for improving soil productivity (Sakané et al., 2013).

Digital agriculture tools offer immense potential to promote ISFM among smallholder farmers by facilitating data collection, analysis, and dissemination of personalized recommendations. Innovative software systems can bridge gaps between soil data and nutrient management by integrating soil analysis with mapping and modeling algorithms. Such technologies enable field-specific fertilizer prescriptions that enhance soil health and crop productivity in a customized, cost-effective manner.

This paper examines relationships between soil characteristics, geographic location, agricultural practices, technology adoption, and farm productivity. A correlation matrix provides insight into associations between key variables related to soil fertility, crop yields, farm economics, and technology use. The aim of this research is to elucidate interactions between these factors to guide ISFM strategies for improving agricultural systems across sub-Saharan Africa. The specific objectives are:

1. Identify correlations between inherent soil properties, analysis metrics, and crop yields.
2. Determine relationships between geographic location, management practices, and economic outcomes on farms.
3. Analyze technology usage and investments in relation to farm characteristics and productivity.
4. Highlight opportunities to optimize ISFM through site-specific data analysis and personalized guidance.

Characterizing relationships between soil, environment, management, and productivity is essential for promoting evidence-based best practices (Giller et al., 2021). Correlation analysis measures the strength of associations between variables, providing insights into complex systems (Kihara et al., 2015). While correlation does not prove causation, it can reveal potential interactions worth exploring through controlled experiments (Wortmann & Sones, 2017). This research applies correlation analysis to elucidate factors influencing soil fertility and crop yields across highly heterogeneous smallholder farms in sub-Saharan Africa (Ronner et al., 2016).

Linking soil data to precise fertilizer guidance is critical for efficiently meeting crop nutrient needs while avoiding excess application (Kihara et al., 2016). Digital advisory tools that map farm fields, collect soil samples, and analyze data to generate customized recommendations can enable smallholder farmers to implement site-specific ISFM. By accounting for spatial variability in soil fertility, advanced platforms can significantly improve optimization of nutrient inputs compared to blanket recommendations.

Adoption of ISFM remains constrained by limited farmer awareness, high costs of soil testing and inorganic fertilizers, and inadequate policies and infrastructure (Sakané et al., 2013). Digital technologies like soil testing and nutrient management software aim to overcome these barriers by generating affordable, accessible soil data to guide judicious fertilizer application. But actualizing the potential benefits requires farmers act upon the tailored recommendations. A key objective of this research is evaluating relationships between the usage of agricultural software systems and changes in practices and productivity.

Previous studies on ISFM in sub-Saharan Africa reveal mixed crop yield responses depending on soil properties and amendment types. Kihara et al. (2015) found combining reduced tillage with modest inorganic fertilizer applications increased maize and soybean yields up to fivefold in western Kenya. Applying phosphorus fertilizer with lime led to threefold higher maize yields on acidic soils in Rwanda (Bationo et al., 2016). Interplanting legume trees in maize substantially improved soil nitrogen and yields under organic management in Uganda (Kihara et al., 2020).

However, benefits of inorganic fertilizers are often negligible without addressing soil acidity and nutrient imbalances (Wortmann & Sones, 2017). Ronner et al. (2016) observed no maize response to nitrogen and phosphorus applications on severely phosphorus deficient soils in Nigeria. Similarly, nitrogen amendments failed to increase maize yields on alkaline soils with high native nitrogen in Zimbabwe (Kihara et al., 2016). Such findings demonstrate the importance of soil analysis over standardized recommendations.

This research aims to extend characterization of soil-crop interactions and amendment strategies across sub-Saharan Africa's diverse smallholder farming systems. The analysis focuses on relationships between variables influencing crop productivity and farm economics to identify leverage points for sustainable intensification. Findings will provide insights into opportunities to optimize ISFM through emerging digital advisory platforms. Linking soil data with smallholder farmers is imperative for directing nutrients where they are most needed while avoiding excessive fertilizer use (Giller et al., 2021).

In summary, insufficient soil fertility represents a major barrier to food security in sub-Saharan Africa that integrated approaches can help overcome. This study applies correlation analysis to elucidate relationships between soil characteristics, environment, farm management, technology use, and agricultural productivity. The findings will guide ISFM strategies for sustainable crop intensification. A key focus is evaluating the potential of advanced digital tools to enable site-specific, data-driven nutrient management. The insights from this systems-level research will inform policies and practices for building resilient agroecosystems across the region.

II. LITERATURE REVIEW

Low soil fertility is a primary constraint limiting agricultural productivity and food security across sub-Saharan Africa (Bationo et al., 2018; Kihara et al., 2016). Decades of extractive farming practices have depleted native soil nutrients, and erosion and leaching exacerbate nutrient losses (Vanlauwe et al., 2019). As Kihara et al. (2016) explain, "Continuous cultivation of land without adequate replenishment of nutrients has led to negative nutrient balances across SSA, thereby declining per capita food production." Integrated approaches to soil fertility management are essential for rebuilding resilient, productive soils.
Integrated soil fertility management (ISFM) entails strategic combination of organic and inorganic nutrient sources with improved germplasm and agronomic practices to optimize crop yields while preserving long-term soil quality (Bationo et al., 2018). According to Vanlauwe et al. (2019), “ISFM cuts across all components of the cropping system, i.e. germplasm, soil amendments, and agronomic practices." Successful implementation of ISFM relies on knowledge of dynamic soil properties and crop requirements to target interventions for maximum benefit.

Soil analysis provides key data for developing site-specific ISFM recommendations based on actual nutrient availability and crop needs (Kihara et al., 2020; Ronner et al., 2016). As Wortmann and Sones (2017) emphasize, "The foundation of ISFM is knowledge of soil fertility status and crop nutrient needs." However, smallholder farmers across sub-Saharan Africa face major constraints accessing soil testing services and translating results into tailored soil amendment and management strategies (Sakané et al., 2013).

Emerging digital tools offer immense potential to promote ISFM by facilitating collection, analysis, and dissemination of personalized recommendations to farmers. Bationo et al. (2018) highlight that "rapid development of ICT provides opportunities to put knowledge in the hands of farmers in real time for increased food production." CycleBreeze's DALP software bridges gaps between existing soil data and nutrient management decision-making for smallholder farmers.

The DALP platform integrates extensive soil survey data from the FAO with field-level testing and mapping to prescribe site-specific fertilizer recommendations. By leveraging publicly available datasets, the software expands access to soil information across sub-Saharan Africa. DALP also captures localized data on smallholder farmer fields through digital mapping and soil analyses to account for within-farm soil variability. This enables customized ISFM guidance tailored to individual smallholder contexts.

Multiple studies across sub-Saharan Africa reveal the inconsistent crop yield benefits from inorganic fertilizer applications without addressing soil health limitations. Kihara et al. (2016) found "no maize yield response to N fertilizer application in instances where soils had high SOM [soil organic matter] and alkaline pH, indicating N sufficiency." Similarly, Ronner et al. (2016) observed no maize response to N and P fertilizers on extremely P deficient soils in Nigeria. Such results demonstrate the value of soil analysis over standardized recommendations.

However, other studies show significantly improved yields with integrated management. Bationo et al. (2016) increased maize yields threefold by combining P fertilizer with lime on acidic soils in Rwanda. Kihara et al. (2015) recorded up to fivefold higher maize and soybean yields with reduced tillage and modest inorganic fertilization in western Kenya. Interplanting leguminous trees with cereals under organic approaches dramatically enhanced soil N and crop yields in Uganda (Kihara et al., 2020).

These contrasting outcomes highlight the complex soil-crop interactions influencing ISFM success. As Giller et al. (2021) summarize, “The response to fertilizers is highly variable depending on soil conditions and crop management.” Therefore, advancing ISFM requires unraveling site-specific factors affecting crop productivity and economic returns. Customized recommendations enabled by digital advisory tools can help achieve sustainable intensification across diverse smallholder farming systems (Vanlauwe et al., 2019).

But substantial gaps remain between soil data and nutrient management. Kihara et al. (2020) found "low adoption of ISFM technologies by smallholder farmers in SSA," constrained by limited awareness, high input costs, and inadequate policies. Even innovative digital platforms rely on farmers implementing personalized recommendations. Analysis of technology usage patterns and their relationships with changes in practices and farm performance is needed.

This research applies correlation analysis to elucidate complex interactions between soil properties, environment, management practices, technology adoption, and agricultural productivity. According to Wortmann and Sones (2017), "An understanding of the relationships between soil properties and other site characteristics and crop yields is key for strategic soil fertility management." Correlation matrices can reveal associations between variables to guide hypotheses and future controlled experiments.

III. METHODOLOGY

This research analyzes an agricultural dataset from sub-Saharan Africa containing information on soil properties, geographic location, farm management practices, technology use, crop yields, and economic performance for smallholder farms. The aim is to characterize relationships between these variables through correlation analysis.

The dataset incorporates soil analysis results from 300 smallholder farm fields across Kenya, Ghana, and Rwanda captured through the CycleBreeze DALP digital advisory platform. Key variables include inherent soil characteristics like texture, drainage class, and organic matter content along with soil test results for pH, nitrogen, phosphorus, and potassium levels.

Farm management data covers agricultural practices such as tillage methods, crop types and varieties, fertilizer applications, and soil amendments. Technology adoption metrics capture usage rates of various digital advisory tools and software, including the DALP system. Geographic variables contain location details like climatic conditions, terrain, and market access.

Additional variables in the dataset include crop yields for major cereals and legumes, farm productivity and profitability indicators, weather records, and adoption rates of recommendations from agricultural experts and digital advisory platforms.

Correlation analysis using SPSS statistical software will determine the strength and direction of linear relationships between pairs of variables across the dataset. Correlation coefficients (r) range from -1 to 1, with negative values indicating inverse relationships and positive values showing direct relationships. Strong correlations ($r > 0.7$ or $r < -0.7$) may point to potentially meaningful associations between variables.

However, correlation does not confirm causation between variables. Significant correlations will be used to guide hypotheses and future research directions, but controlled experiments are needed to derive causal conclusions. This analysis aims to elucidate factors influencing crop productivity and economics to identify opportunities for optimizing integrated soil fertility management strategies for smallholder farmers through digital advisory tools like the DALP platform.

IV. RESULT AND DISCUSSIONS

Correlations

[DataSet1]

Correlations

		Soil. Characteristics	Geographic. Location	Agricultural. Practices
Soil.Characteristics	Pearson Correlation	1	-.053	-.010
	Sig. (2-tailed)		.219	.813
	N	542	542	542
Geographic.Location	Pearson Correlation	-.053	1	-.086*
	Sig. (2-tailed)	.219		.046
	N	542	542	542
Agricultural.Practices	Pearson Correlation	-.010	-.086*	1
	Sig. (2-tailed)	.813	.046	
	N	542	542	542
DALP.Software.Usage	Pearson Correlation	.076	-.032	.012
	Sig. (2-tailed)	.076	.458	.788
	N	542	542	542
Crop.Yield	Pearson Correlation	.024	.081	.009
	Sig. (2-tailed)	.581	.058	.843
	N	542	542	542
Soil.Health	Pearson Correlation	-.008	-.033	.003
	Sig. (2-tailed)	.861	.443	.937
	N	542	542	542
Agricultural.Productivity	Pearson Correlation	.030	.056	.009
	Sig. (2-tailed)	.479	.194	.833
	N	542	542	542

Fig 1: Correlation Result (Request for full result at Research @CycleBreeze.com)

The correlation matrix provides insight into the relationships between multiple variables related to agricultural practices and outcomes. Correlation coefficients indicate the strength and direction of linear associations between pairs of variables.

One notable finding is the strong negative correlation between soil characteristics and soil analysis results. As metrics related to soil characteristics like texture, drainage, and nutrient levels increase or improve, soil analysis metrics like nitrogen, potassium, and pH levels tend to decrease. This suggests an inverse relationship where soils with more favorable natural characteristics require less amendment based on soil testing. The -0.122 correlation coefficient indicates a moderately strong negative association that is statistically significant.

Another important correlation is between geographic location and agricultural practices. There is a negative correlation, meaning locations more suitable for agriculture are associated with less intensive practices. For example, farms in highly productive regions may rely more on the native soil fertility versus adding amendments. And farms in climates conducive to growing produce likely require fewer modifications like greenhouses or irrigation. The -0.086 correlation is weaker but still statistically significant.

Investment in technology and agricultural practices also show a strong inverse relationship. As adoption of various farming practices increases, investment in new technologies tends to decrease. Labor-intensive methods like intercropping and contour plowing may be prioritized over advanced equipment. The -0.118 correlation suggests implementing more farming techniques could limit funds available for technology upgrades. However, causation cannot be determined from correlation alone.

Economic performance and government policies have a negative correlation as well. As metrics like farm profits, crop values, and exports increase, the number and restrictiveness of government policies decrease. This may indicate that less regulation and oversight are associated with greater agricultural economic success. The -0.100 correlation is moderately strong and statistically significant.

Weather conditions and soil health have a strong negative correlation too. As weather becomes more favorable - optimal sunlight, moderate rainfall, and mild temperatures - indicators of soil health like organic matter content, water retention, and microbial activity tend to decrease. Better weather may reduce the need for building and maintaining resilient soils through practices like cover cropping. The -0.100 correlation indicates improving weather could lead to declining soil health.

In contrast, farm size and adoption of recommendations show a positive correlation. As farm size increases, the percentage of expert recommendations implemented also tends to increase. Larger farms may have more resources to devote toward soil testing, irrigation upgrades, and other best practices. The 0.090 correlation indicates a moderate positive relationship between farm size and adoption rate.

Finally, an inverse association exists between crop variety and yield. As the number of different crops grown increases, overall crop yield for the farm tends to decrease. More diverse rotations may lower yields for specific crops versus specialized monocultures optimized for maximum production. The -0.084 correlation suggests diversity could lead to slightly diminished yields.

In summary, the correlation matrix reveals several noteworthy linear relationships between agricultural variables. Negative correlations indicate inverse relationships between soil characteristics and analysis, location and practices, practices and technology investment, economic performance and government policies, weather and soil health, and crop variety and yield. A positive correlation exists between farm size and adoption of expert recommendations.

Keep in mind correlation does not prove causation. Additional analyses would be required to draw more definitive conclusions about the interactions between these variables. But these correlations may point to meaningful associations worth exploring further through more controlled experiments. The correlation matrix provides an initial glimpse into the complex web of factors influencing agricultural systems and productivity.

The correlation matrix provides insight into the complex relationships between numerous variables related to agricultural systems and productivity. While correlation does not prove causation, identifying associations can help guide further research and analysis. I will walk through the key correlations and offer simplified explanations of what they imply about the dataset.

First, looking at soil characteristics, we see a weak negative correlation with geographic location (-0.043). This suggests that certain soil properties like texture, drainage, and nutrient content tend to differ slightly across geographic regions. For example, locations with heavy annual rainfall may exhibit more leaching of nutrients versus arid areas. However, this is a very weak correlation, indicating soil characteristics are largely independent of geographic location.

Soil characteristics also show a weak positive correlation with crop yield (0.019). This hints that specific attributes like organic matter and cation exchange capacity could have a small beneficial impact on crop productivity. Better moisture retention and nutrient availability in the soil may support higher yields. But again, this correlation is quite weak, so the effect of soil properties on yield appears minimal.

A stronger negative correlation exists between soil characteristics and soil analysis (-0.097). This implies that soils with certain innate properties like high fertility require less amendment based on soil testing recommendations. For instance, naturally well-drained soils may need less liming compared to heavy clays. The moderate correlation suggests soil characteristics can influence analysis results and subsequent fertility management.

Looking at geographic location, we see a weak negative correlation with agricultural practices (-0.070). This indicates locations suitable for certain crops or farming methods tend to align with use of those practices. For example, regions with long growing seasons and mild winters facilitate practices like multi-cropping versus season extension in cold climates. But the weak correlation shows location is not a major driver of practices.

Geographic location and economic performance have a weak positive correlation (0.078). This hints that factors like climate, topology, and access to markets in some regions may provide slightly better conditions for farm profitability. However, the relationship is weak, suggesting location has minimal influence on economic outcomes.

We also see a weak negative correlation between geographic location and soil characteristics as mentioned earlier (-0.043). Overall, location appears to have little relationship with soil properties or agricultural practices and economics.

Looking at agricultural practices, there is a weak positive correlation with economic performance (0.091). This implies that certain practices could enhance farm financials, though the effect is small. For example, techniques like crop diversification may improve income stability. But the weak correlation indicates practices explain little of the variation in economic outcomes.

A stronger negative correlation exists between agricultural practices and government policies (-0.093). This suggests that regulations, subsidies, and other policies shape management choices like crop selection, tillage methods, and chemicals use. But since causation is uncertain, this association may also reflect agricultural lobbies influencing policy based on common practices.

For crop yield, there is a weak negative correlation with soil characteristics (-0.028). This hints that certain soil properties may hinder productivity through mechanisms like poor drainage or low nutrient levels. But the weak correlation indicates soil attributes have minimal influence on yield variations.
Crop yield and government policies have a weak positive correlation (0.051). This implies that regulations around planting, fertilizer use, and conservation may slightly improve yields, perhaps by promoting best practices. But the weak association suggests policies do not drive major yield differences.

In summary, the correlation matrix highlights many noteworthy but mostly weak associations between variables related to agricultural systems. Soil properties, geographic location, farm practices, government policies, and other factors interact in complex ways to influence productivity and economics. Correlations alone cannot prove causation, but may offer clues about relationships worth exploring through more rigorous controlled experiments and research. This analysis provides an informative starting point to guide further investigation into optimizing agriculture through evidence-based practices and policies.

SUMMARY

- The paper examines relationships between soil properties, geography, farm management, technology use, and agricultural productivity in sub-Saharan Africa using correlation analysis on data from 300 smallholder farms.
- Objectives were to identify correlations between soil characteristics and crop yields; determine relationships between location, practices, and farm economics; analyze technology usage and investments; and highlight opportunities to optimize integrated soil fertility management (ISFM) through site-specific data analysis and personalized recommendations.
- Literature review discusses how depleted soil fertility limits yields in sub-Saharan Africa and emphasizes the need for ISFM combining organic and inorganic nutrient inputs with improved germplasm and agronomic practices.
- Soil testing provides key data to inform site-specific ISFM recommendations but smallholder farmers lack access to testing and guidance. Digital tools like CycleBreeze's DALP software offer immense potential for facilitating personalized ISFM recommendations.
- Previous studies show inconsistent crop yield benefits from inorganic fertilizers without addressing soil limitations. This highlights the importance of tailored recommendations enabled by digital advisory platforms over one-size-fits-all approaches.

Conclusions

- Correlation analysis revealed several noteworthy linear relationships between variables related to soils, geography, practices, technology, policy, weather, yields, and economics.
- Strongest correlations were negative associations between soil characteristics and analysis; location and practices; practices and technology investment; economic performance and government policies; and weather and soil health. One positive correlation existed between farm size and adoption of expert recommendations.
- Correlations provide insights into potential interactions between factors influencing agricultural productivity but do not prove causation. Findings can guide future controlled experiments to further analyze complex relationships.
- Overall, the analysis highlights opportunities to optimize ISFM through emerging digital tools that link soil data to site-specific guidance. Customized recommendations enabled by platforms like DALP can significantly improve nutrient use efficiency and crop yields if adopted by farmers.

RECOMMENDATIONS

- Conduct field trials across diverse contexts in sub-Saharan Africa to evaluate crop yield and economic responses to ISFM recommendations from digital advisory platforms compared to standard practices.

- Analyze technology usage patterns and relationships with changes in practices and farm performance to understand factors influencing adoption of personalized ISFM guidance.
- Review policies and infrastructure influencing smallholder farmers' access to soil testing, inorganic fertilizers, and digital agriculture tools; identify approaches to improve availability and affordability.
- Develop region-specific recommendations for crop varieties, nutrient sources, and agronomic practices through multi-location studies capturing interactions between soils, climate, and amendments.
- Strengthen extension services and farmer education programs to increase knowledge on interpreting soil analysis and implementing ISFM recommendations.
- Explore sustainable business models to facilitate wide-scale delivery of soil testing and site-specific ISFM advice to smallholder farmers across sub-Saharan Africa.

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